Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

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PQP
Praecipitationis
Quantitativae
Praedictio

Idealized Simulation of Shallow-to-Deep Convection Transition Over Land with LM

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Seminar of the LM User Group, Langen, 6.3.2007

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Introduction

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 LM.
- Quite detailed cloud microphysics parameterization: 2-moment-scheme of Seifert and Beheng (2006).
- Idealized simulations to investigate the influence of environmental parameters on single convective systems, (height of 0°C-level, moisture, wind profile, orography, aerosol regime) $\Longrightarrow$ Dynamical feedback of cloud microphysics
- Are there other parameters as, e.g., $CAPE$, Ri_B, Fr to discriminate different regimes?

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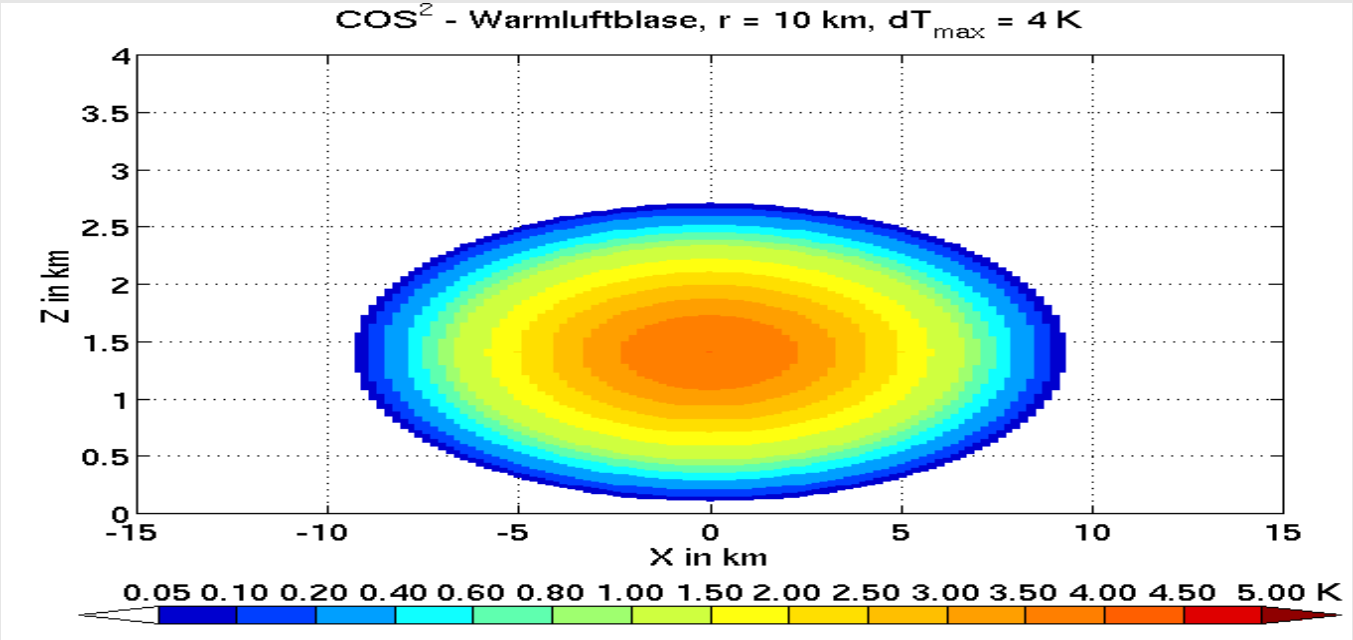
Idealized initiation: classical ”warm bubble”

$\cos^2$ – Bubble:

$$\Delta T(x,z) = \Delta T_0 \cos^2\left(\frac{\pi}{2} f(x,z)\right)$$

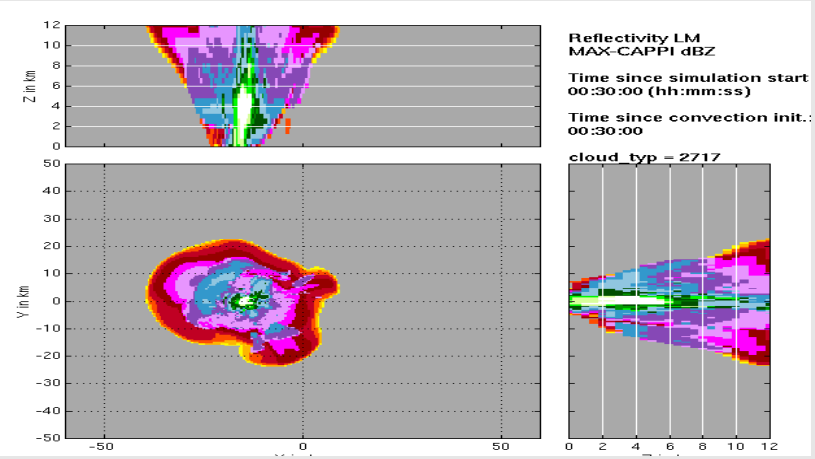
with: $f(x,z) = \min[1\,,\, r(x,z)]$ and $r(x,z) = \sqrt{\left(\frac{x-x_0}{r_x}\right)^2 + \left(\frac{z-z_0}{r_z}\right)^2}$



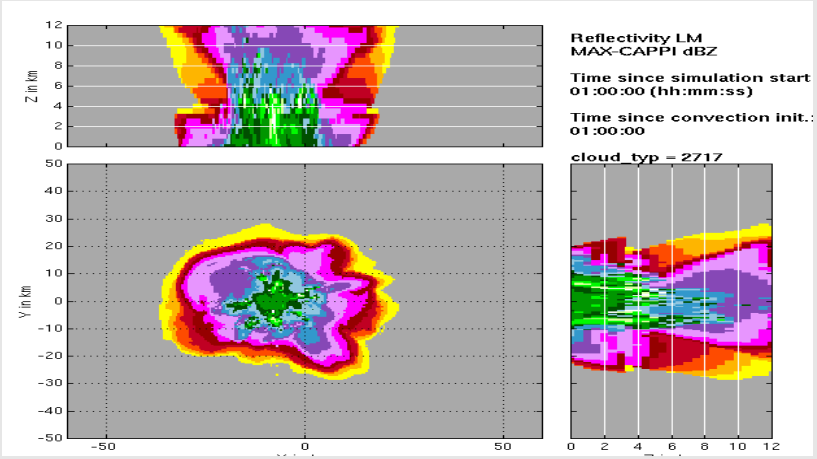
Idealized initiation: classical ”warm bubble”

LM ($\Delta X = 500$ m): Typical result for multicell-type system

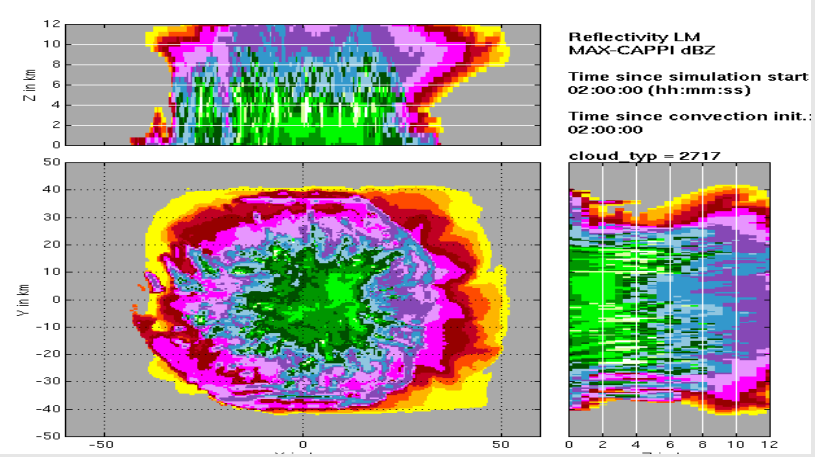
dBZ 0:30 h



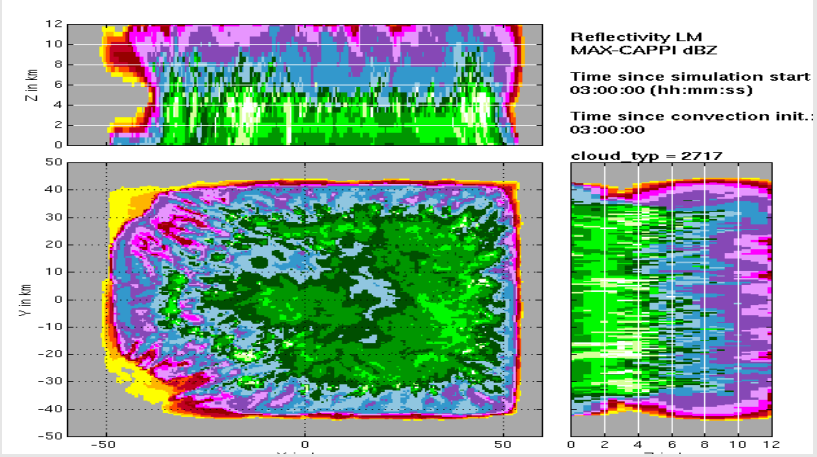
dBZ 1:00 h

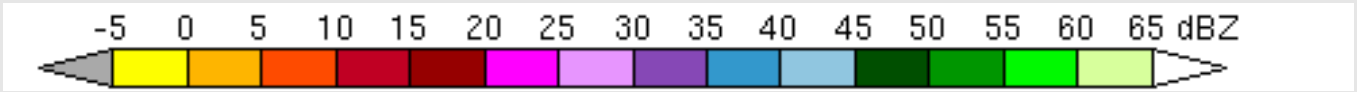


dBZ 2:00 h



dBZ 3:00 h





Idealized initiation: mountain wave flow

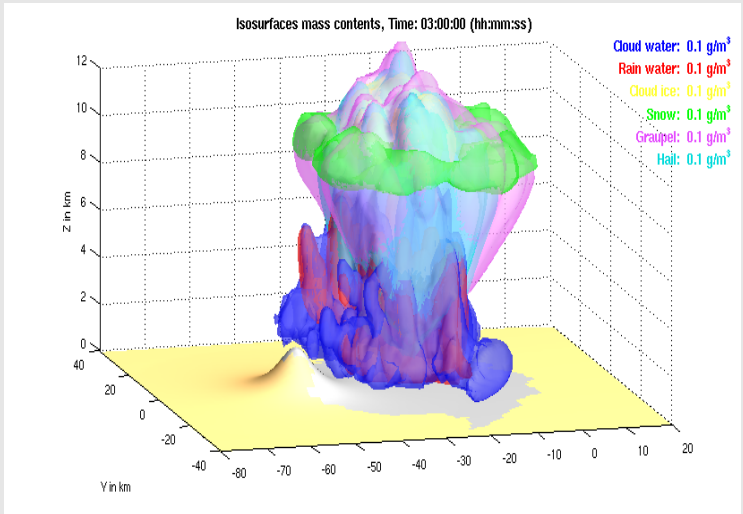
Isosurfaces of mass densitiy 0.1 g m^{-3} after 3:00 h

