Some Idealized Sensitivity Studies on Shallow-Convection-Triggered Storms with the COSMO-model

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(thanks to A. Seifert, H. Noppel and K.D. Beheng)

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Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Motivation

Forecast skill in case of convective precipitation comparatively bad $\Longrightarrow$ Improvement of the physical understanding of the phenomenon by:

- Numerical sensitivity- and process studies with a cloud resolving test version of COSMO-model.
- Quite detailed cloud microphysics parameterization: 2-moment-scheme of Seifert and Beheng (2006).
- Idealized simulations to investigate the influence of environmental parameters on convective systems, (height of 0°C-level, moisture, wind profile, orography, aerosol regime) $\Longrightarrow$ Dynamical feedback of cloud microphysics

2-moment bulk microphysical scheme

- Cloud droplets, rain, cloud ice, snow, graupel, ”hail”
- For each hydrometeor category: rate equations for

  1. number density n (0. moment of PSD $f(x)$)
  2. mass density q (1. moment of PSD $f(x)$)

- Parameterizations of microphysical processes based on

$$f(x) = N_0 x^{\nu} \exp(-\lambda x^{\mu})$$

Recent updates to the two-moment scheme

Implemented "hail" class as 6. hydrometeor type (Noppel et al., 2006)

$\Longrightarrow$ Some oddities, e.g., simulated radar reflectivity too low in convective towers above freezing level (graupel and "hail" particles rather small)

Main measures:

- Changed size-mass- and fallspeed-mass-relations of ice, graupel and "hail", such that decreased number density and increased riming rate per particle.
- Hail initiation: now only by large freezing drops (spectral partitioning);
  added graupel → hail conversion by wet growth process;

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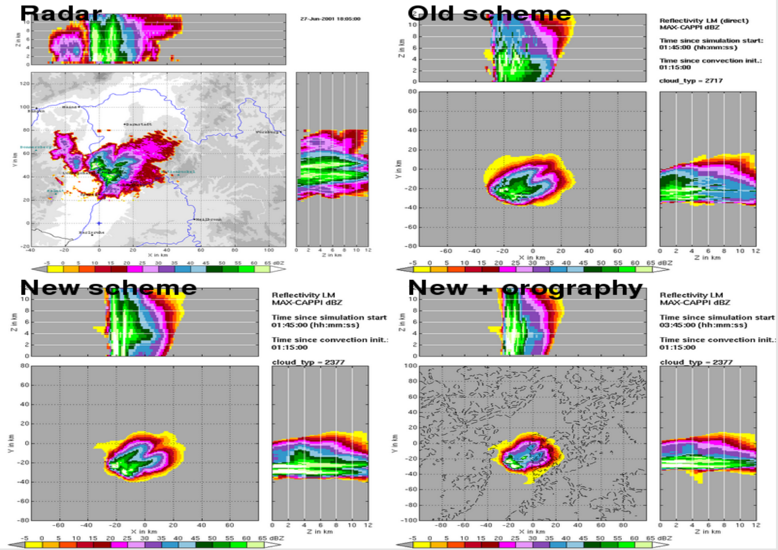

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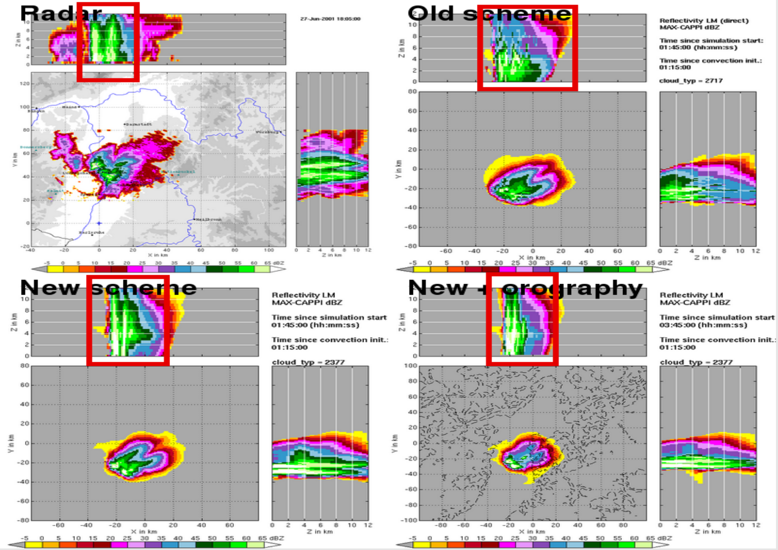
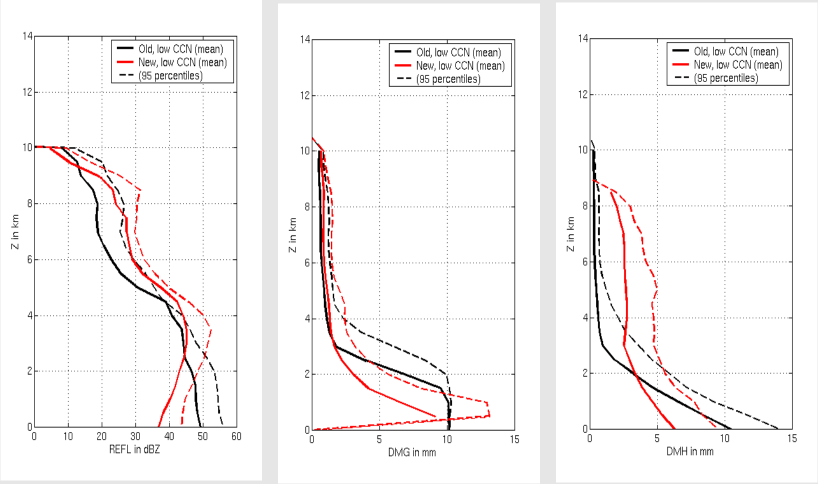


Space-time-average profiles (different case, but typical)

dBZ | D_{mean} graupel | D_{mean} hail

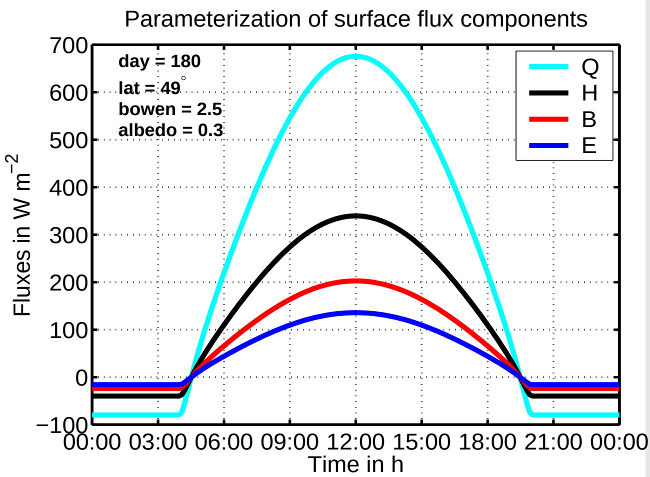


Simulation of pure shallow convection

1. COSMO-model version 3.19
2. Fully periodic b.c.
3. 3D Mellor-Yamada 2.5 type turbulence scheme (not the operational scheme!)
4. Idealized daily cycle of latent/sensible heat flux at bottom
5. Idealized sounding (initially stable boundary layer, potentially moist unstable free troposphere)
6. Adding some noise in the PBL

$\Longrightarrow$ Development of shallow convection, transition to deep convection, interaction of neighbouring thermals and convective cells, feedback to the environment.

Daily cycle of sensible and latent heat fluxes



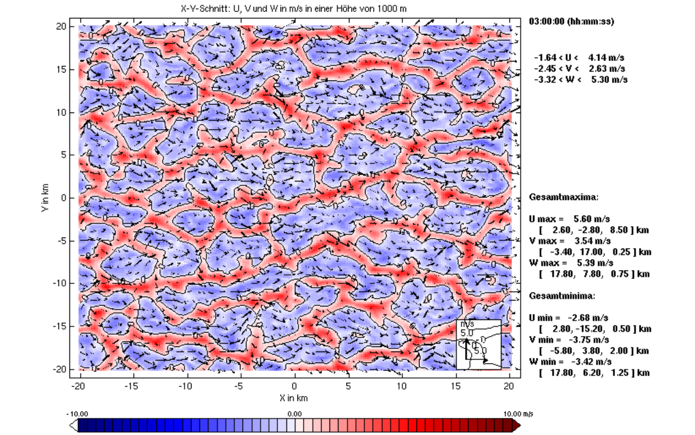
Simulations start at 9:00 or 10:00 LT

Simulation of pure shallow convection

- Model behaviour during development of convective boundary layer?
- Scale selection: which modes are excited?
- Typical distance between thermals?
- Convective patterns?

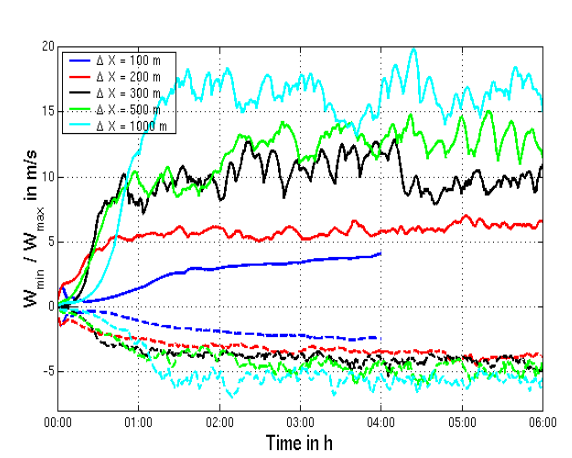
Example: "dry" run with $\Delta X = 200$ m

Z = 1000 m, t = 03:00 h, 40 x 40 km^2



Results about resolution dependency

Max./Min. vertical velocity of thermals

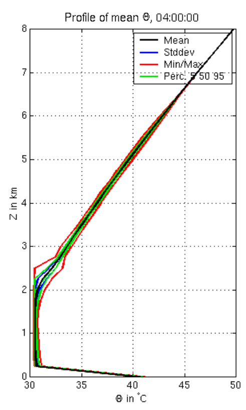


Results about resolution dependency

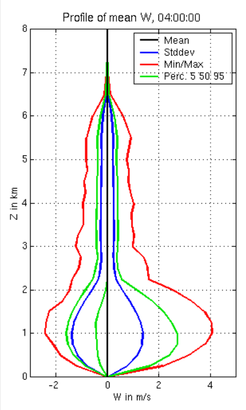
$\Delta X = 100$ m, domain size 20 x 20 km

Mean profiles of Θ, W and Q_v after 4:00 h

Θ



W

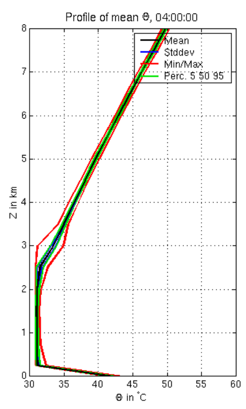


Results about resolution dependency

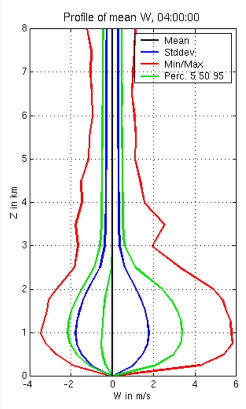
$\Delta X = 200$ m, domain size 40 x 40 km

Mean profiles of Θ, W and Q_v after 4:00 h

Θ



W

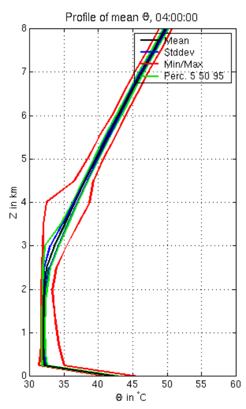


Results about resolution dependency

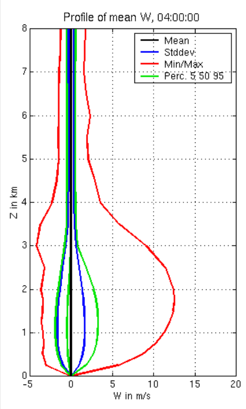
$\Delta X = 500$ m, domain size 40 x 40 km

Mean profiles of Θ, W and Q_v after 4:00 h

Θ



W



Reasons for the observed resolution dependency

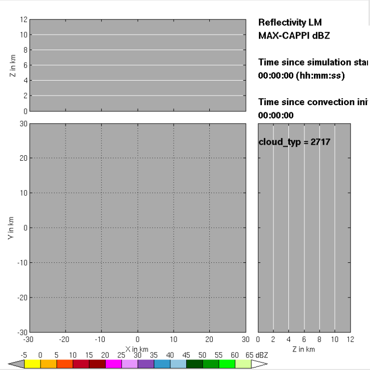
1. Issues with turbulence scheme?

2. Typical thermal updraft D $\approx$ 200 – 500 m
   $\Rightarrow$ these scales not or only marginally resolved, even at ΔX = 100 m (remember: "6-ΔX-rule"). In this case, model performs the vertical heat transport by spiky and isolated strong updrafts. Effect increasing with decreasing resolution.

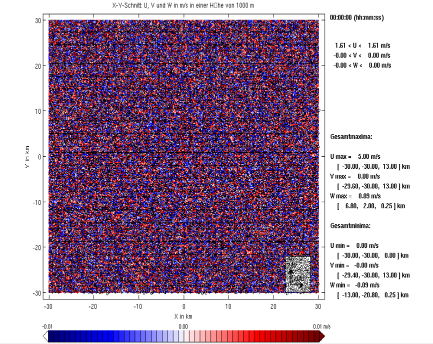
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



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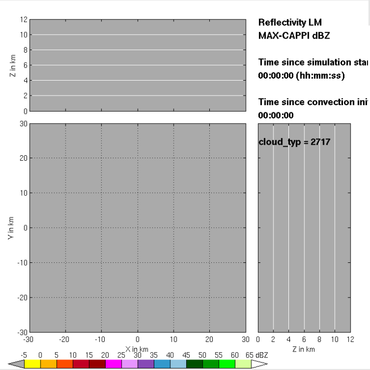

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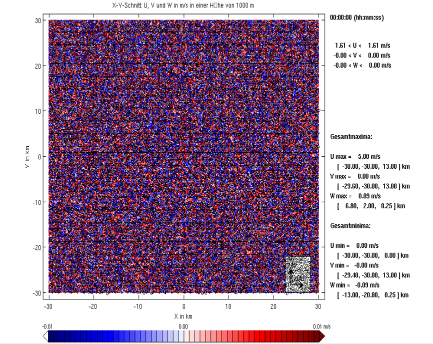

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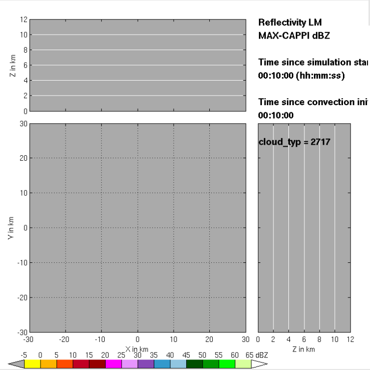

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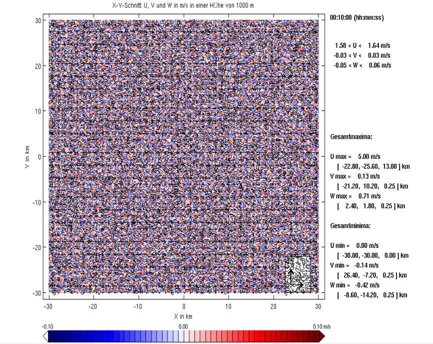

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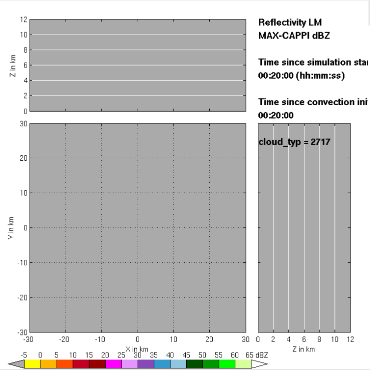

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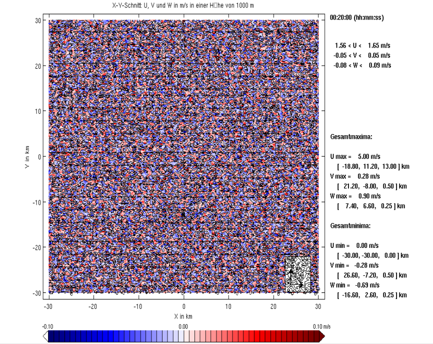

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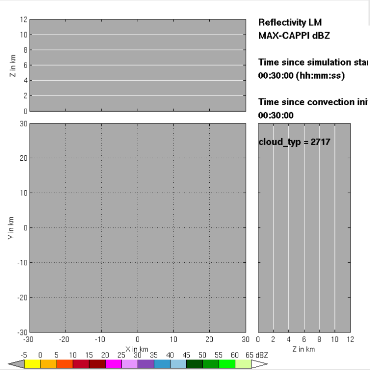

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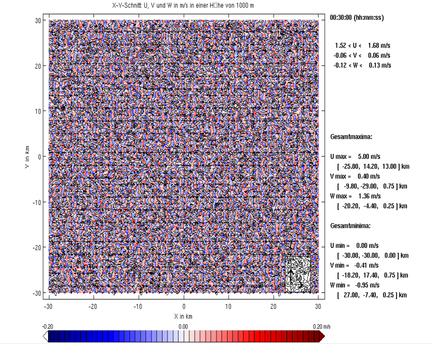

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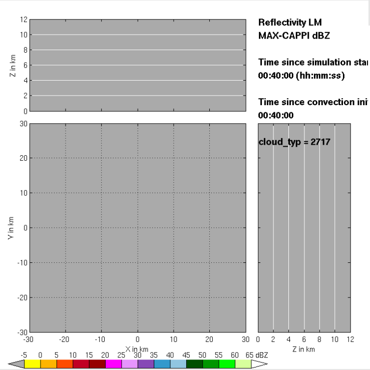

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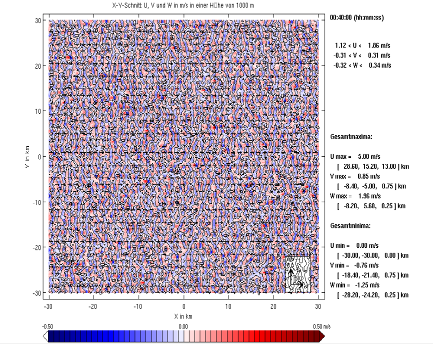