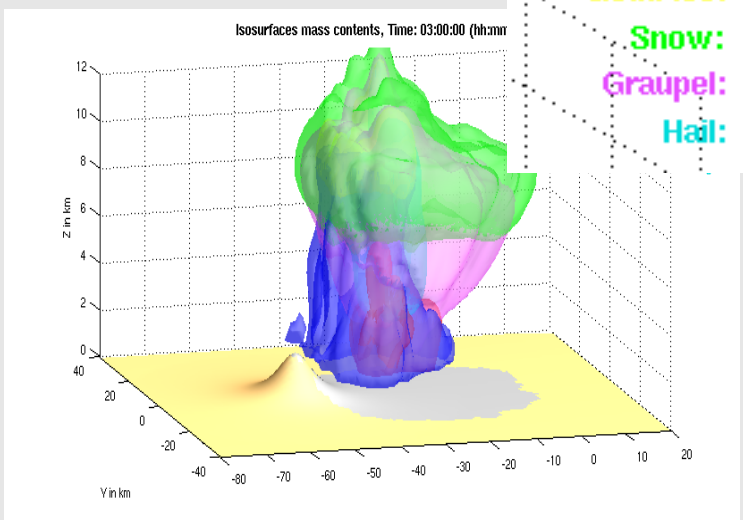
Maritime

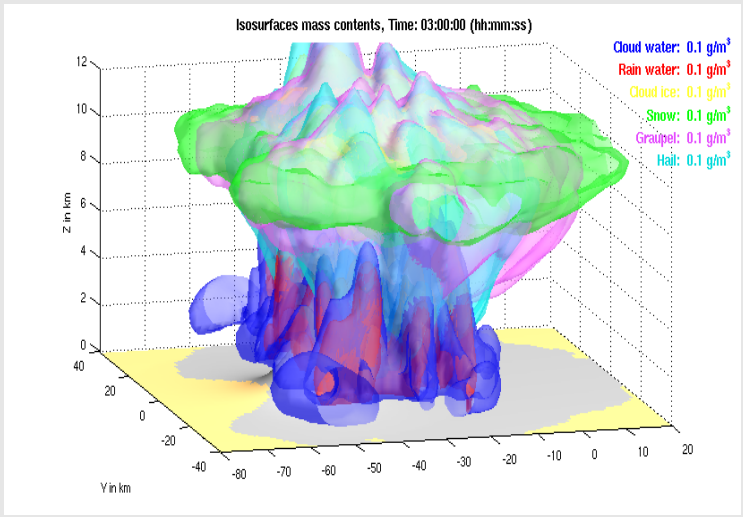
Continental

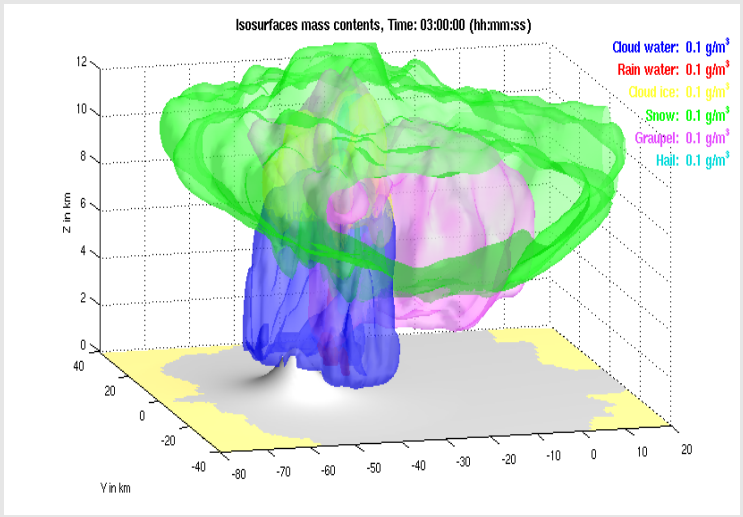
High 0°C-level

Low 0°C-level









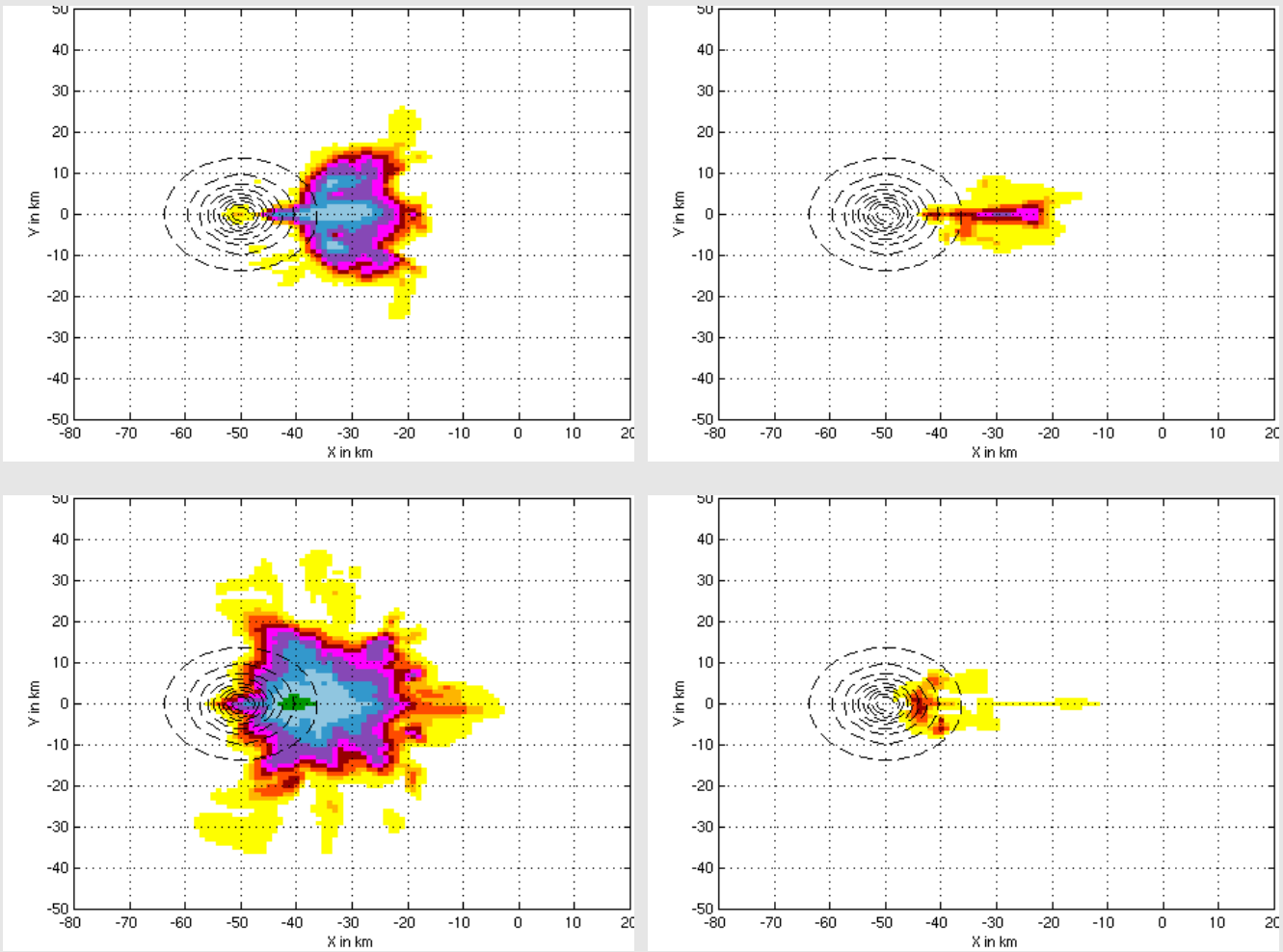
Idealized initiation: mountain wave flow

Accumulated precipitation in mm after 3 h.

Maritime | Continental

High 0°C-level

Low 0°C-level



Brief description of simulations

1. LM Version 3.19
2. Flat topography, fully periodic b.c.
3. LES-type turbulence scheme `itype_turb=5` (”dry” scheme only)
4. $\Delta X = 200$ m (1 sim. with 100 m)
5. Constant sensible heat flux of 300 W m^{-2} at bottom
6. Idealized sounding (initially stable boundary layer, potentially moist unstable free troposphere)

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

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Initial sounding: thermodyn. profiles

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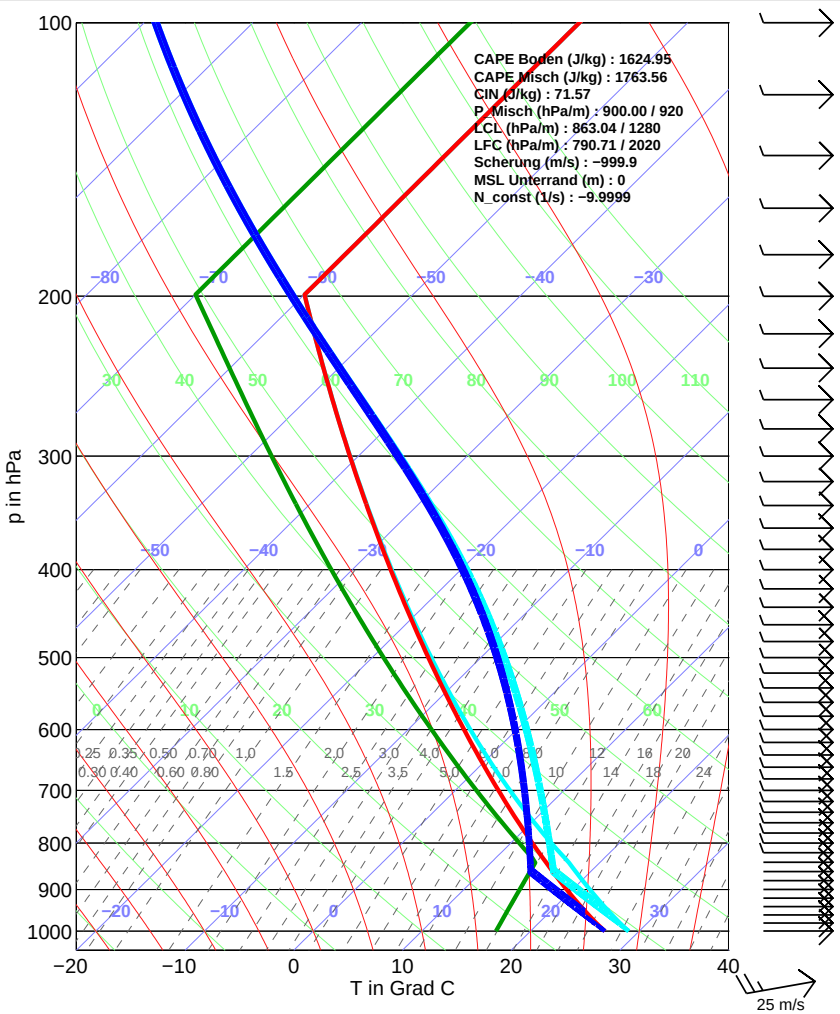

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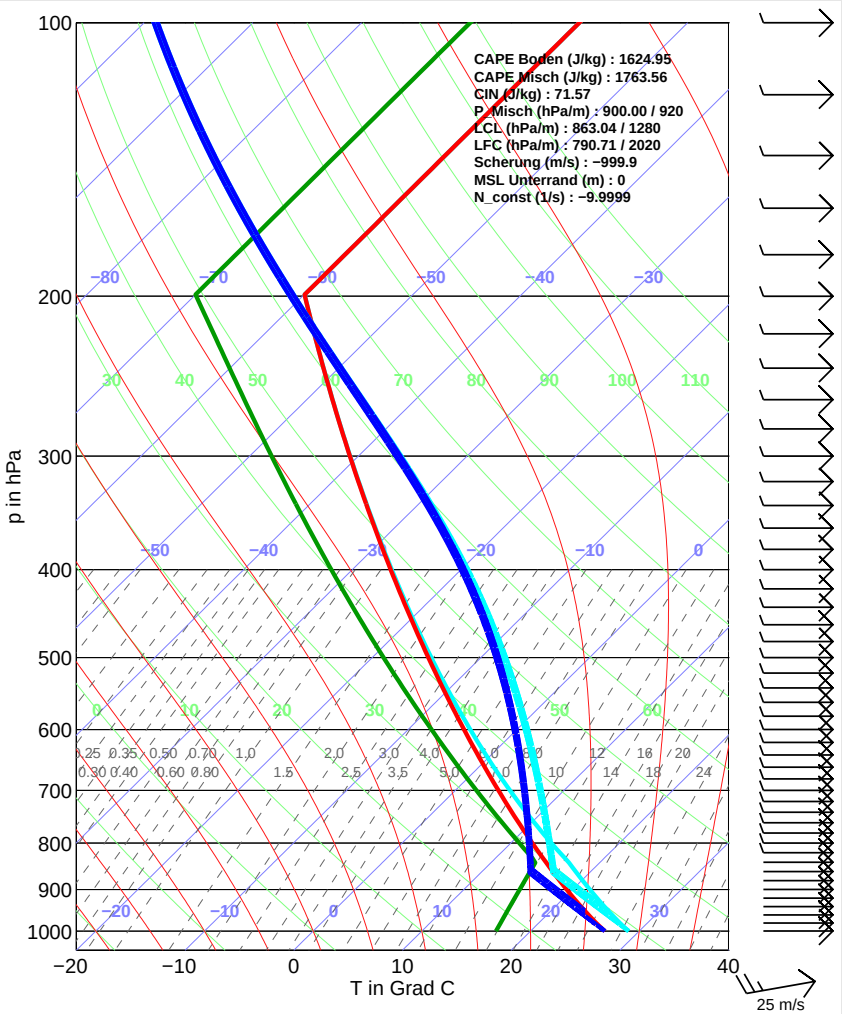

- $T_B = 28°C$
- $Q_{BL} = 12 g\,kg^{-1}$
- LCL in 1280 m AGL
- $CAPE = 1700\ J\,kg^{-1}$
- $CIN = 70\ J\,kg^{-1}$
- $U_\infty = 5\ m\,s^{-1}$
- Single-/multicell regime

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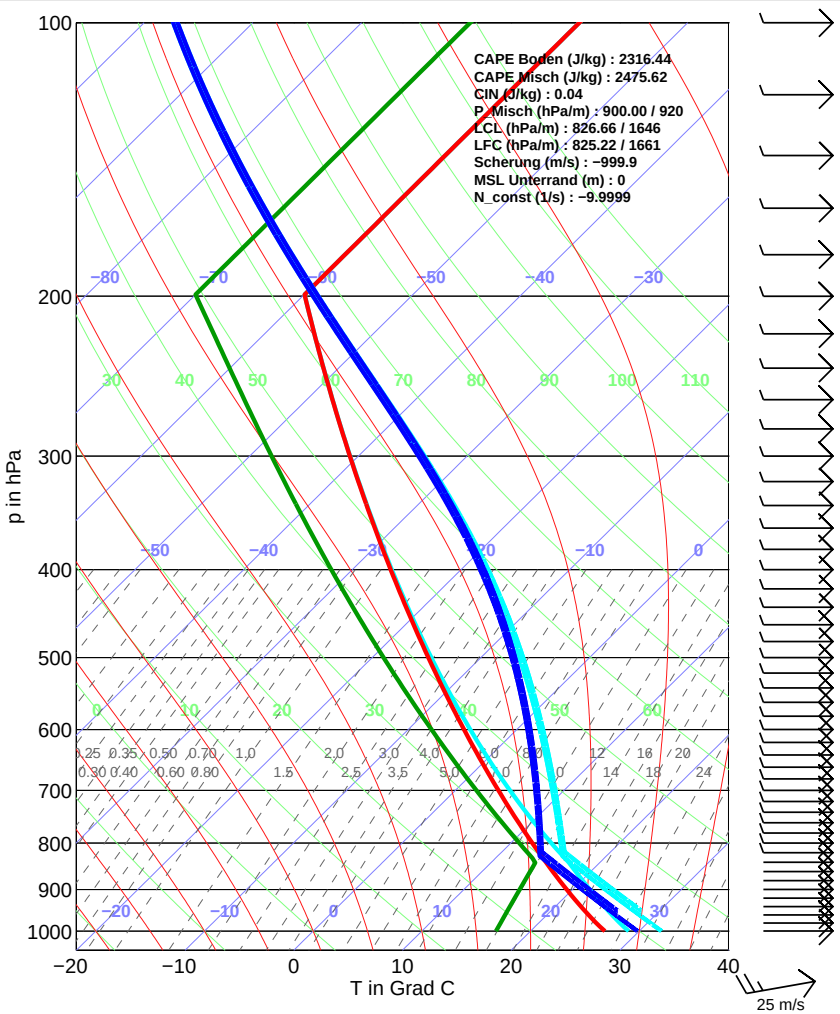

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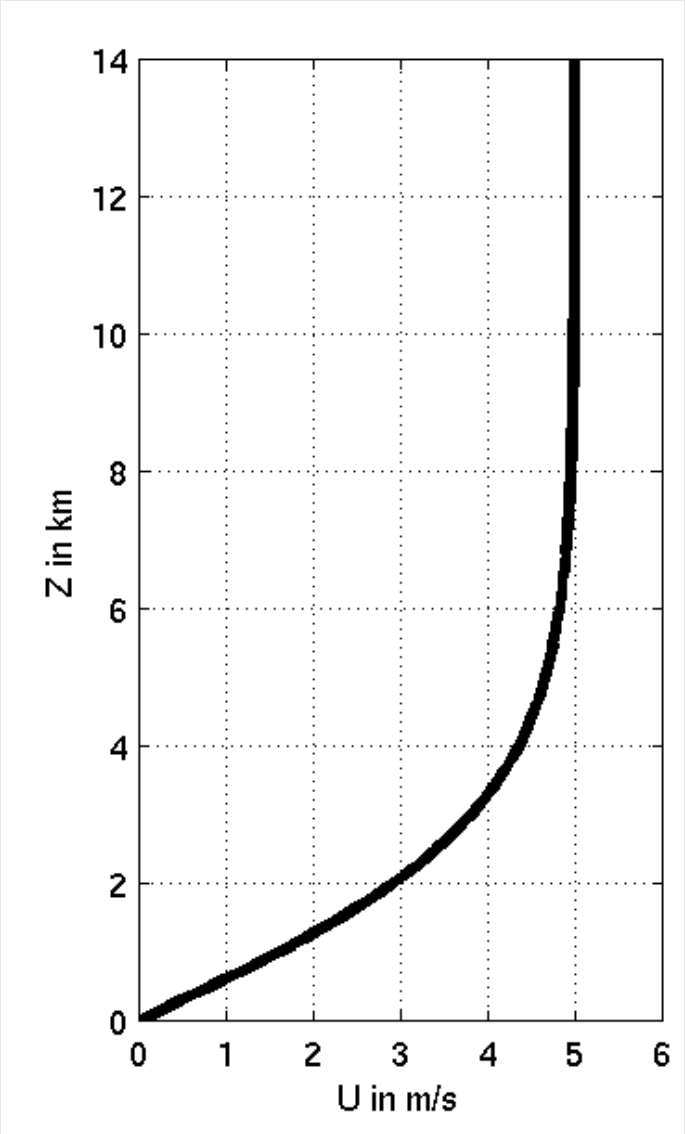
- $T_A = 31°C$
- CCL in 1650 m AGL
- $CAPE_{TA} = 2400\ \mathrm{J\,kg^{-1}}$