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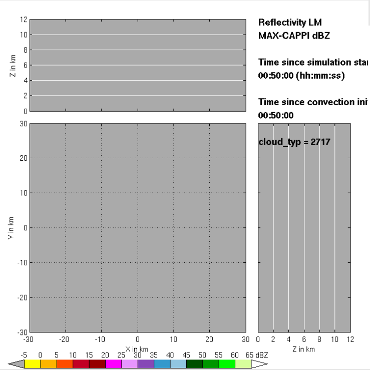

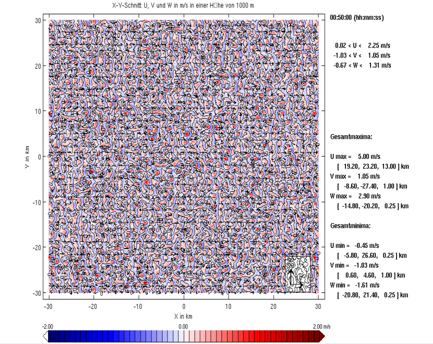

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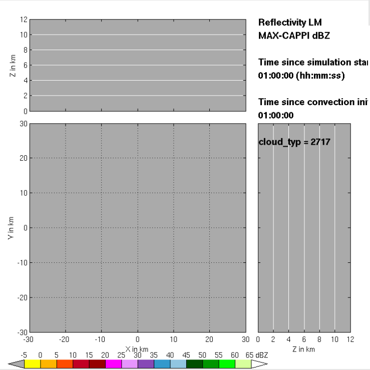

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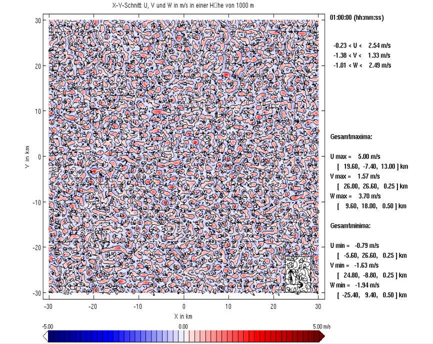

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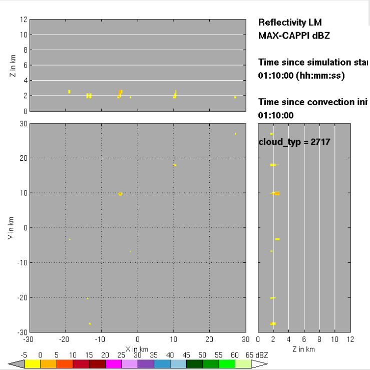

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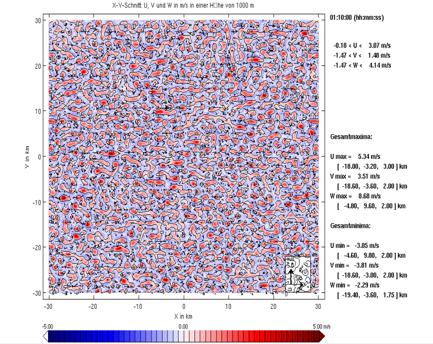

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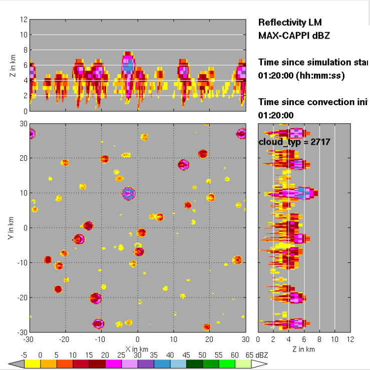

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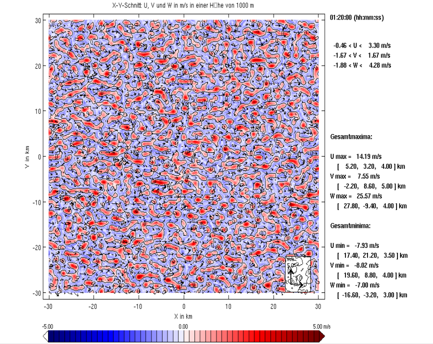

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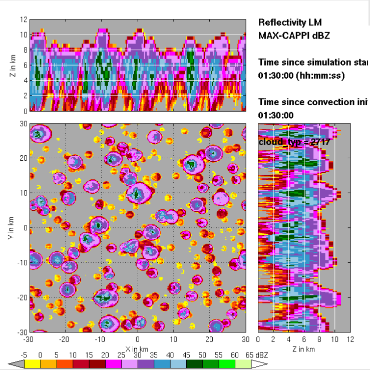

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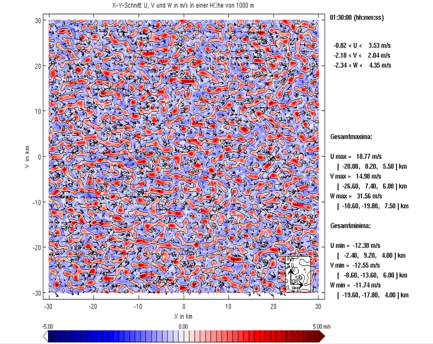

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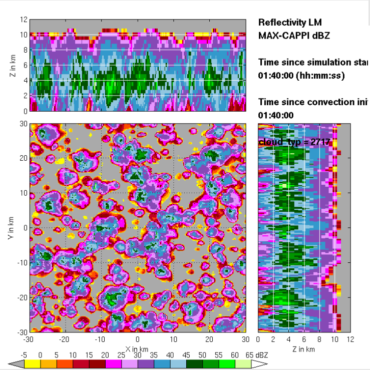

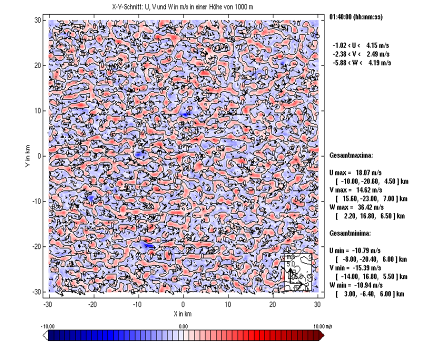

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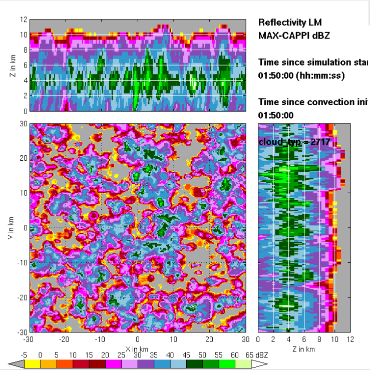

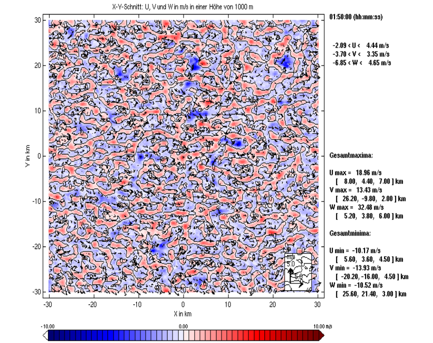

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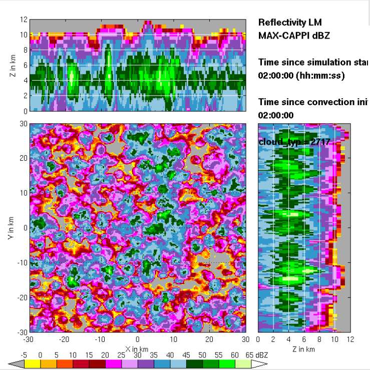

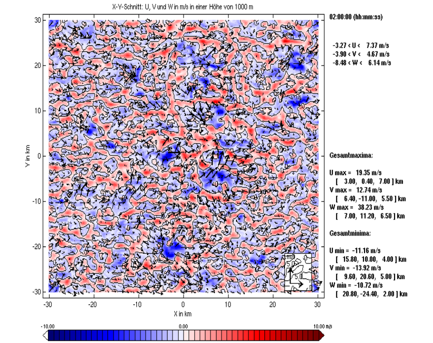

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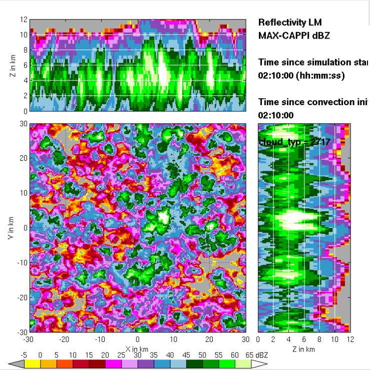

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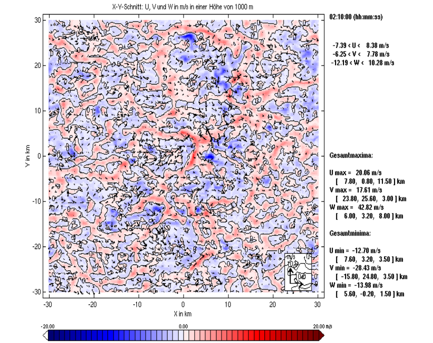

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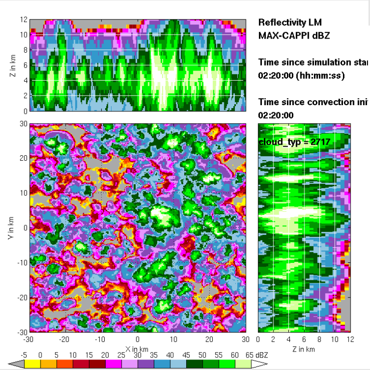

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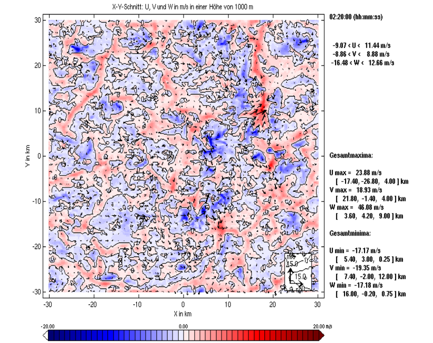

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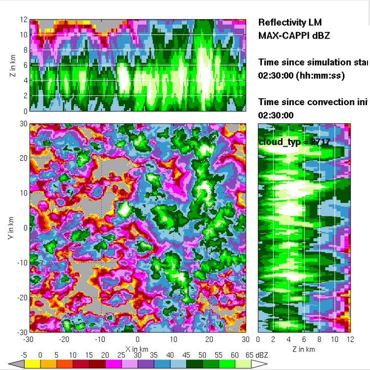

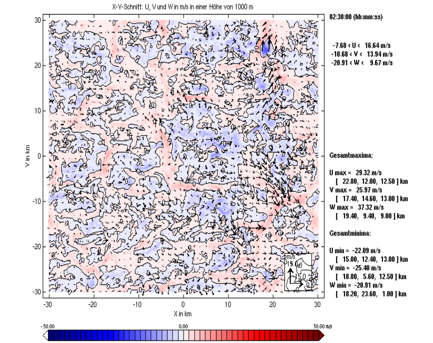

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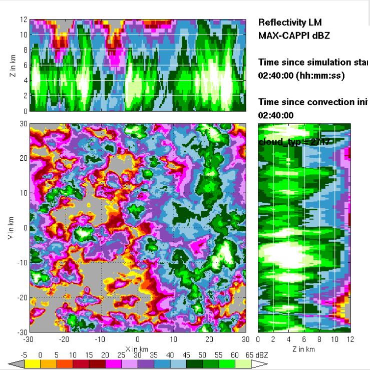

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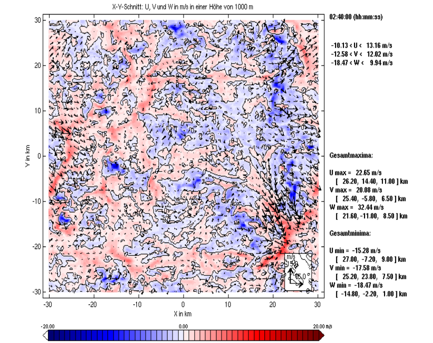

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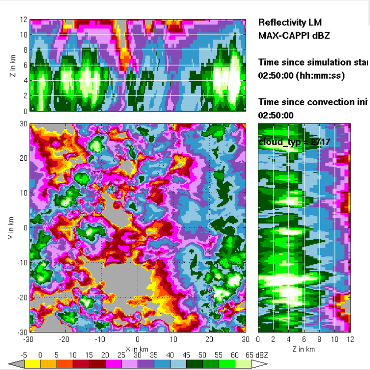

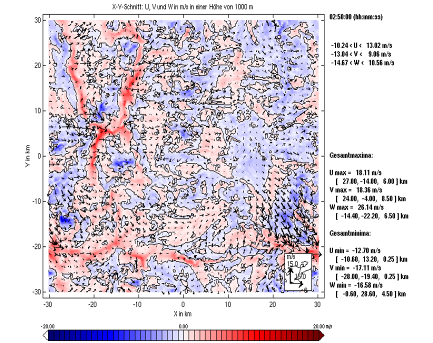

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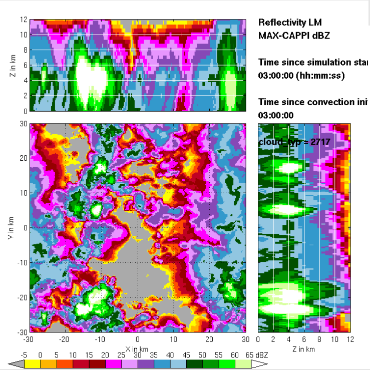

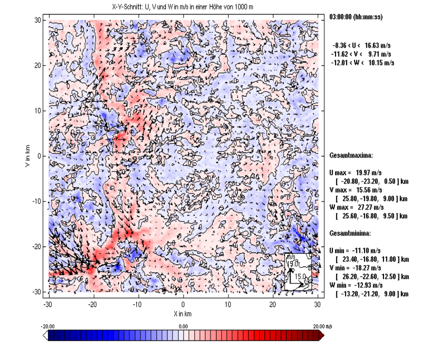

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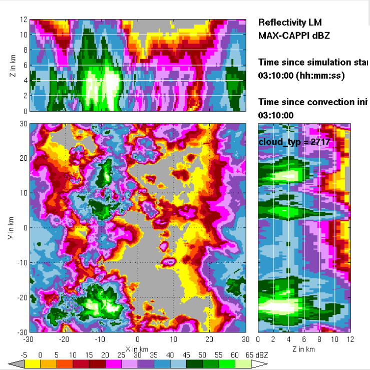
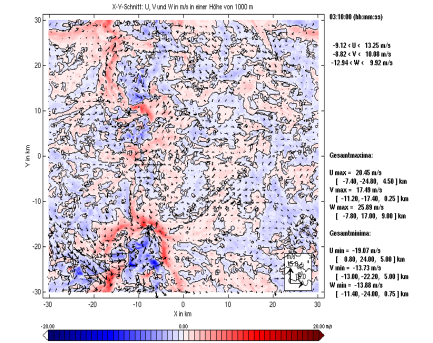
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

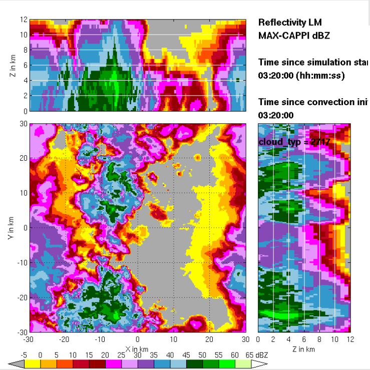


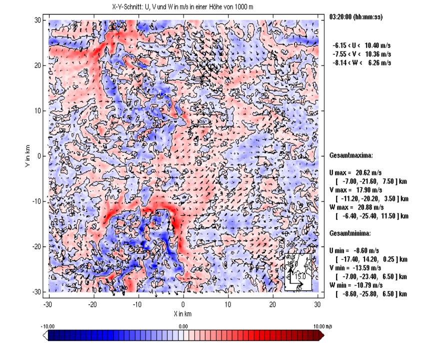
play

”Moist” run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ — W in m/s at Z=1000 m

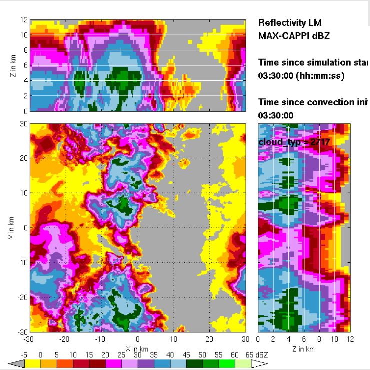




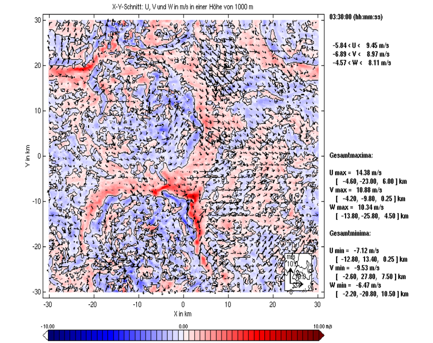
play

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

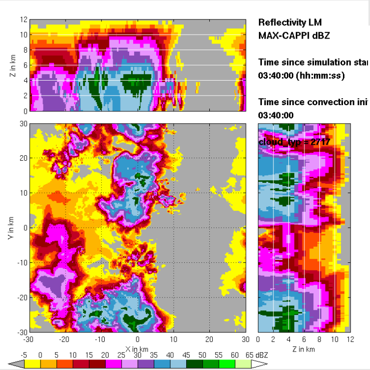


play

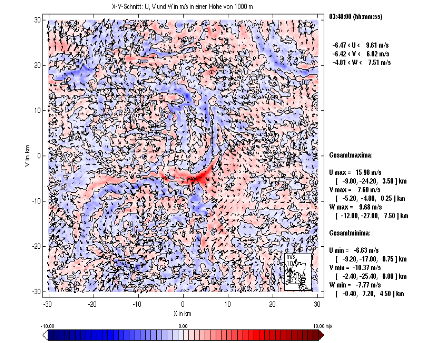
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