Initial sounding: wind profile



1. experiment: ”dry” runs

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

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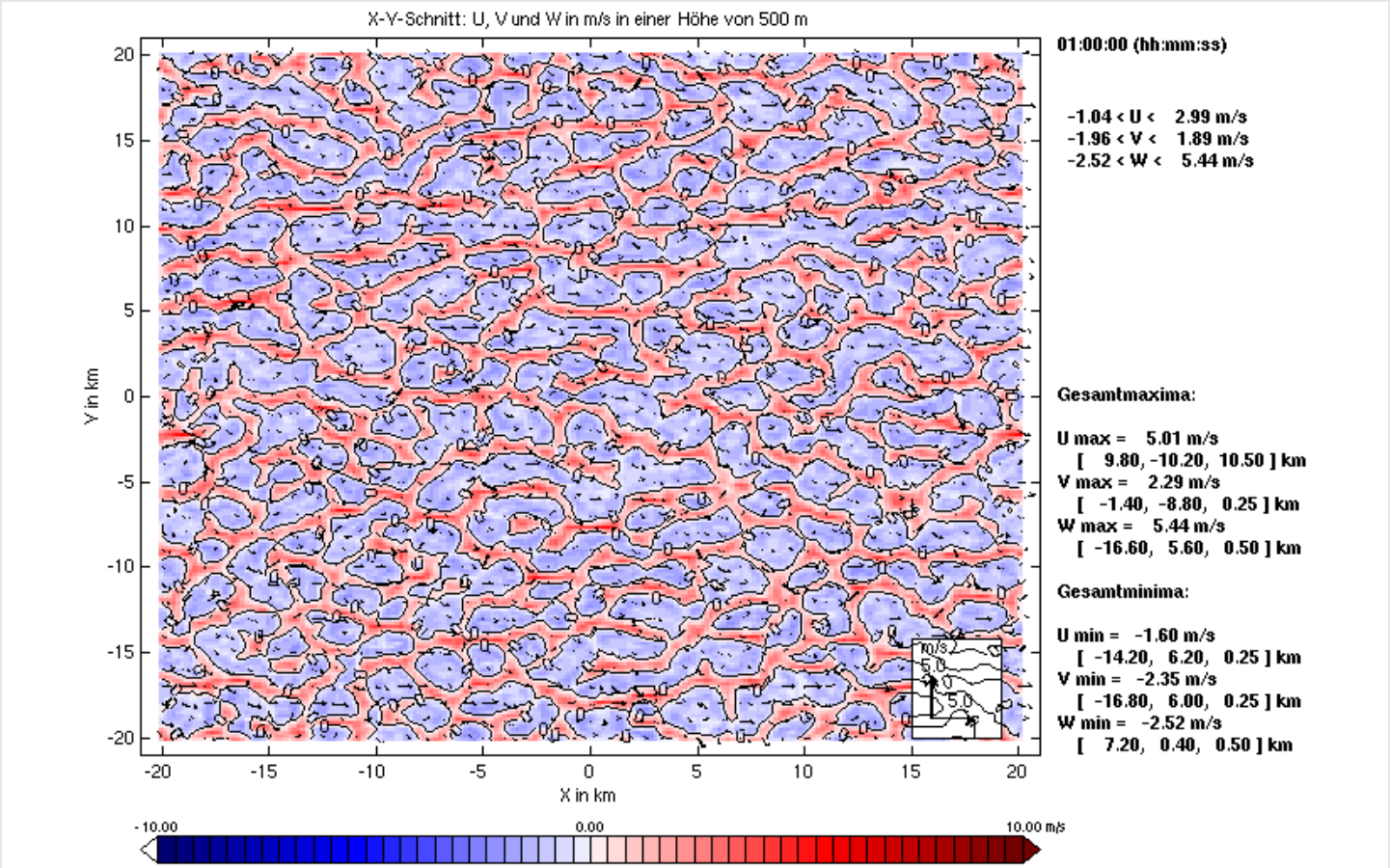
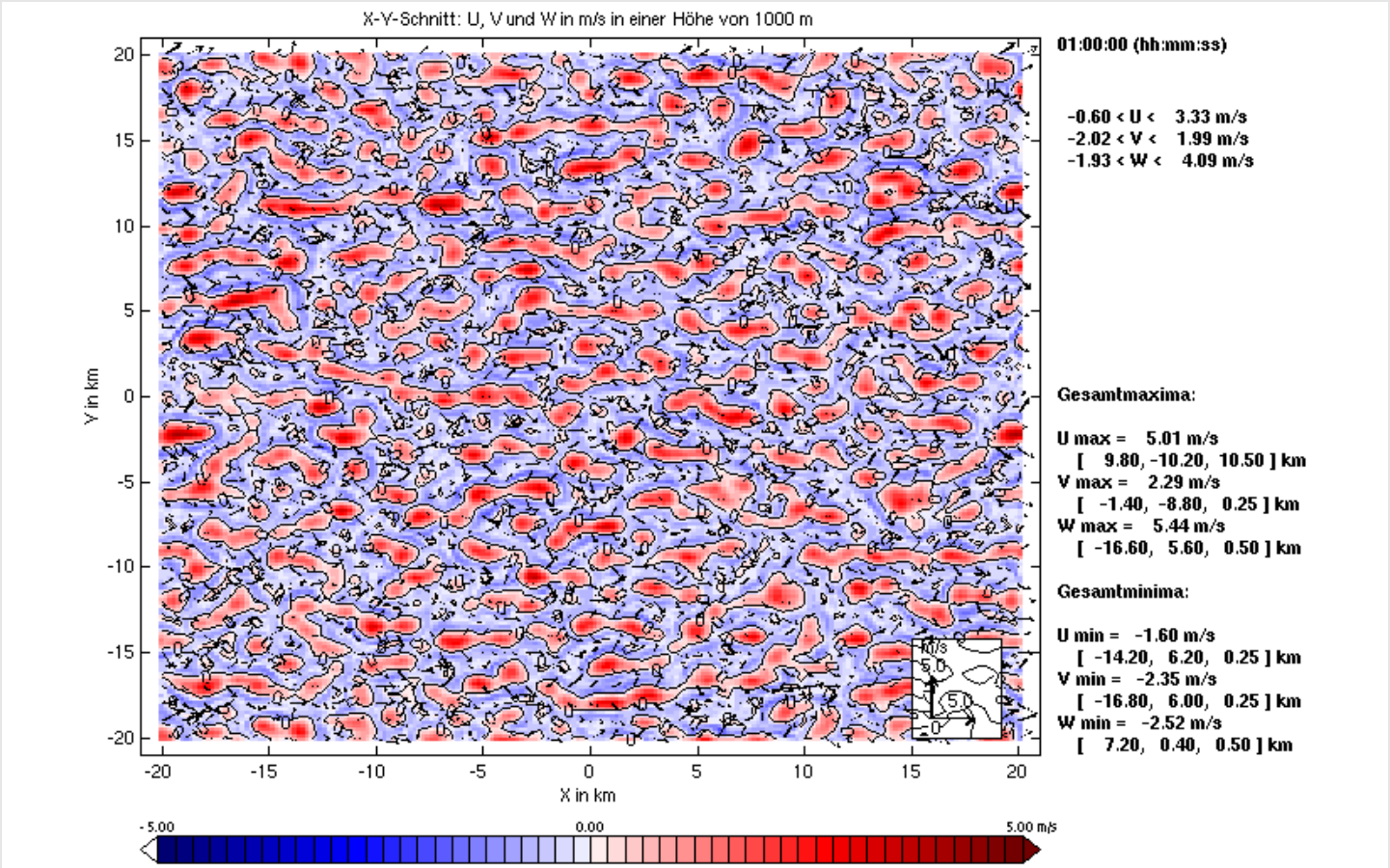
Example: ”dry” run with $\Delta X = 200$ m

$Z = 500$ m, $t = 01{:}00$ h, 40×40 km^2



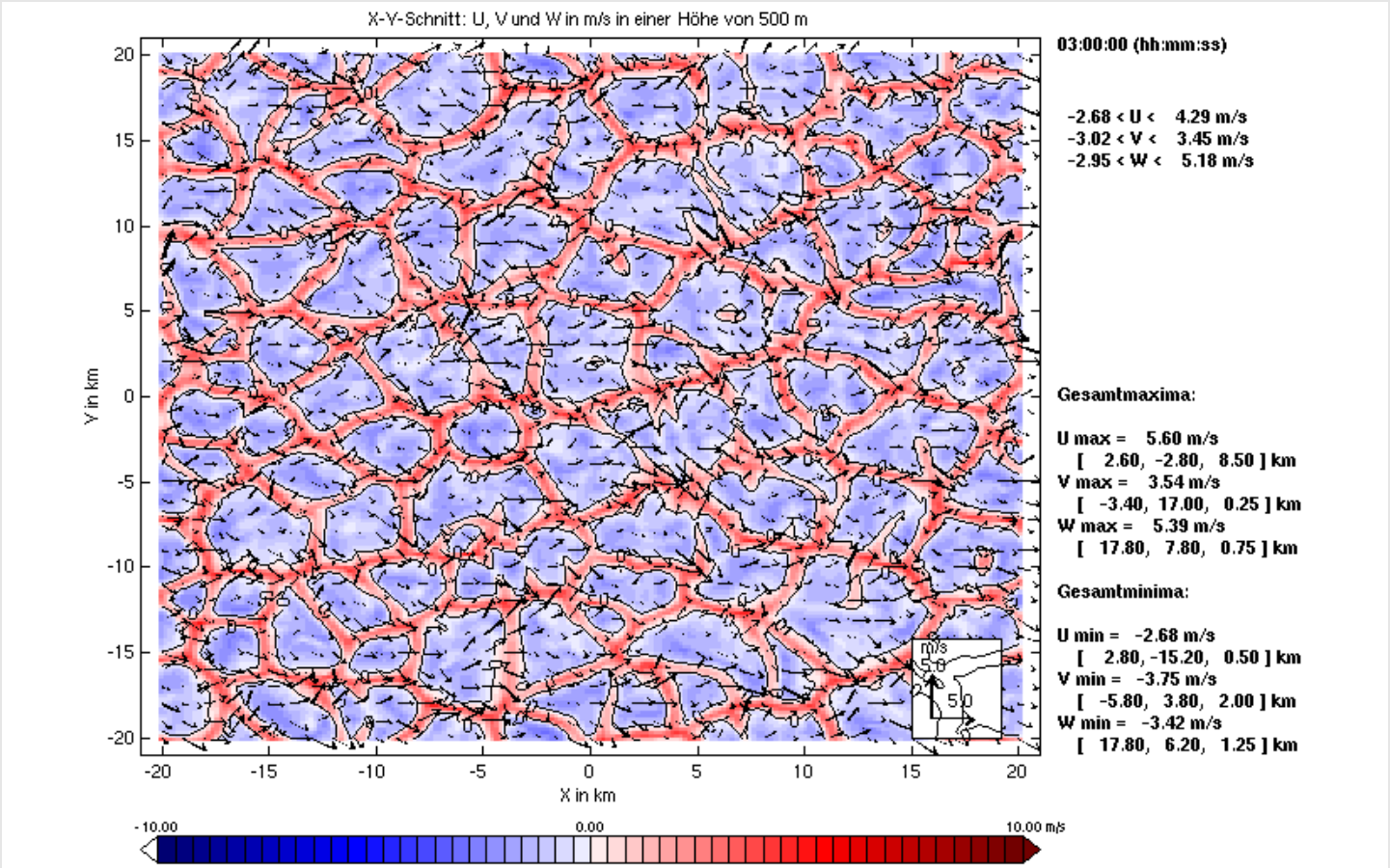
Example: ”dry” run with $\Delta X = 200$ m

Z = 1000 m, t = 01:00 h, 40 x 40 km^2



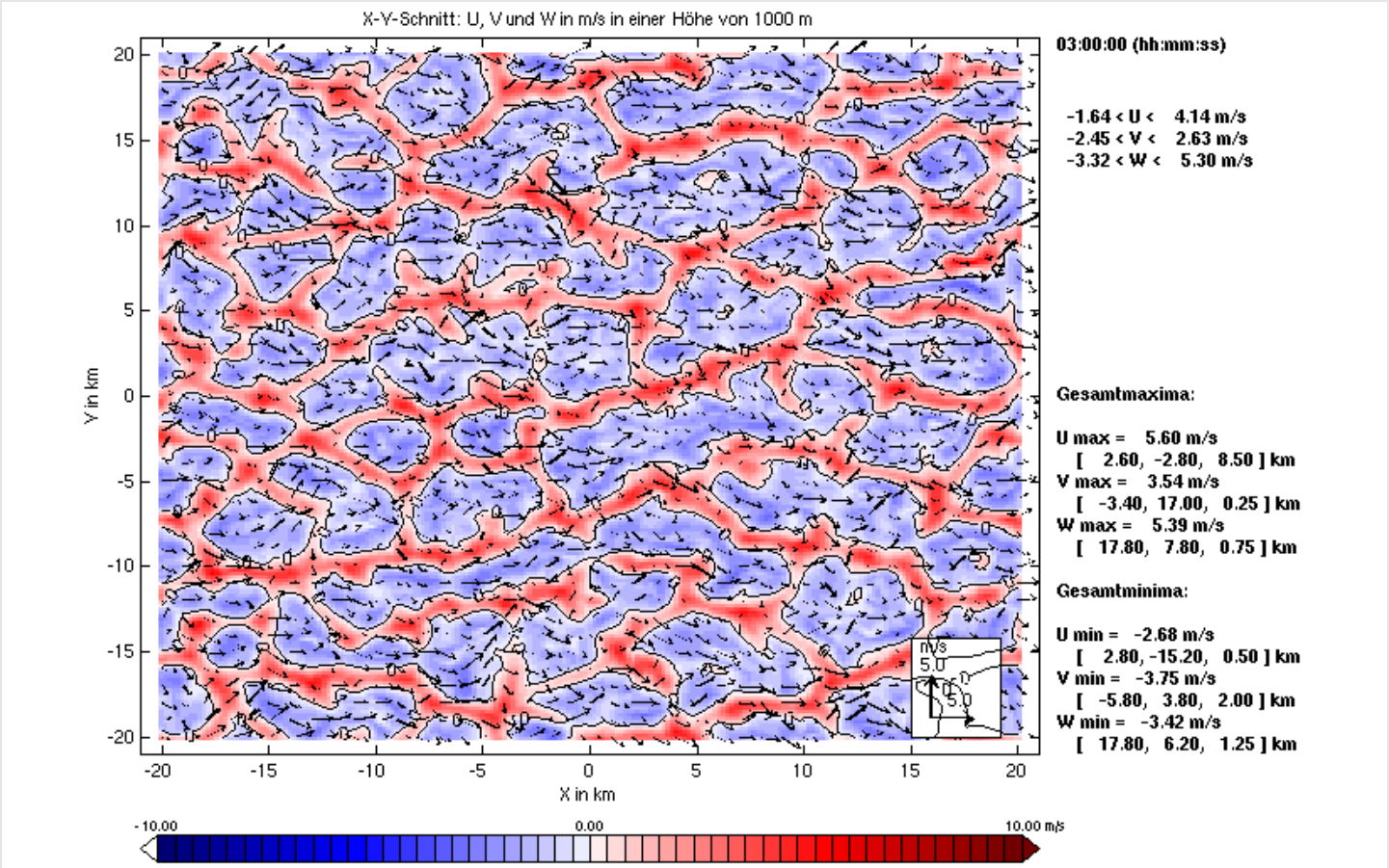
Example: ”dry” run with $\Delta X = 200$ m