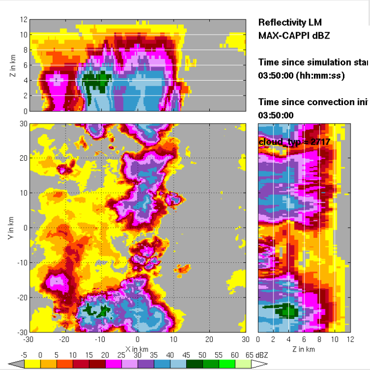
play

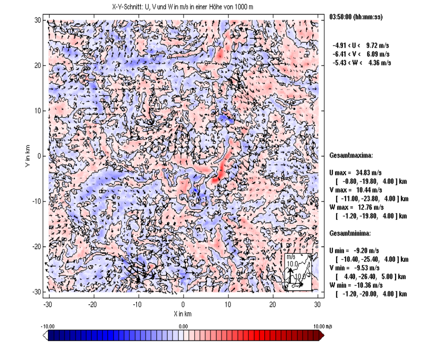
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ

W in m/s at Z=1000 m



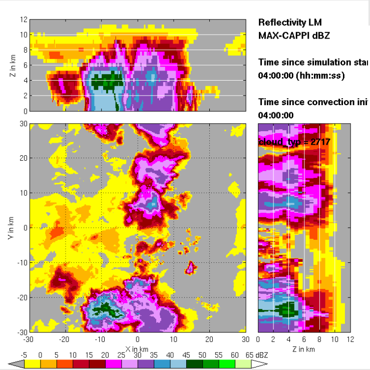


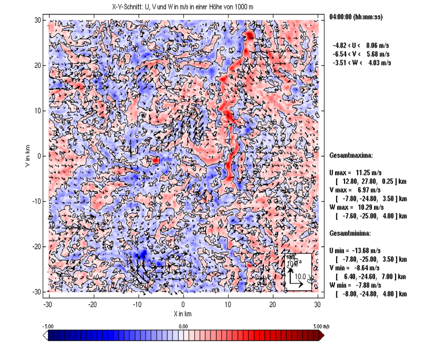
play

"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ | W in m/s at Z=1000 m



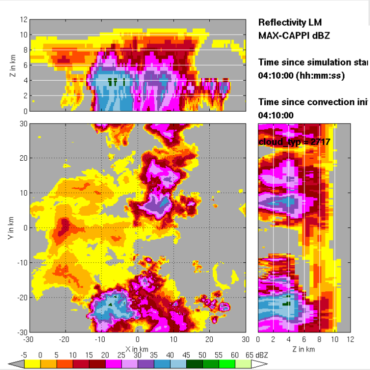


play

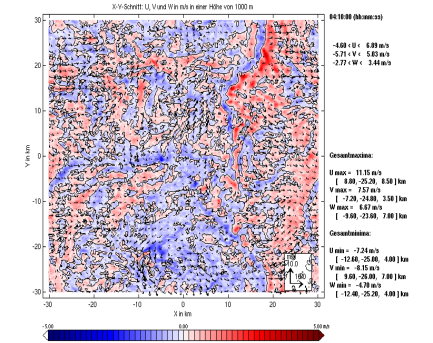
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



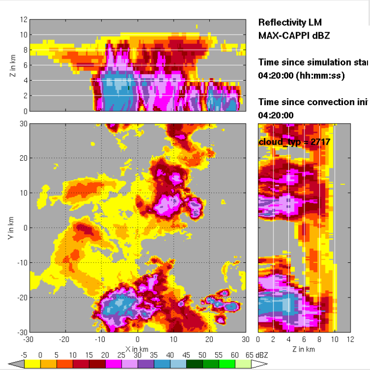
play

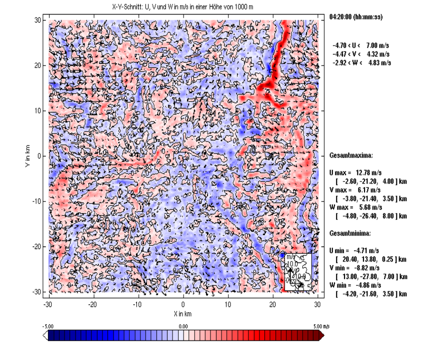
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ

W in m/s at Z=1000 m



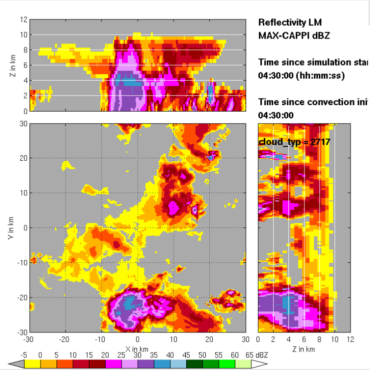


play

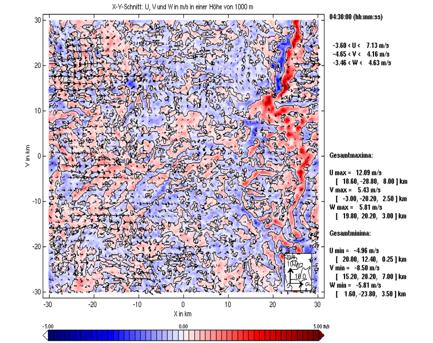
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

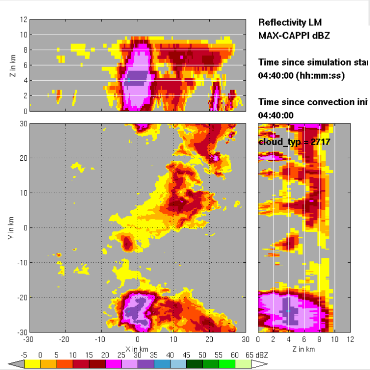


play

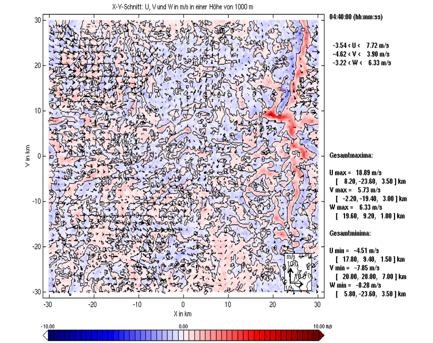
"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

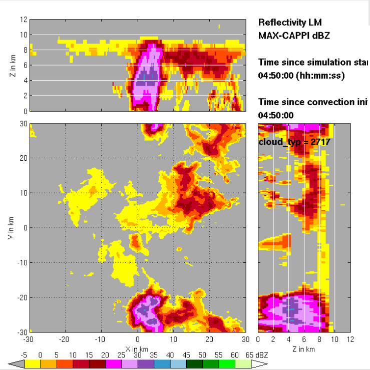


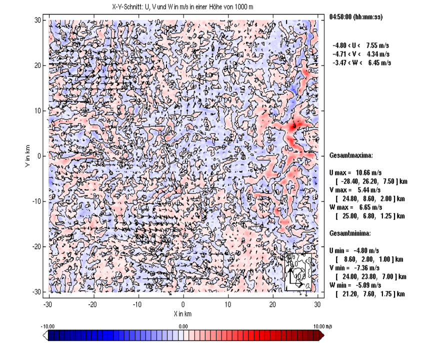
play

"Moist" run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ | W in m/s at Z=1000 m





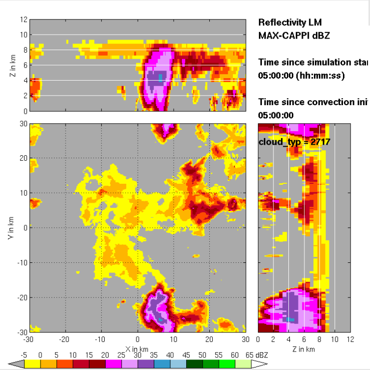
play

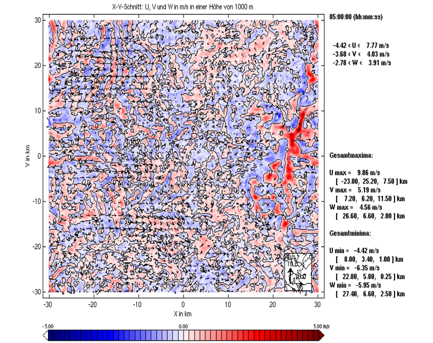
”Moist” run with $\Delta X = 200$ m

301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ

W in m/s at Z=1000 m

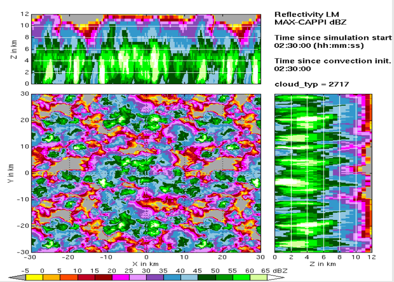




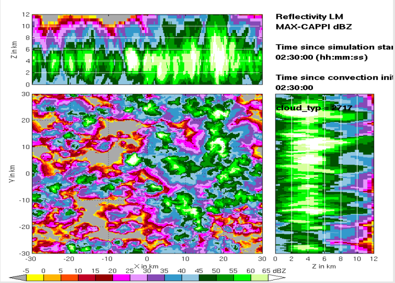
revert

Resolution dependency?