$Z = 500$ m, $t = 03{:}00$ h, 40×40 km^2



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

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

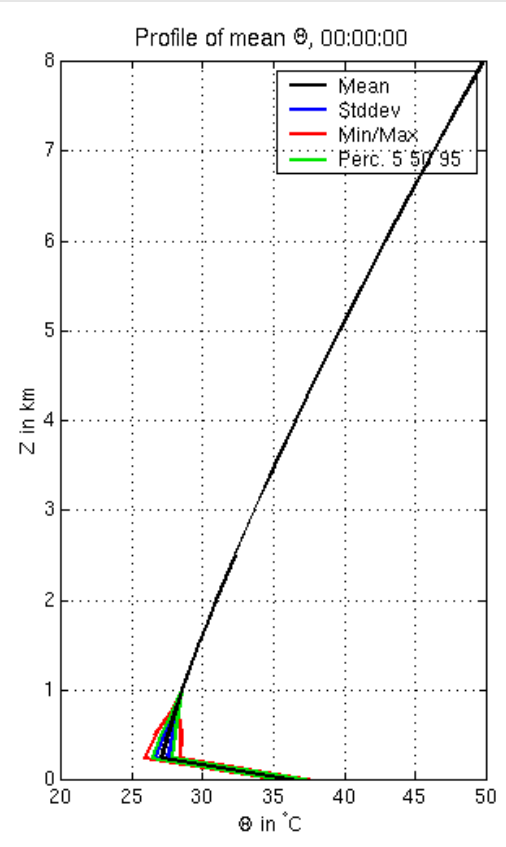


Example: ”dry” run with $\Delta X = 200$ m

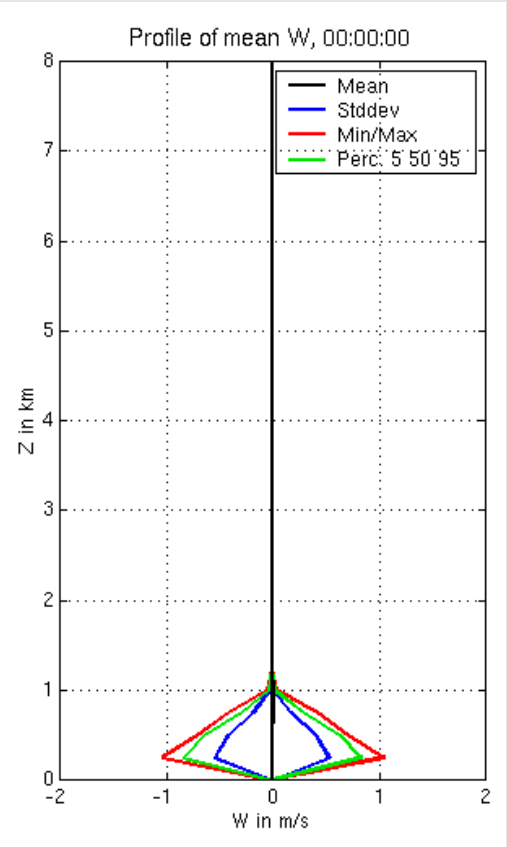
$\Delta X = 200$ m, domain size 40 x 40 km

Mean profiles of Θ, W and Q_V after 00:00 h

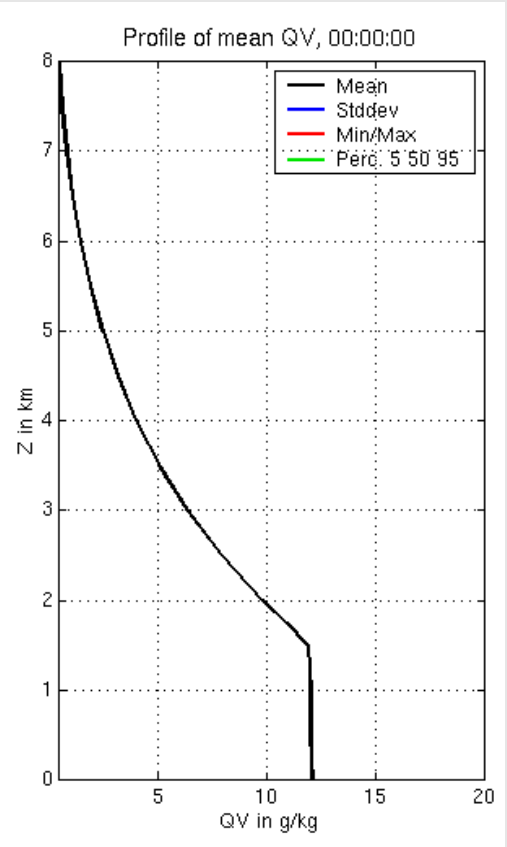
Θ



W



Q_V

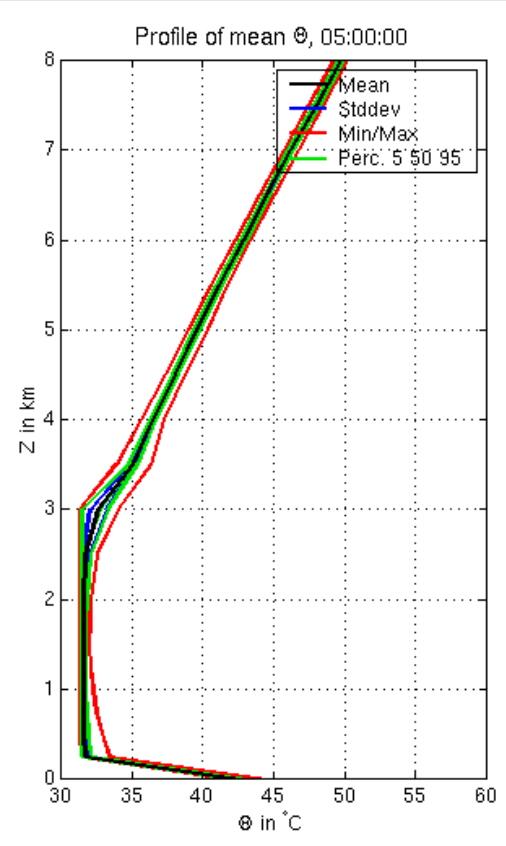


Example: ”dry” run with $\Delta X = 200$ m

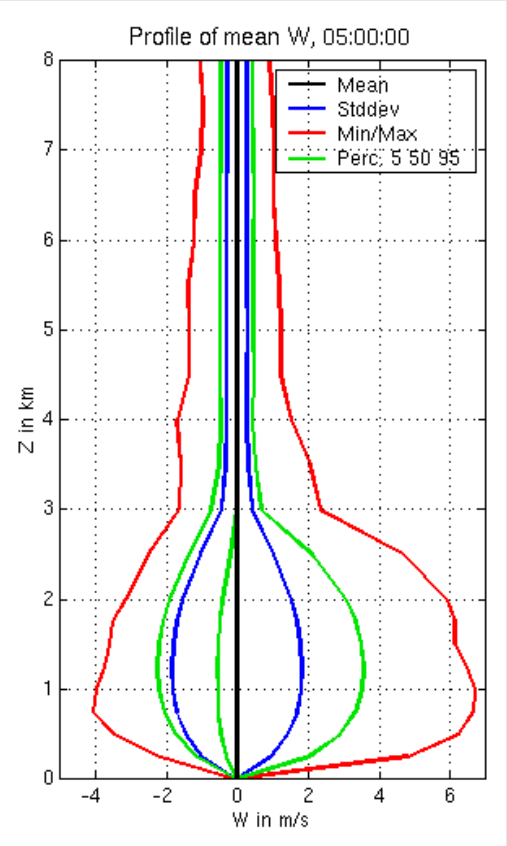
$\Delta X = 200$ m, domain size 40 x 40 km

Mean profiles of Θ, W and Q_V after 05:00 h

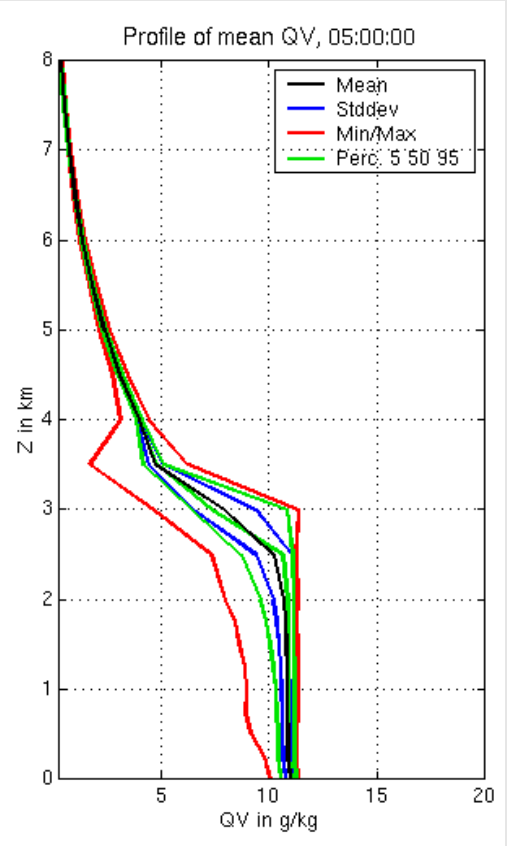
Θ



W

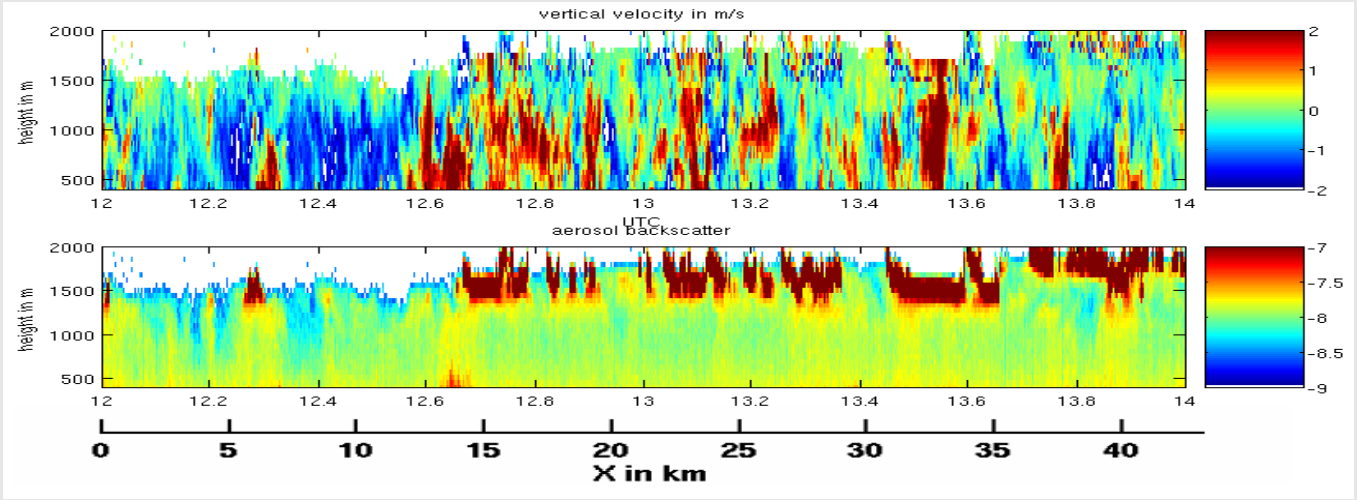


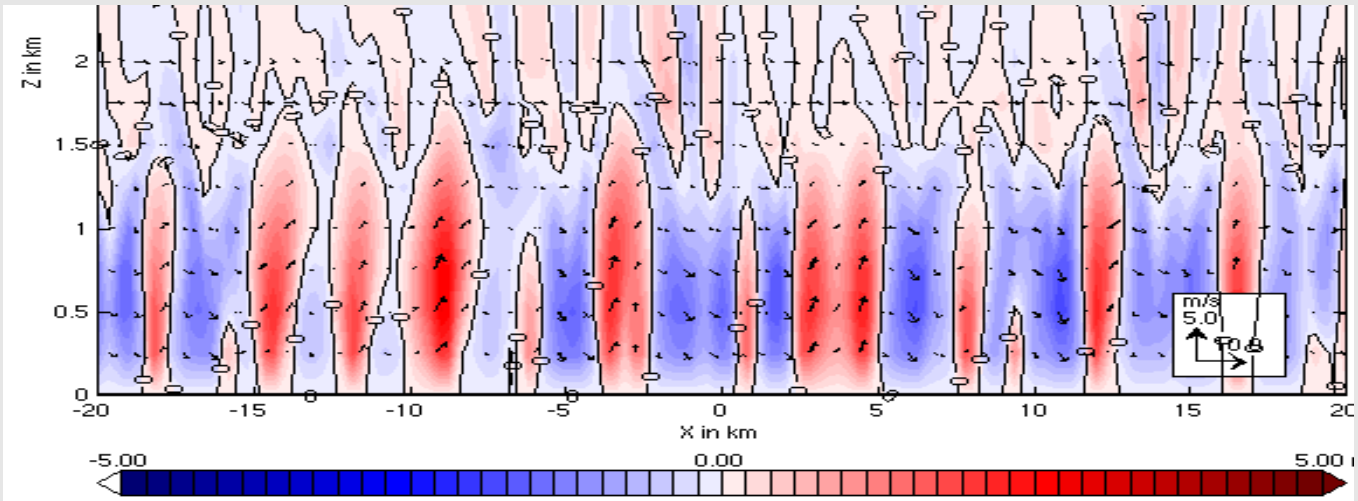
Q_V



Horizontal and vertical scales?

Qualitative comparison with measurements of IMK Lidar (CSIP, 11.7.2005, Chilbolton)



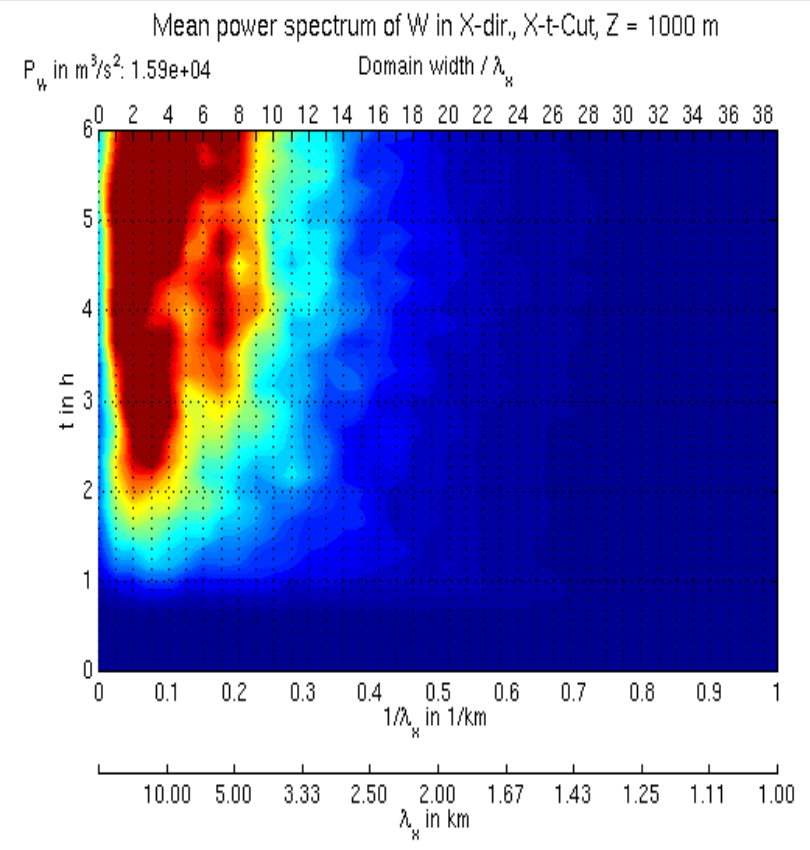


Horizontal and vertical scales?