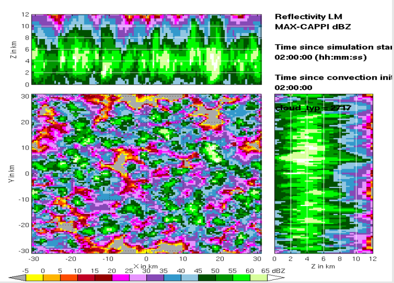
$\Delta X = 100$ m



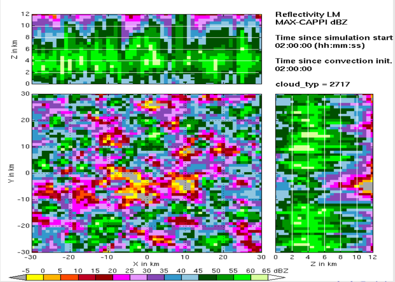
$\Delta X = 200$ m



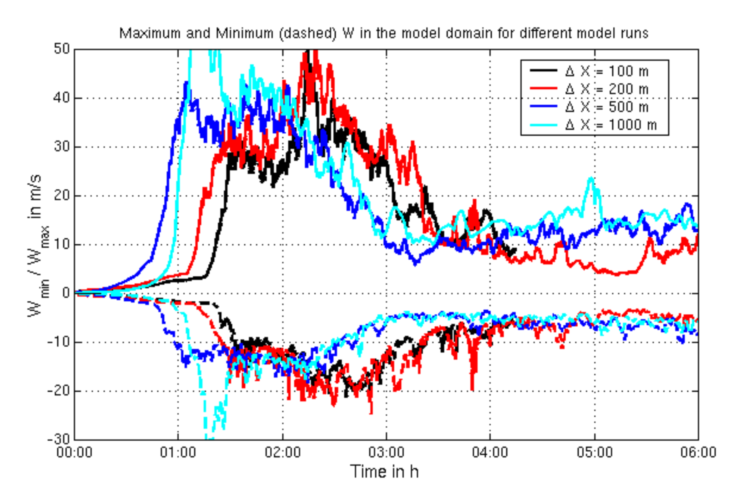
$\Delta X = 500$ m



$\Delta X = 1000$ m



Resolution dependency?



$\Longrightarrow$ $\Delta X \leq 500$ m seems adequate

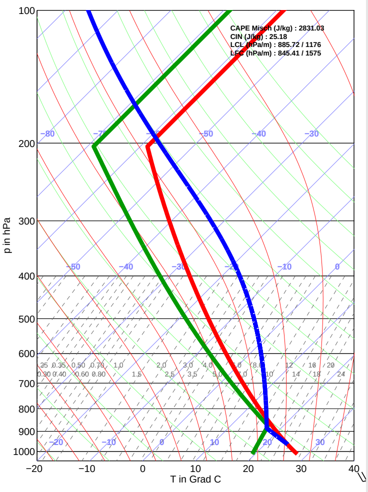
Study on „Continentality“/ temperature regime

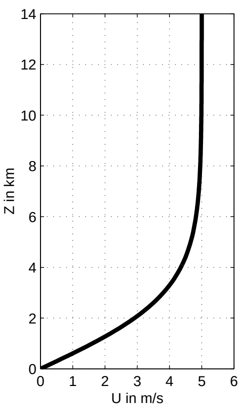
1. 4 Simulations: 2 different 0°C-levels, maritime/continental, 3D bell-shaped mountain
2. Shifting of T-profile at constant $CAPE$, U and vertical buoyancy distribution
3. $\Delta x = 300$ m

$\Longrightarrow$ Variation of relative importance of ice-phase processes

Study on „Continentality"/ temperature regime

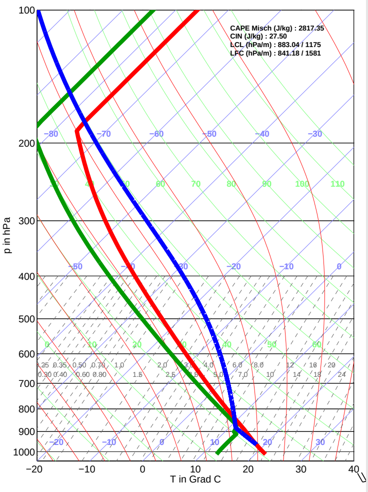
High 0°C-level
3700 m

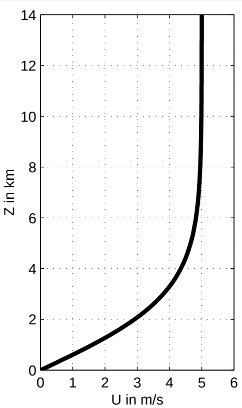




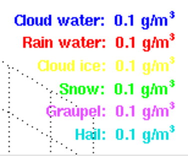
Study on „Continentality“/ temperature regime

Low 0°C-level
2700 m





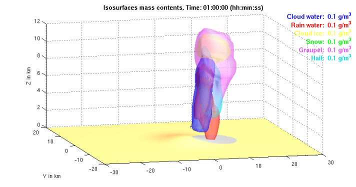
Study on „Continentality“/ temperature regime

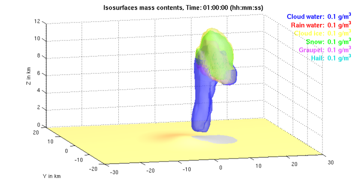


Isosurfaces of mass densitiy 0.1 $\mathrm{g\,m^{-3}}$ after 1:00 h

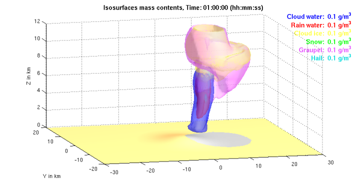
Low CCN | High CCN

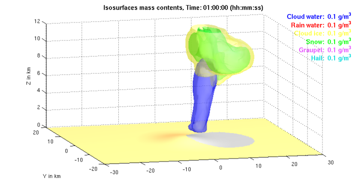
High 0°C-level





Low 0°C-level



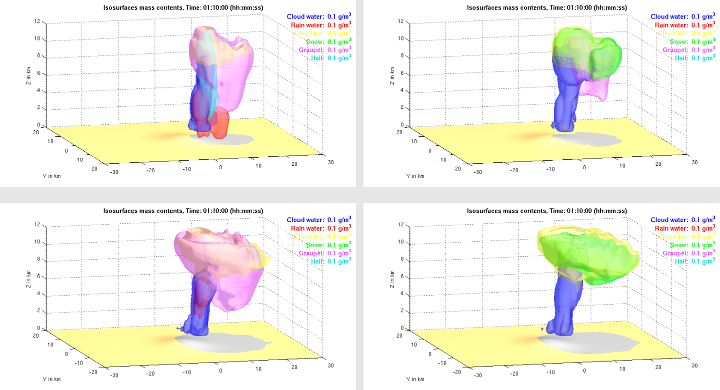


Isosurfaces of mass densitiy 0.1 $\mathrm{g\,m^{-3}}$ after 1:10 h

Low CCN | High CCN

High 0°C-level

Low 0°C-level



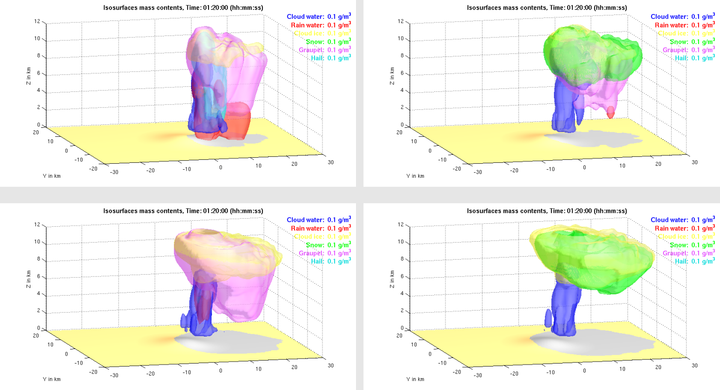
Study on „Continentality“/ temperature regime