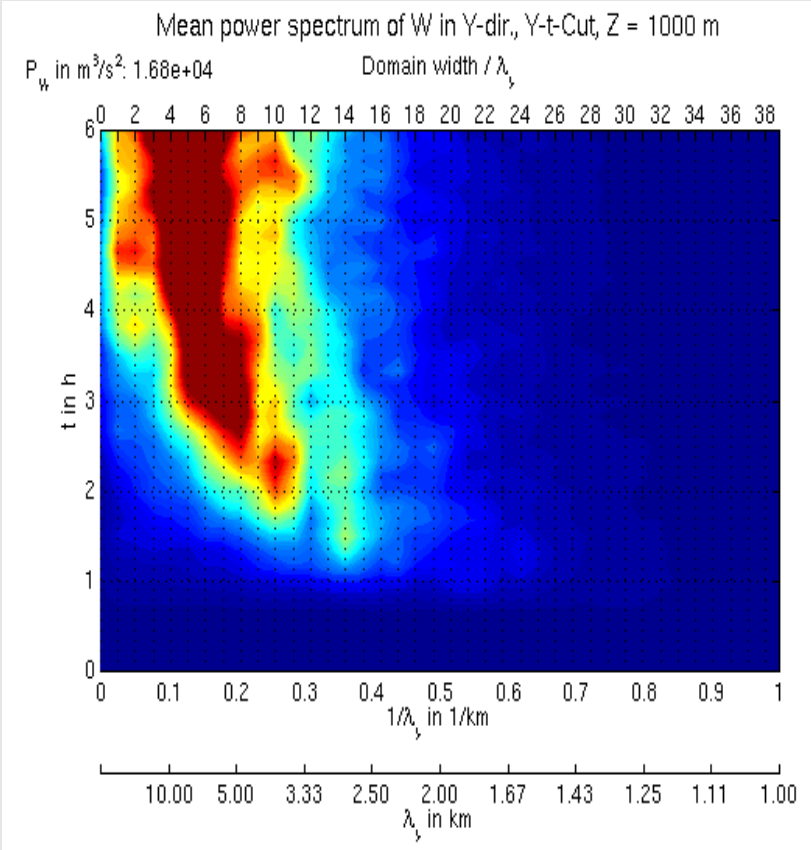
Power spectra of W in $Z = 1000$ m as Hovmöller-Plots

(Spectra computed columnwise in X-(Y-)direction, mean spectrum averaged over all X-(Y-)columns)

$P_X\{W\}$ (X-dir.)

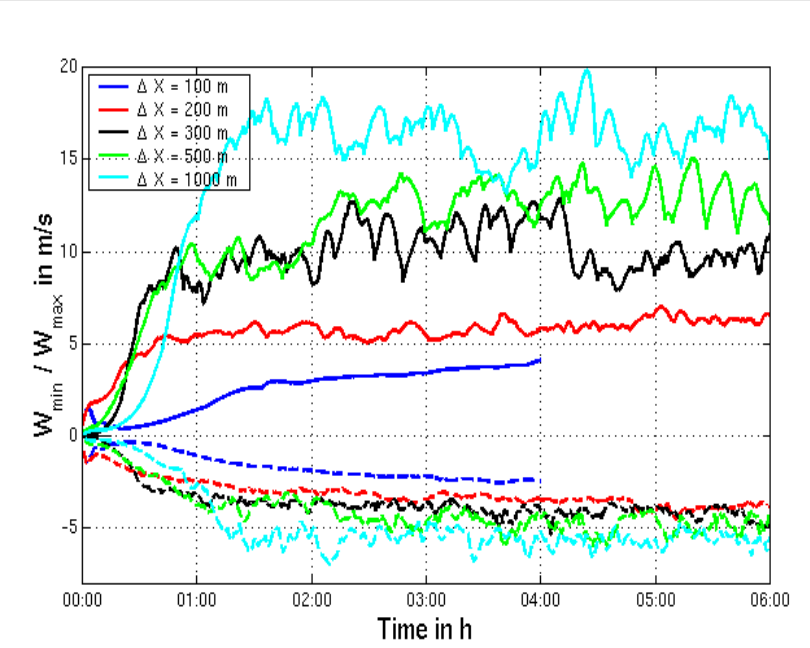


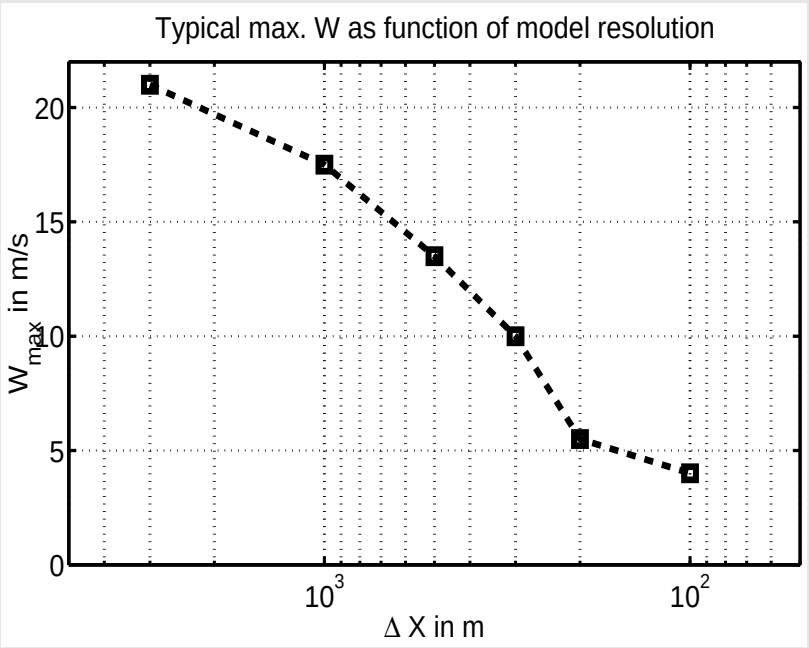
$P_Y\{W\}$ (Y-dir.)



Results about resolution dependency

Max./Min. and typical vertical velocity of thermals



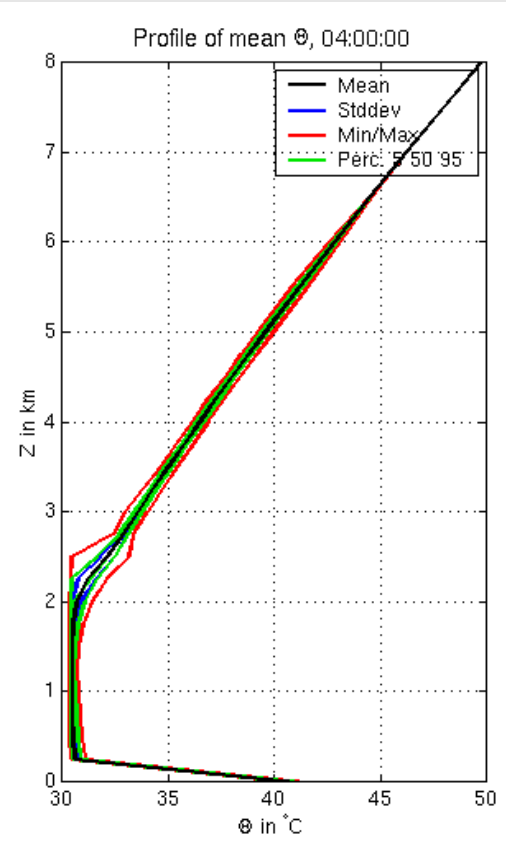


Results about resolution dependency

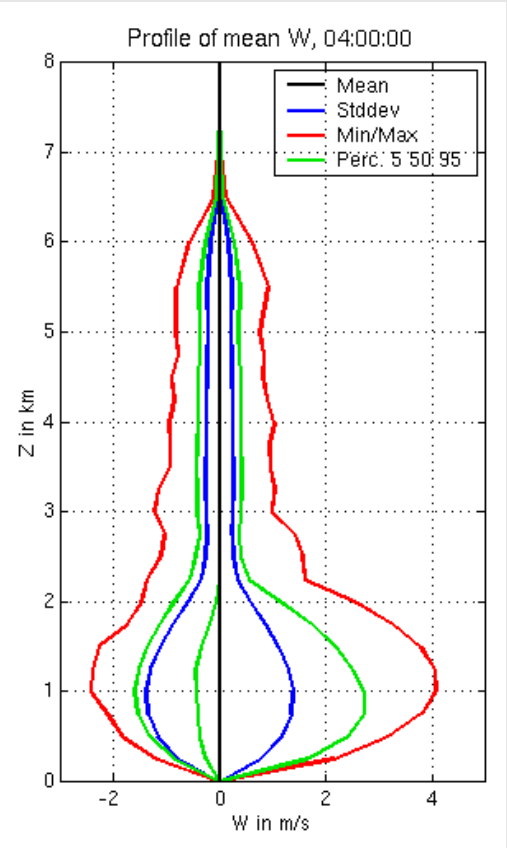
$\Delta X = 100$ m, domain size 20 x 20 km

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

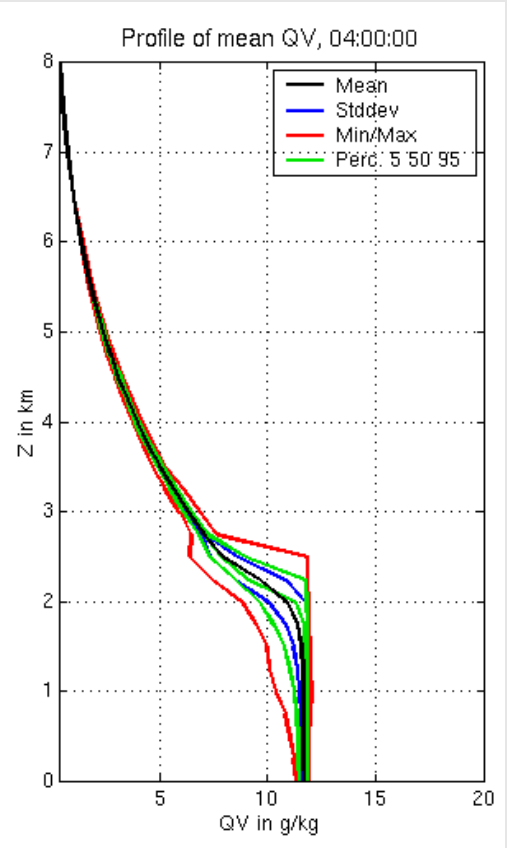
Θ



W



Q_v

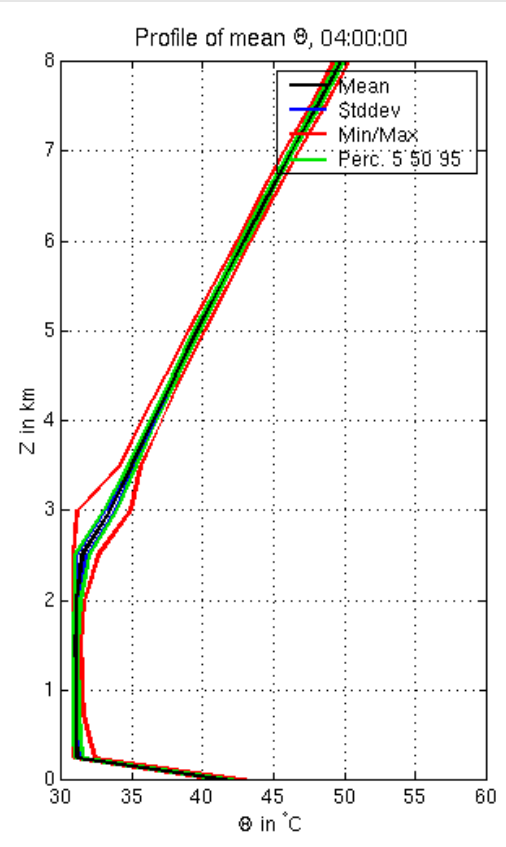


Results about resolution dependency

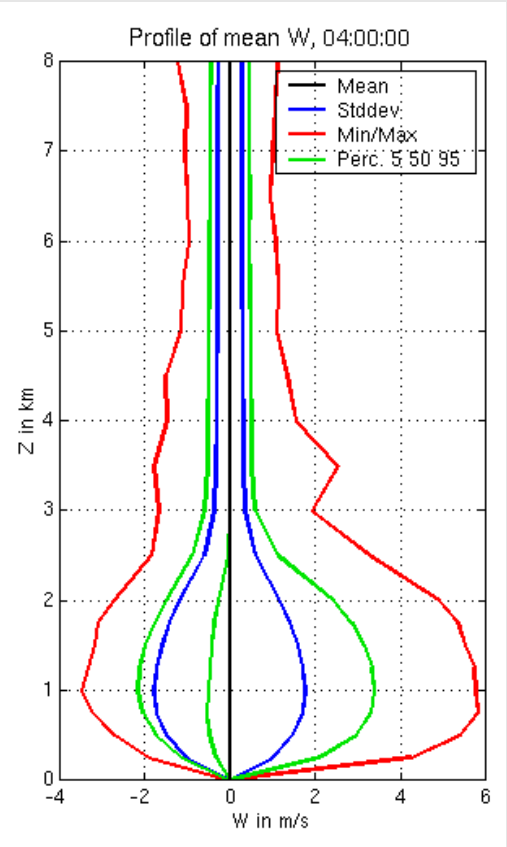
$\Delta X = 200$ m, domain size 40 x 40 km