Isosurfaces of mass densitiy 0.1 g m^{-3} after 1:20 h

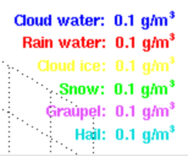
Low CCN | High CCN

High 0°C-level

Low 0°C-level



Study on „Continentality“/ temperature regime

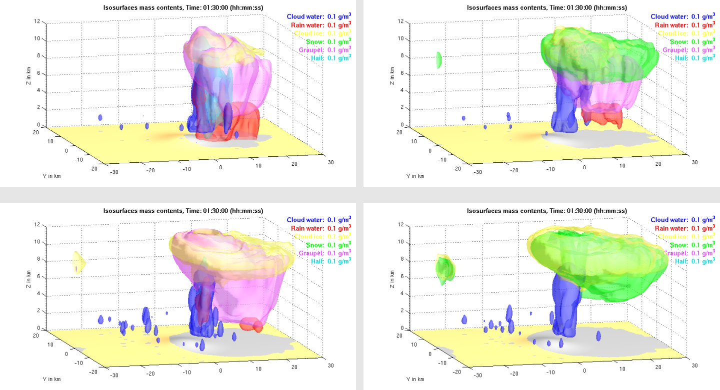


Isosurfaces of mass densitiy 0.1 $g\,m^{-3}$ after 1:30 h

Low CCN | High CCN

High 0°C-level

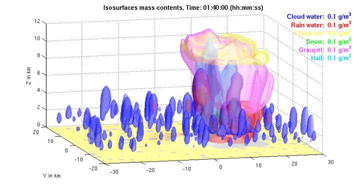
Low 0°C-level

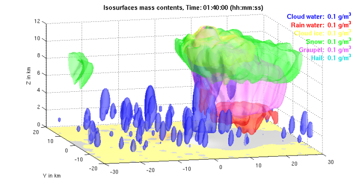


Isosurfaces of mass densitiy 0.1 $\mathrm{g\,m^{-3}}$ after 1:40 h

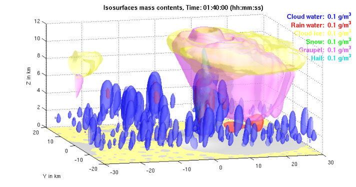
Low CCN | High CCN

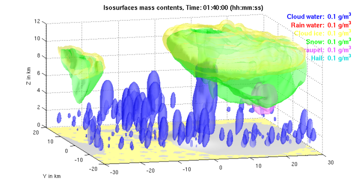
High 0°C-level



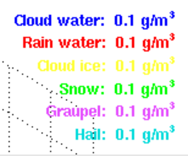


Low 0°C-level





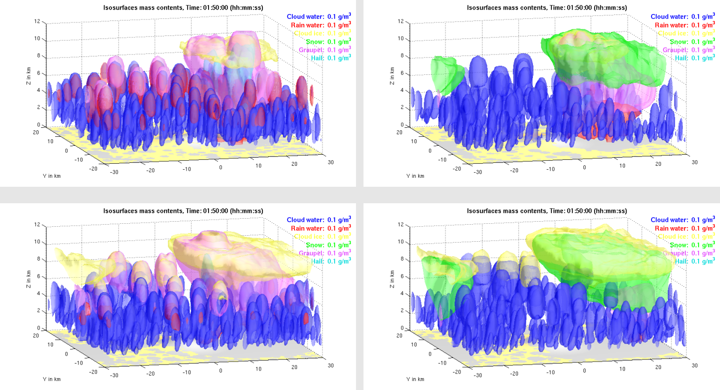
Isosurfaces of mass densitiy 0.1 $g\,m^{-3}$ after 1:50 h



Low CCN | High CCN

High 0°C-level

Low 0°C-level

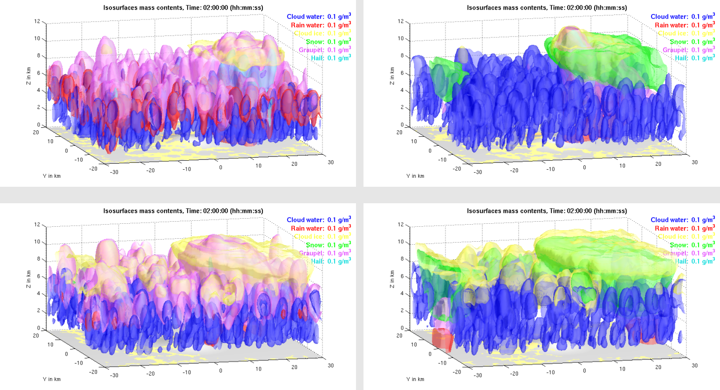


Isosurfaces of mass densitiy 0.1 $g\,m^{-3}$ after 2:00 h

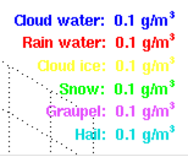
Low CCN | High CCN

High 0°C-level

Low 0°C-level



Study on „Continentality“/ temperature regime



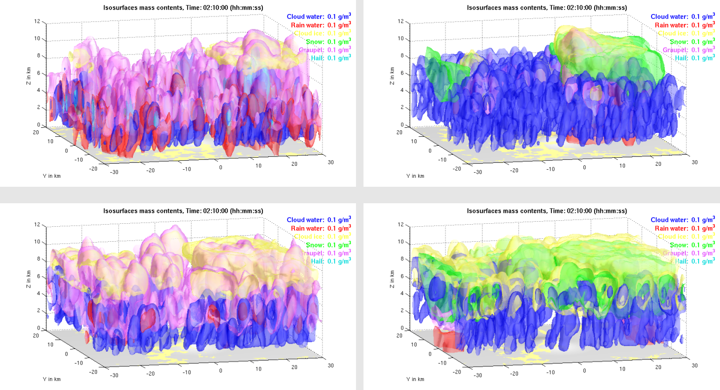
Isosurfaces of mass densitiy 0.1 g m^{-3} after 2:10 h

Low CCN

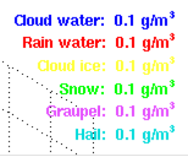
High CCN

High 0°C-level

Low 0°C-level



Study on „Continentality“/ temperature regime



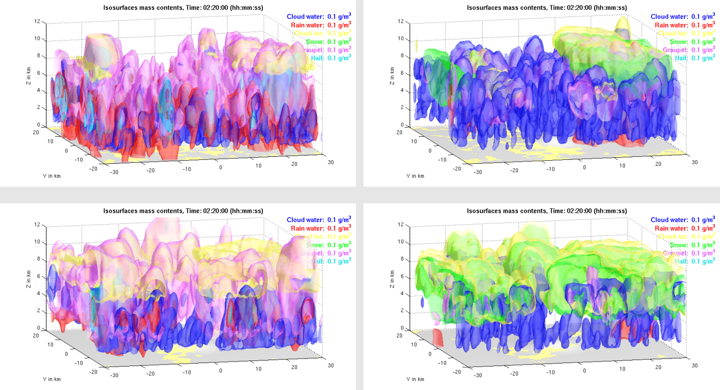
Isosurfaces of mass densitiy 0.1 g m^{-3} after 2:20 h

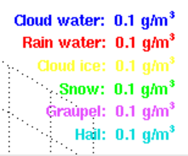
Low CCN

High CCN

High 0°C-level

Low 0°C-level

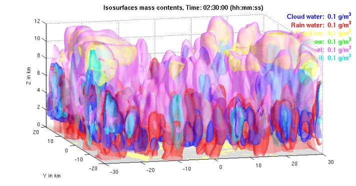


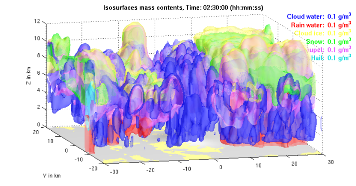


Isosurfaces of mass densitiy 0.1 g m^{-3} after 2:30 h

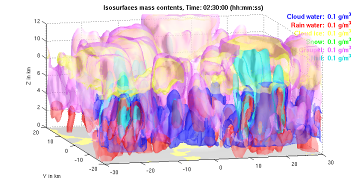
Low CCN | High CCN

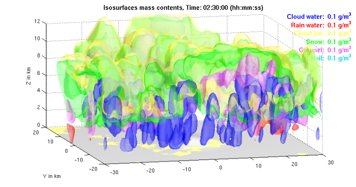
High 0°C-level





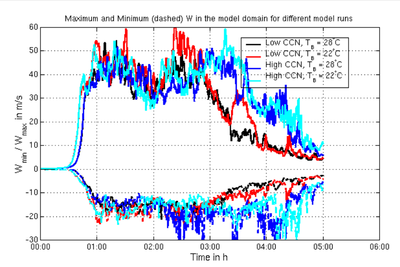
Low 0°C-level



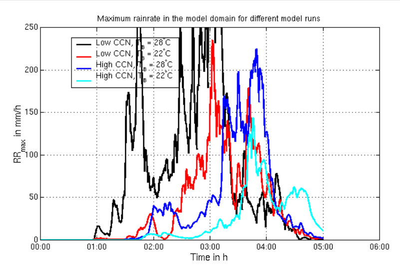


Study on „Continentality“/ temperature regime

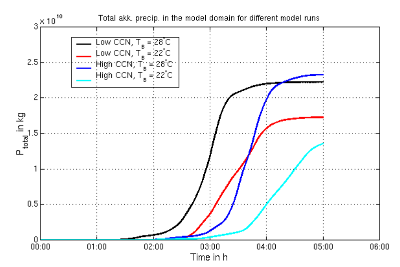
Max./min. W in $\mathrm{m\,s^{-1}}$



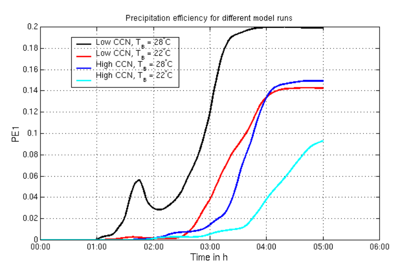
Max. R in $\mathrm{mm\,h^{-1}}$



Total precipitation in kg



Precipitation efficiency



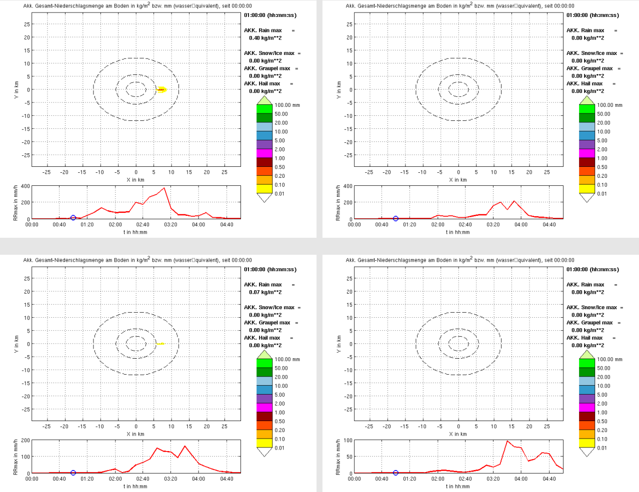
Study on „Continentality"/ temperature regime