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

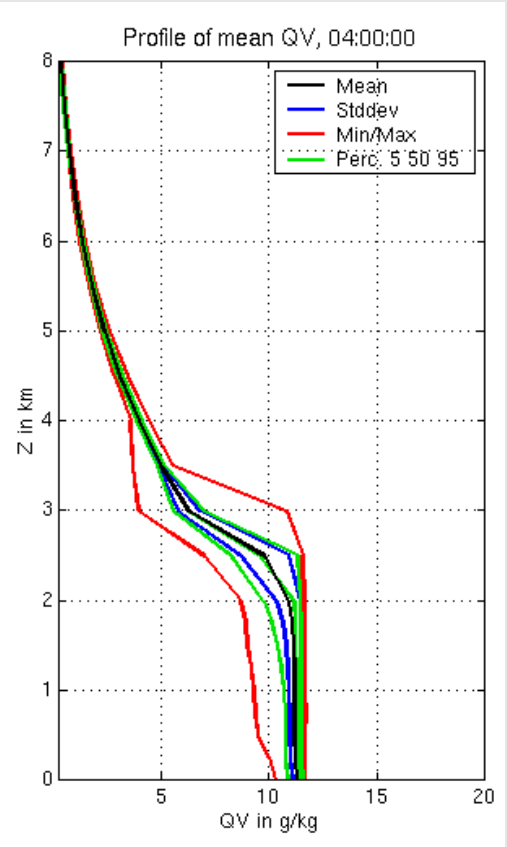
Θ



W



Q_V



Results about resolution dependency

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

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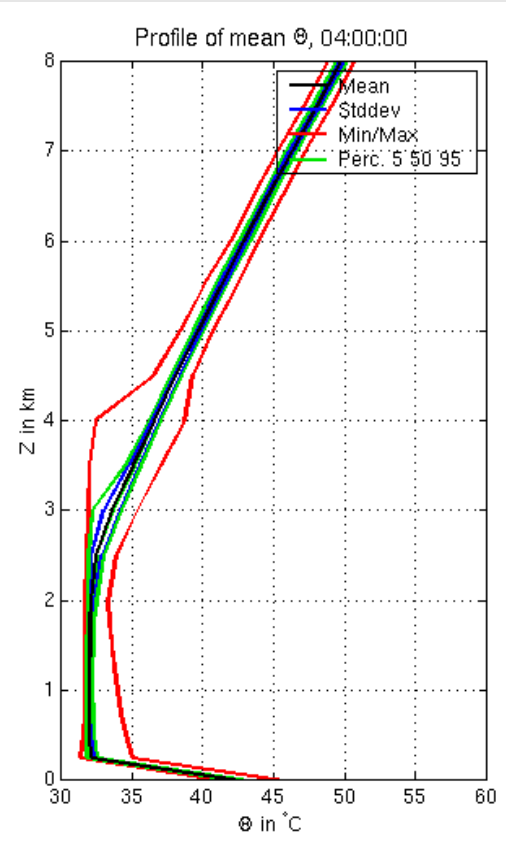
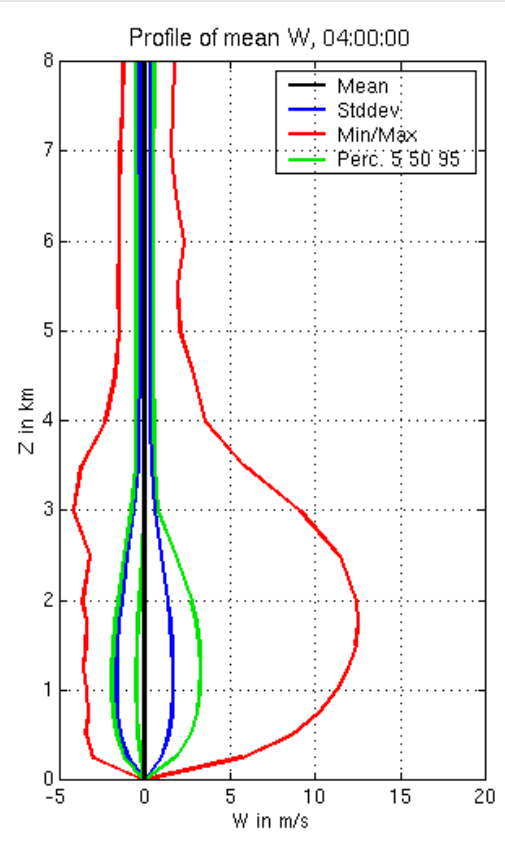
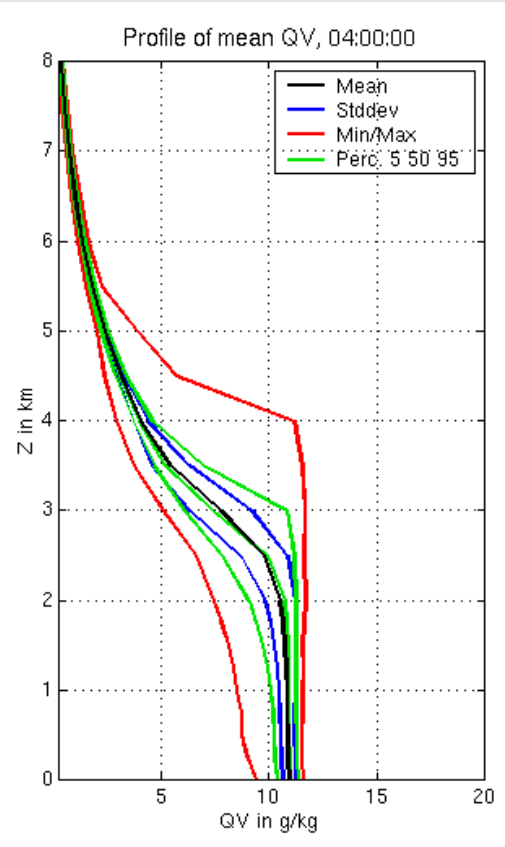
Θ



W



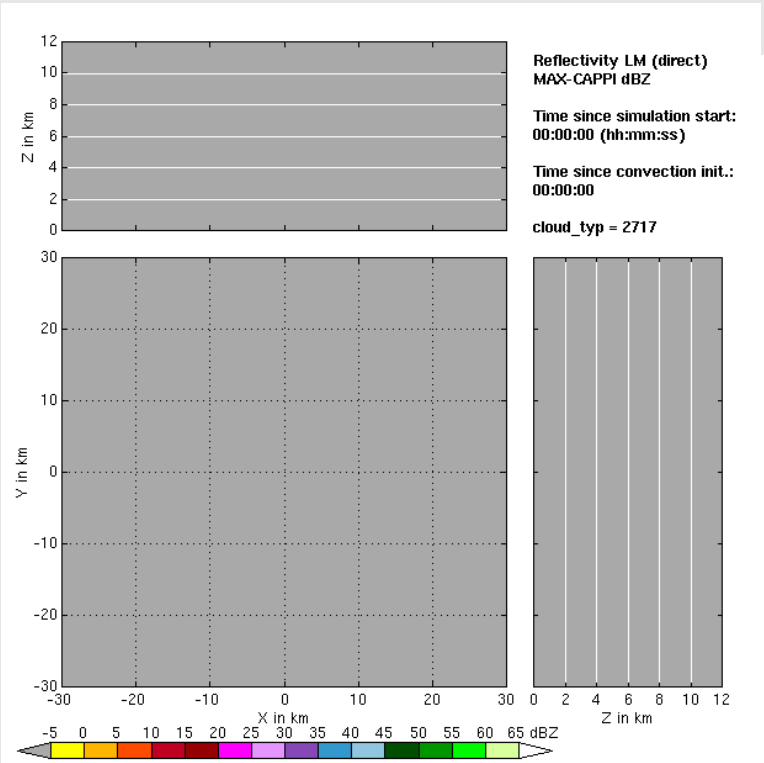
Q_V



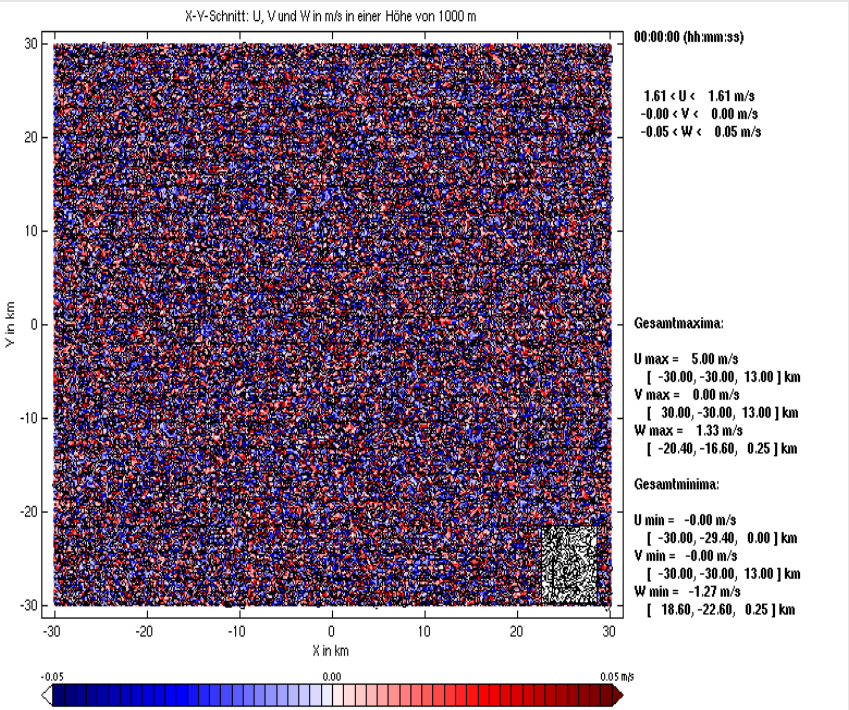
2. experiment: ”moist” run with $\Delta X = 200$ m

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

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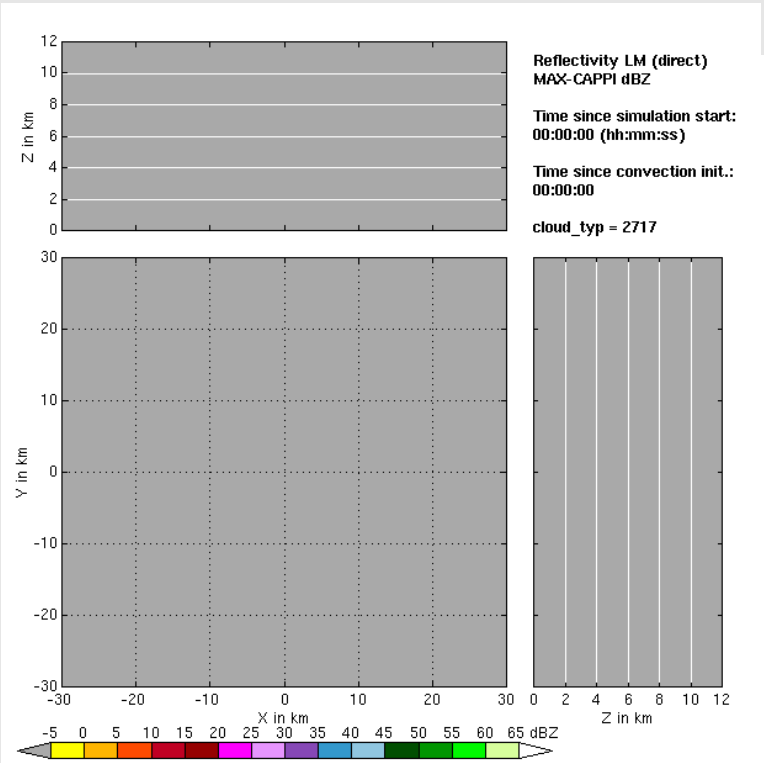
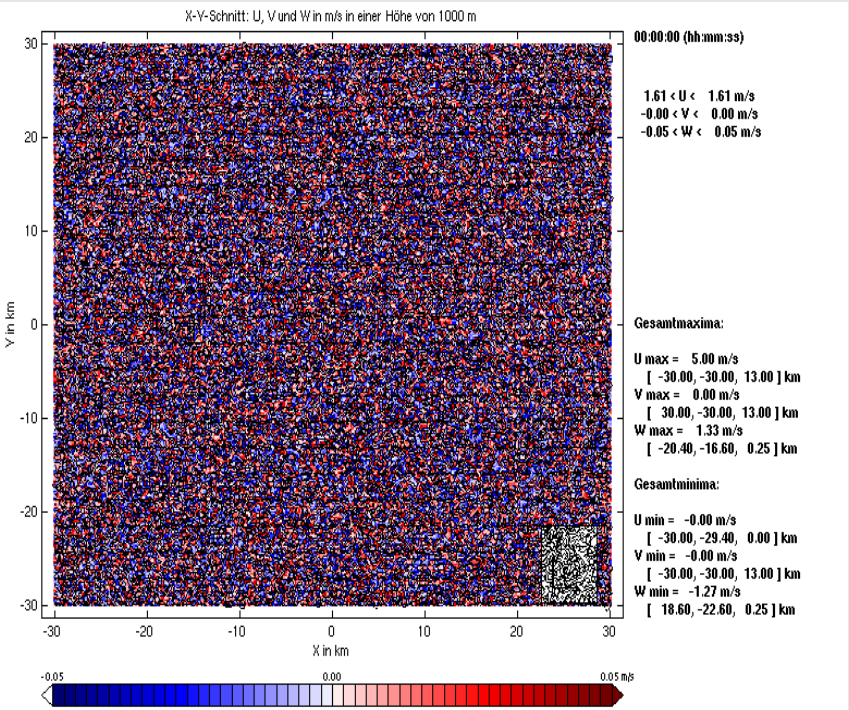
Max-Cappi Z in dBZ



W in m/s at Z=1000 m



play

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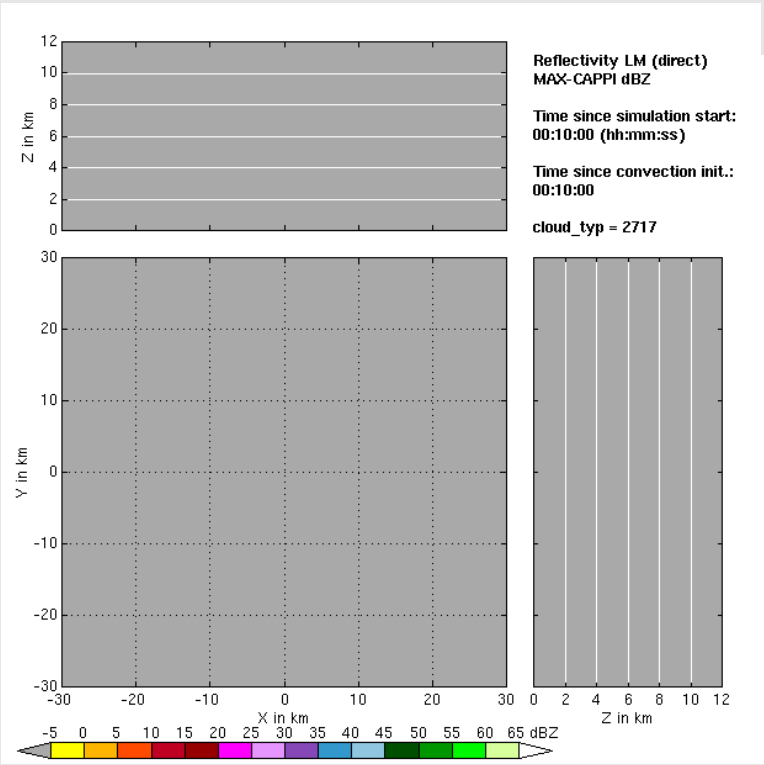
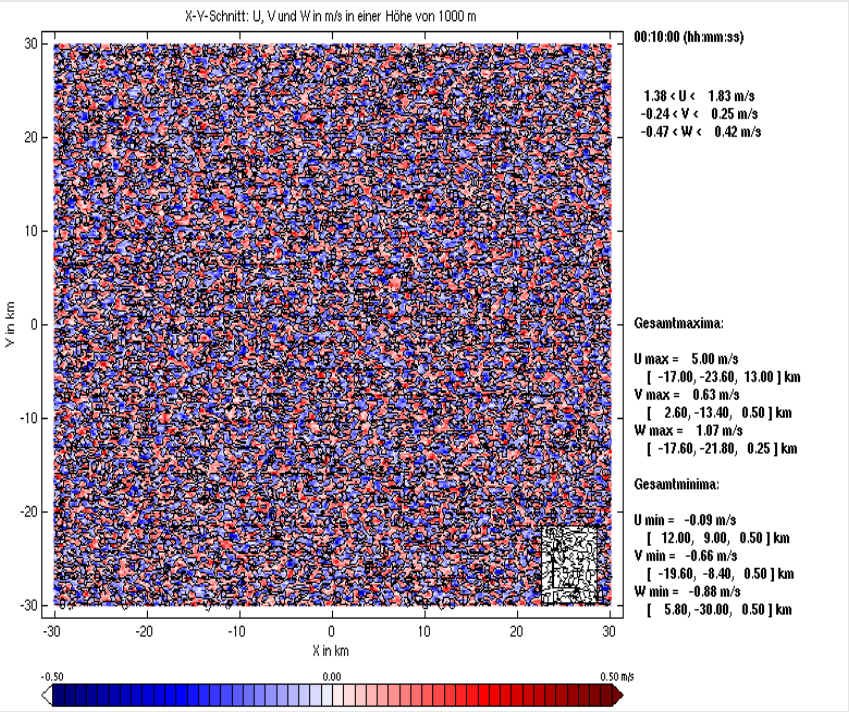


W in m/s at Z=1000 m



play

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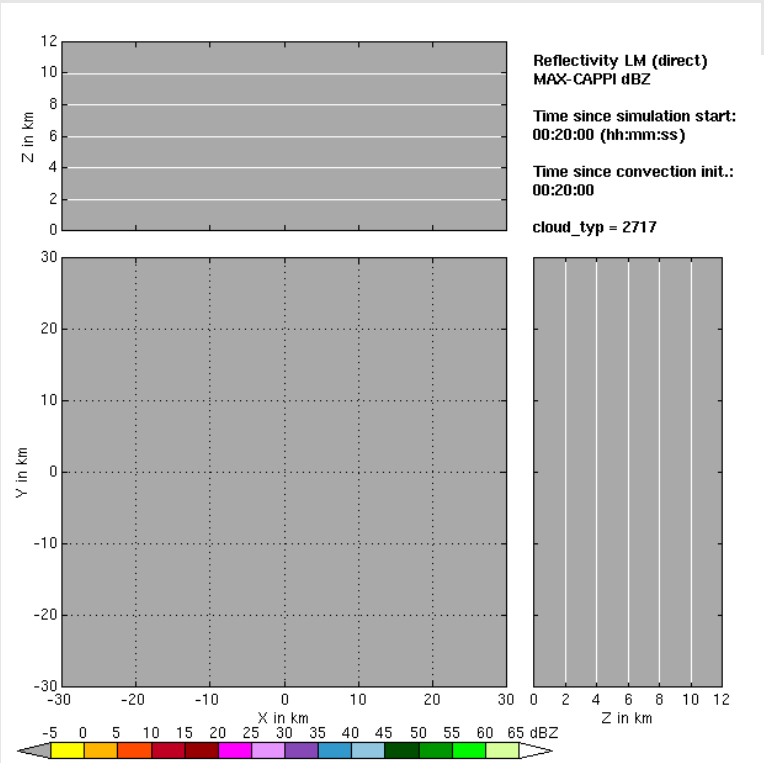
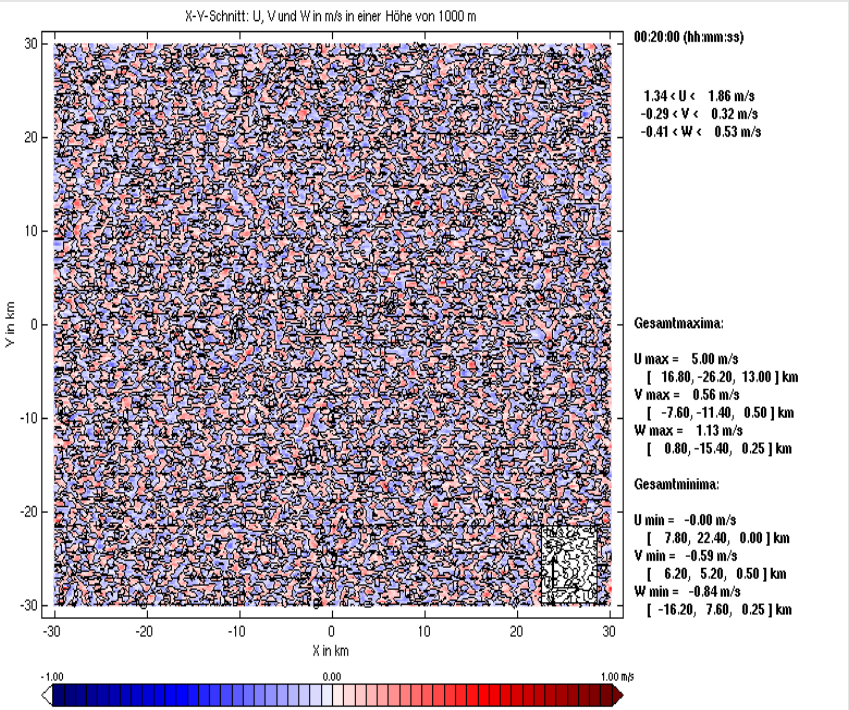


W in m/s at Z=1000 m



play

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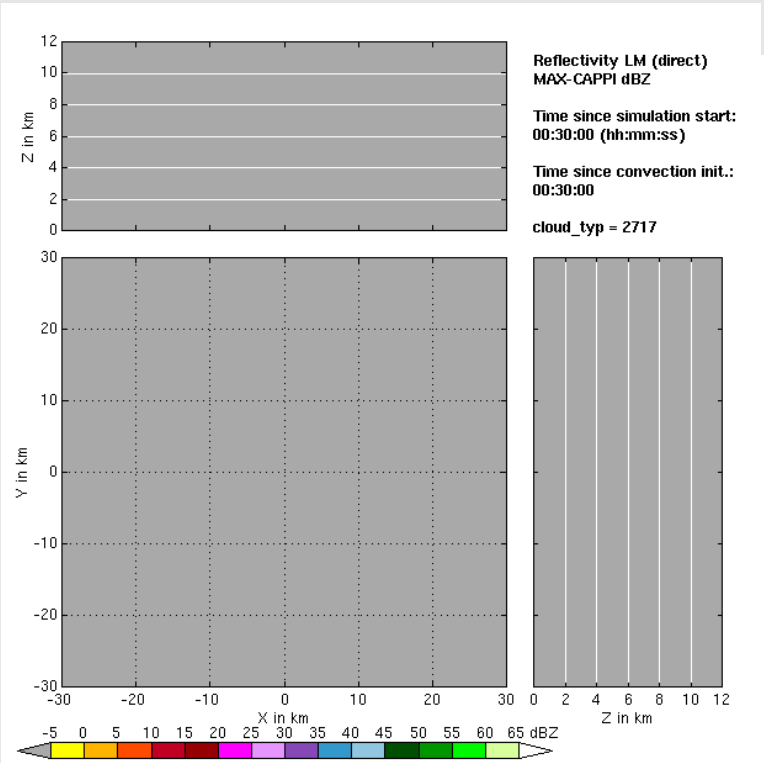
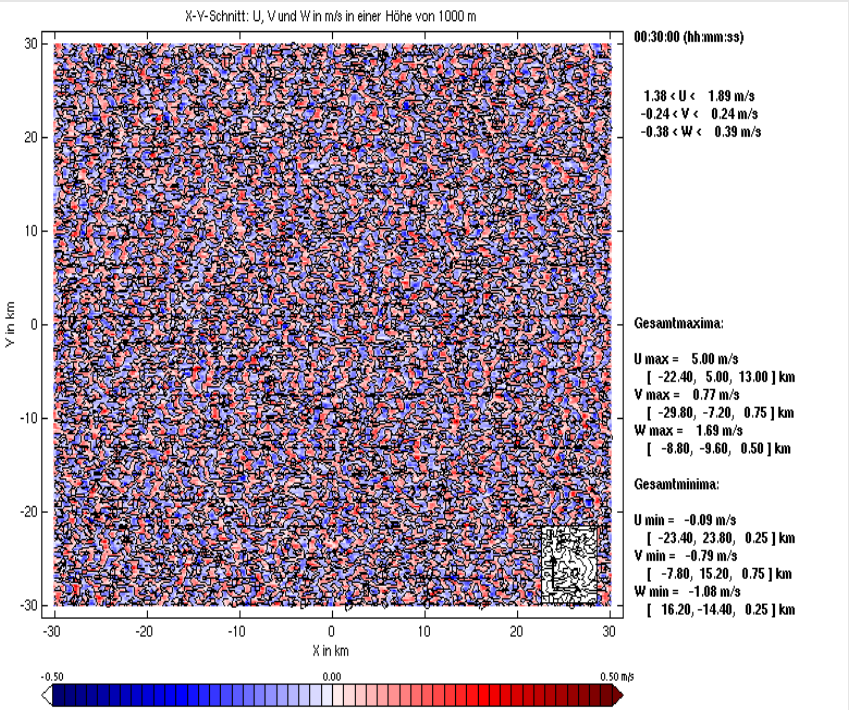


W in m/s at Z=1000 m



play

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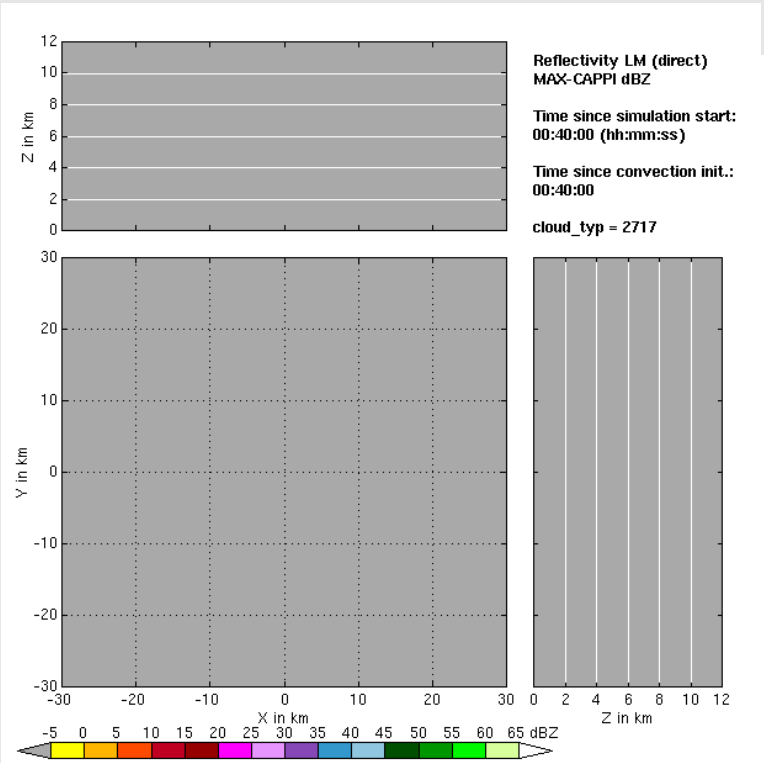
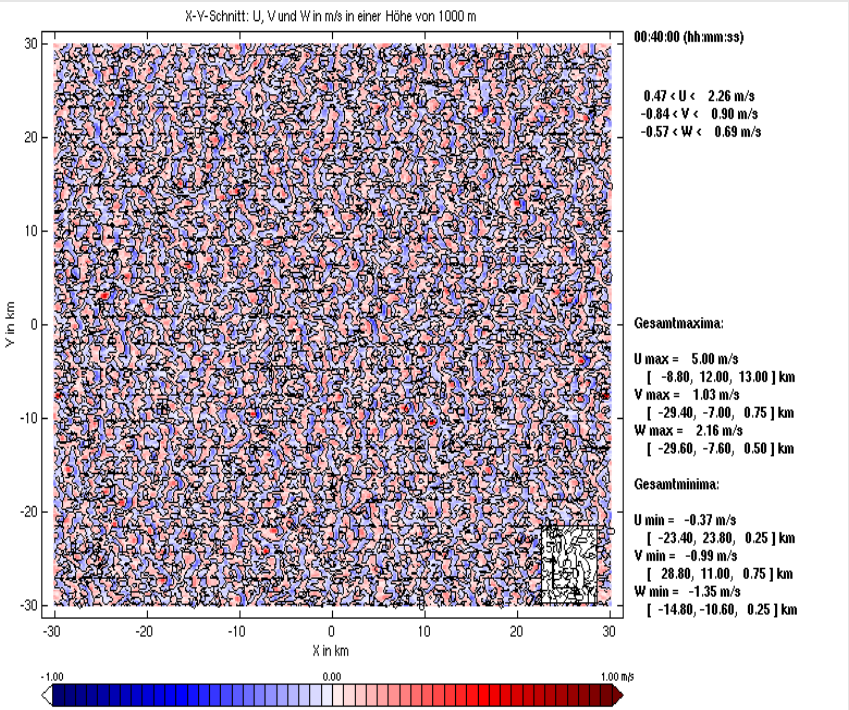
Max-Cappi Z in dBZ



W in m/s at Z=1000 m



play

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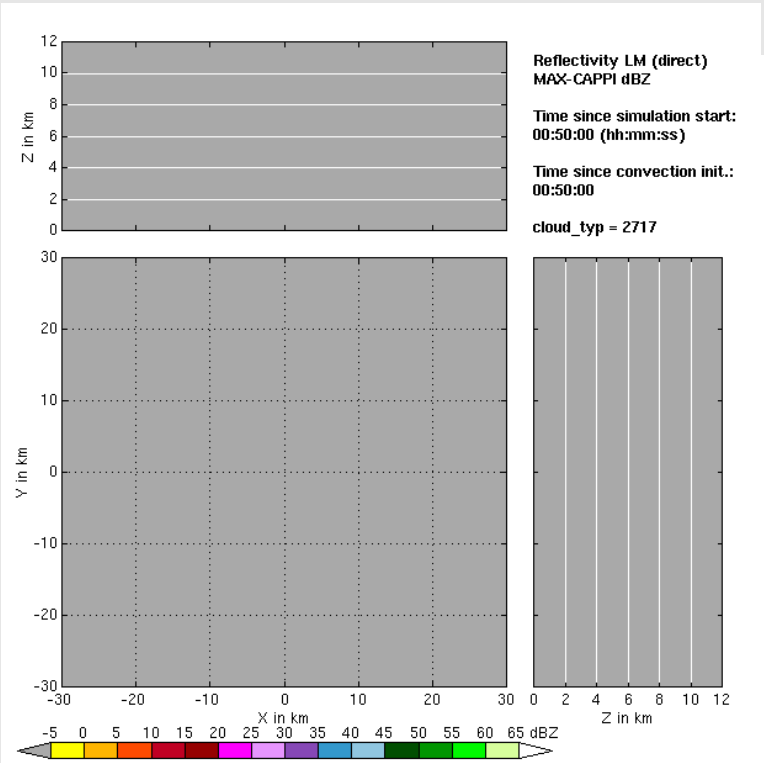
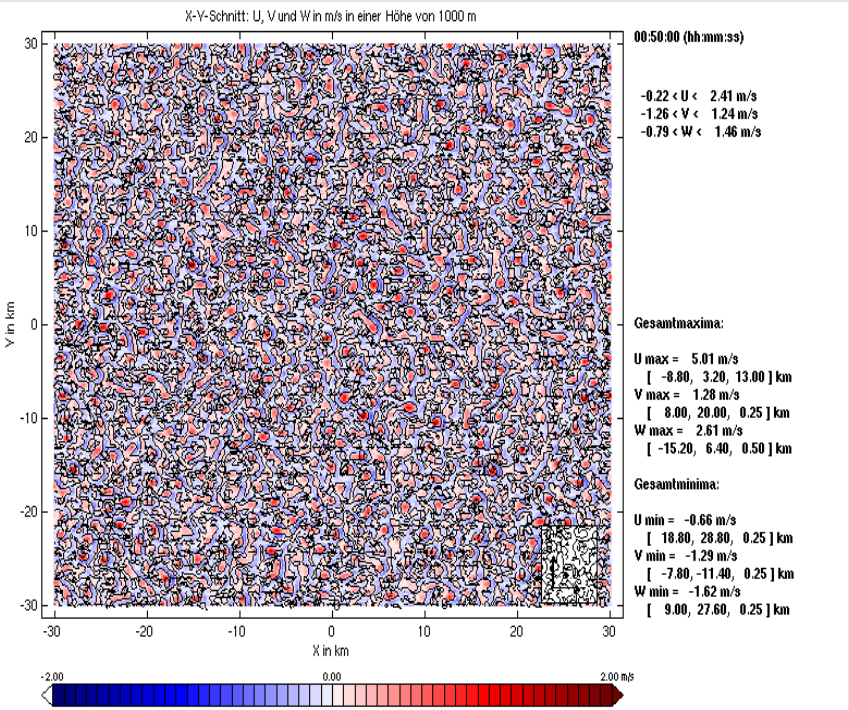