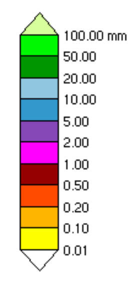
Accumulated precipitation in mm after after 1:00 h

Low CCN | High CCN

High 0°C-level

Low 0°C-level





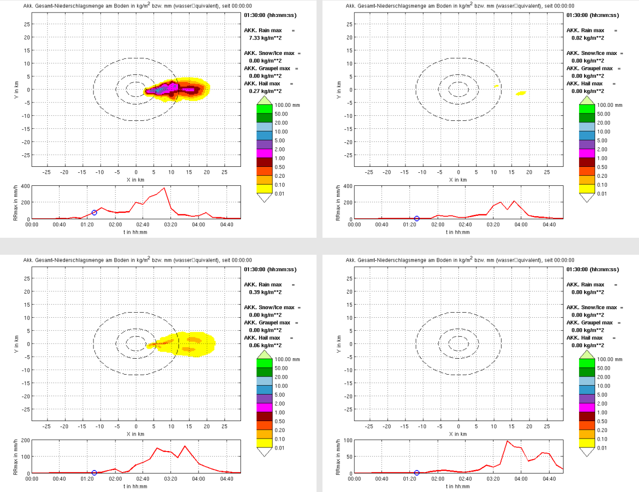
Study on „Continentality“/ temperature regime

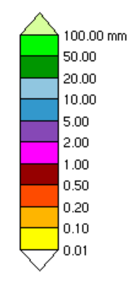
Accumulated precipitation in mm after after 1:30 h

Low CCN | High CCN

High 0°C-level

Low 0°C-level

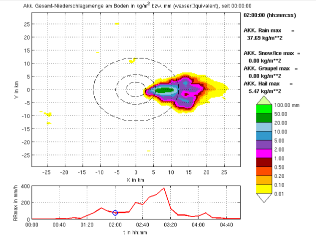


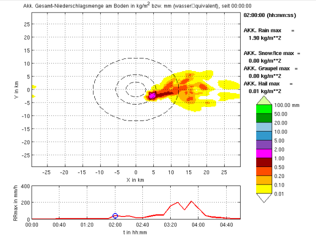


Accumulated precipitation in mm after after 2:00 h

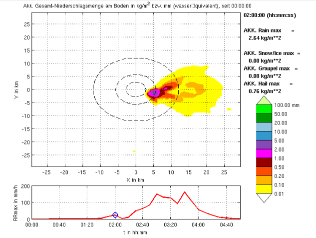
Low CCN | High CCN

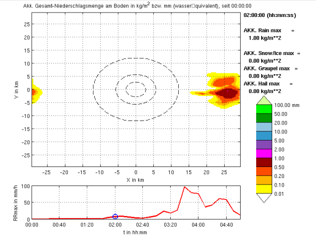
High 0°C-level

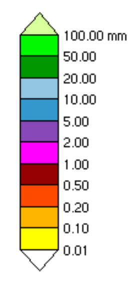




Low 0°C-level





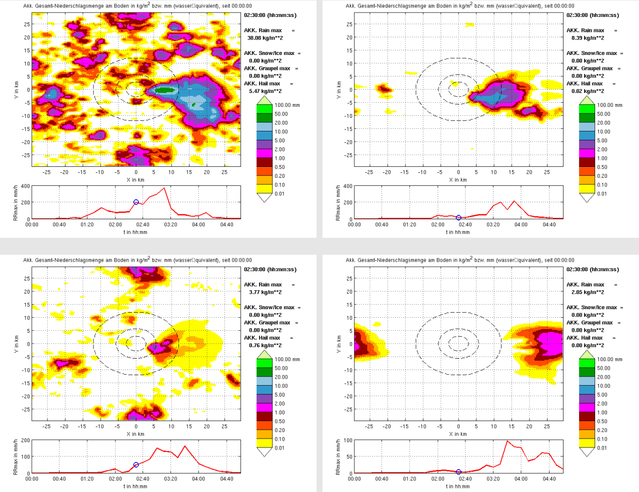


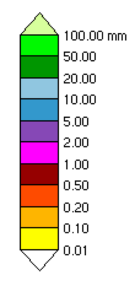
Accumulated precipitation in mm after after 2:30 h

Low CCN | High CCN

High 0°C-level

Low 0°C-level





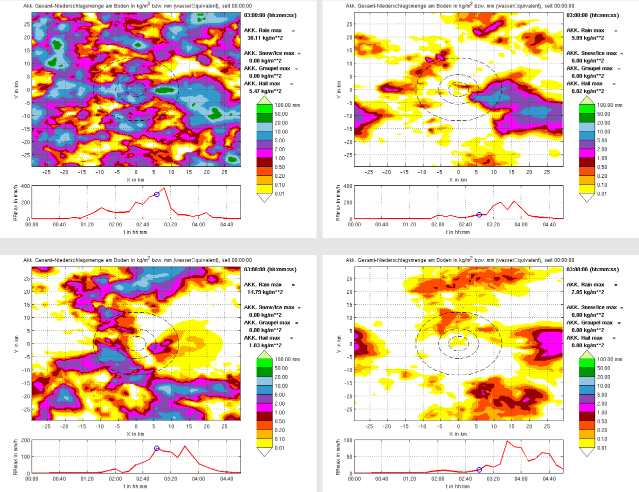
Study on „Continentality“/ temperature regime

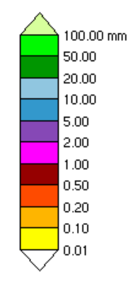
Accumulated precipitation in mm after after 3:00 h

Low CCN | High CCN

High 0°C-level

Low 0°C-level





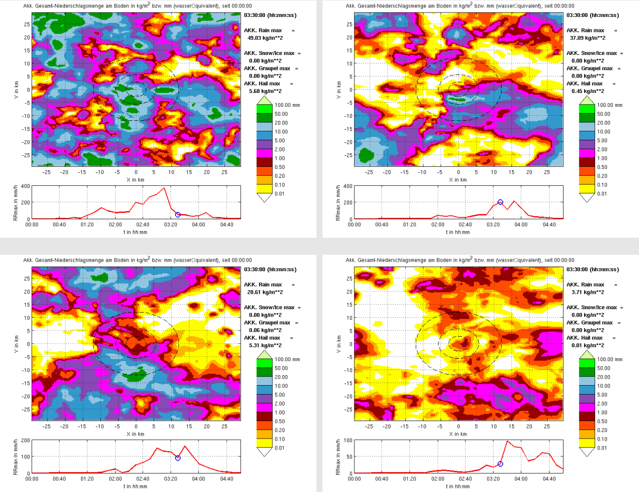
Study on „Continentality“/ temperature regime

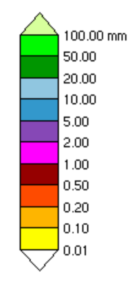
Accumulated precipitation in mm after after 3:30 h

Low CCN — High CCN

High 0°C-level

Low 0°C-level





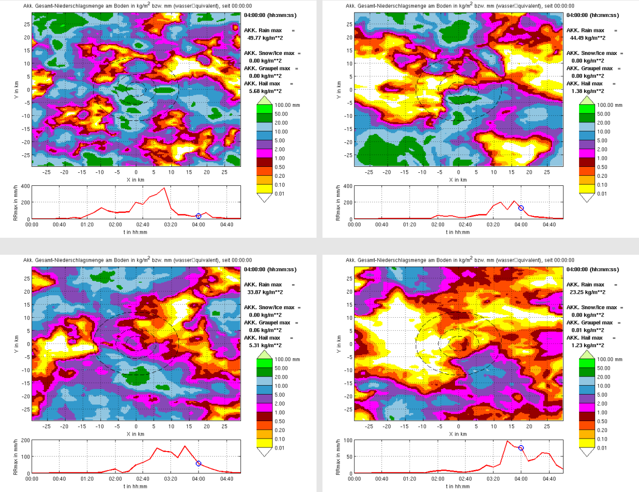
Study on „Continentality“/ temperature regime

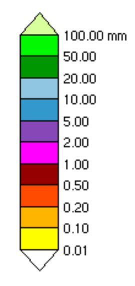
Accumulated precipitation in mm after after 4:00 h

Low CCN | High CCN

High 0°C-level

Low 0°C-level





Conclusions

- Shallow convection: simulation of thermals seems qualitatively realistic up to $\Delta X = 200$ m. Coarser resolution leads to unrealistically strong updrafts and faster development of convective circulations.
- Transition to deep convection: at $\Delta X = 500$ m similar properties as with $\Delta X = 200$ m, although shallow convection unrealistic. $\Longrightarrow$ For microphysical sensitivity studies on convective systems with our COSMO-version, a model resolution of 500 m seems adequate though higher resolution desireable.

Conclusions

- Two-moment scheme: recent changes enhance reflectivity aloft in convective cells, better agreement with radar observations.
- Temperature/ Continentality: apart from temperature effect on updraft strength, precipitation efficiency of the mountain induced ”first” cell different to the later forming surrounding cells.