W in m/s at Z=1000 m



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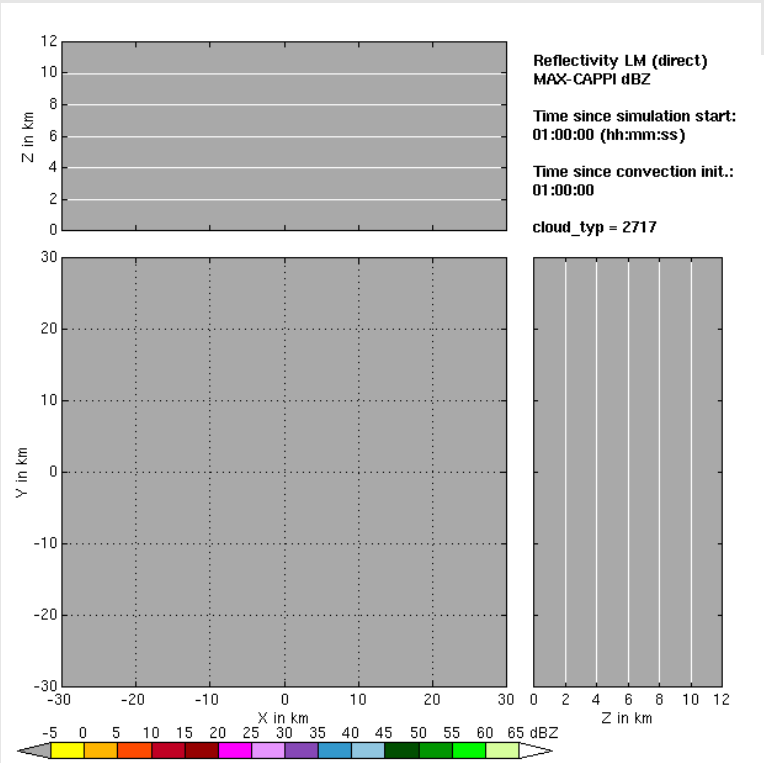
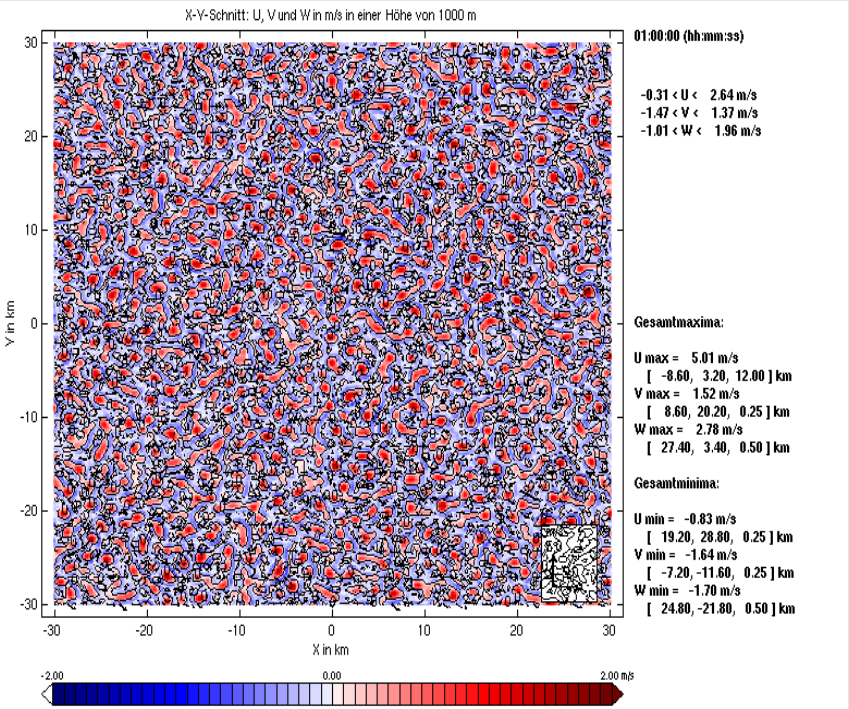


W in m/s at Z=1000 m



play

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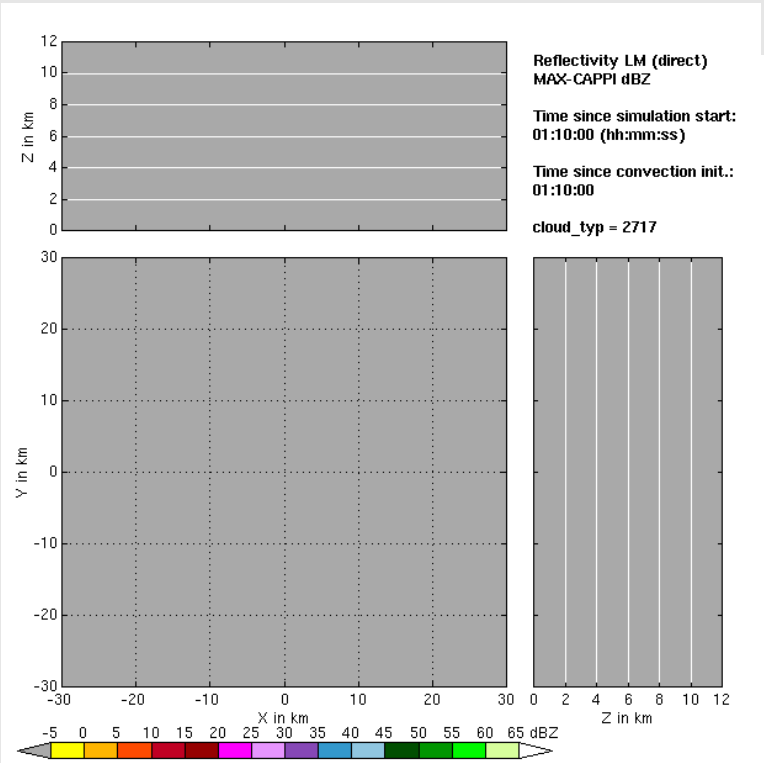
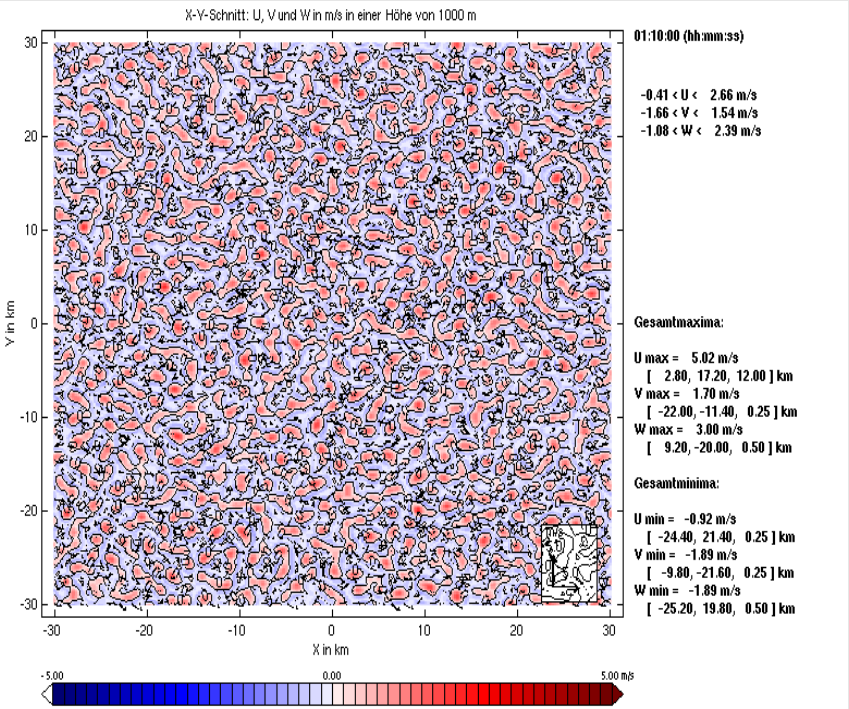
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



play

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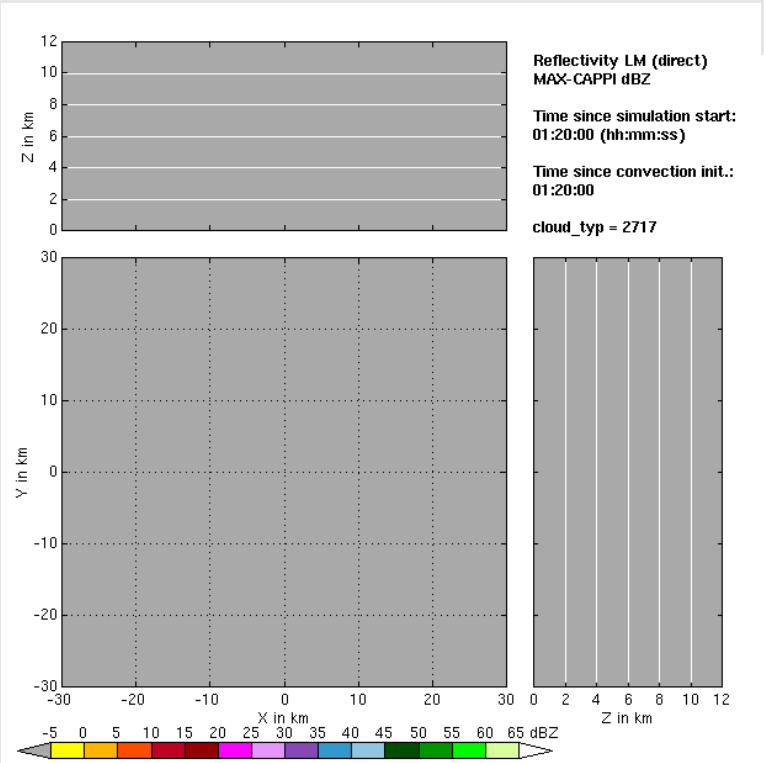
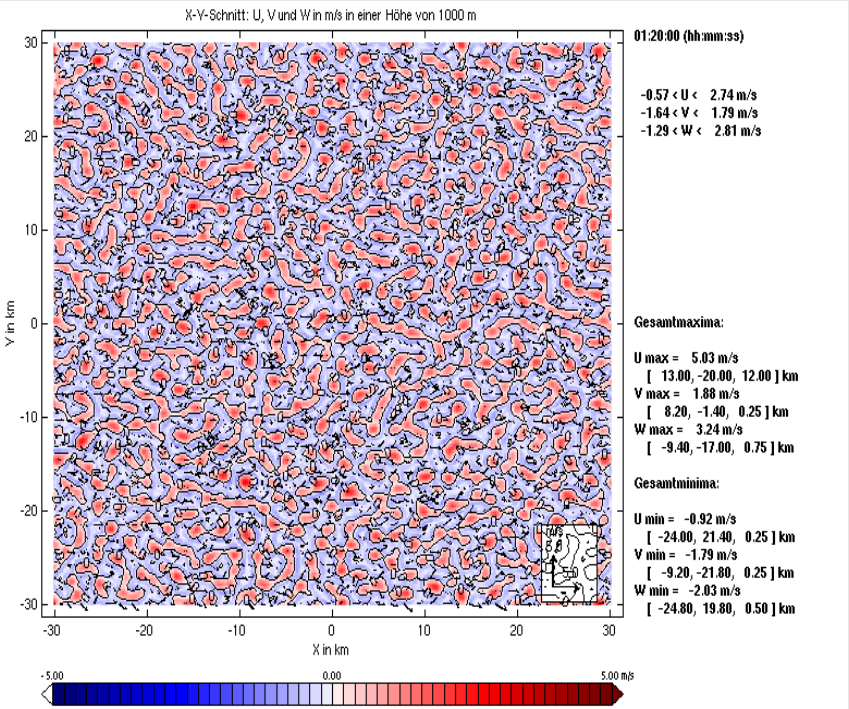
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



play

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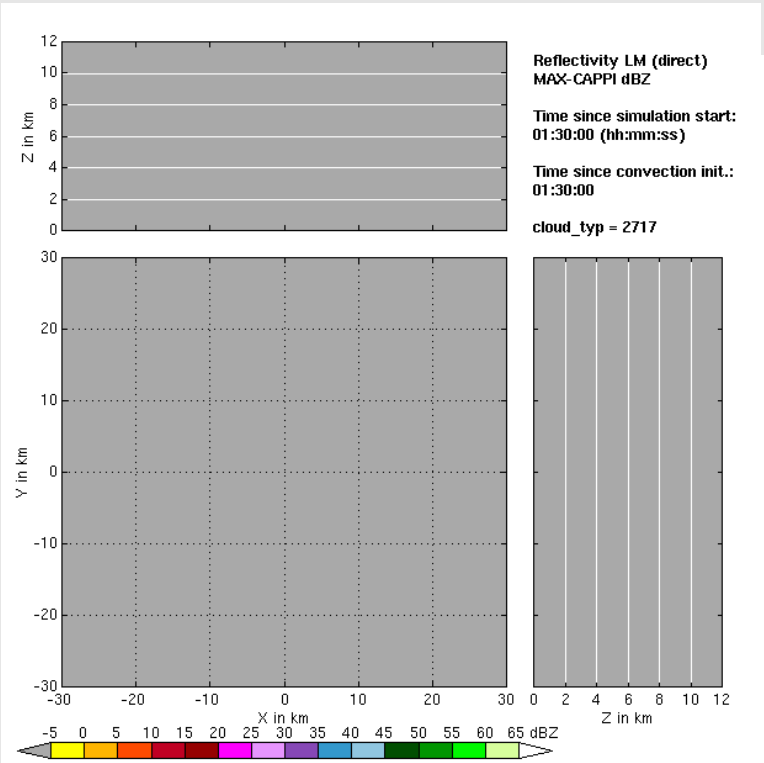
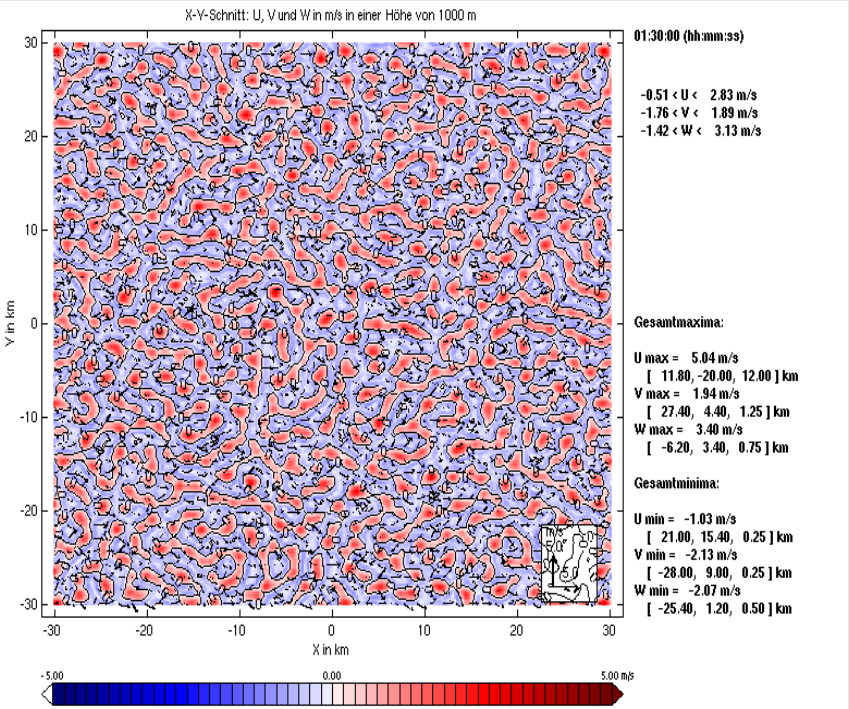
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



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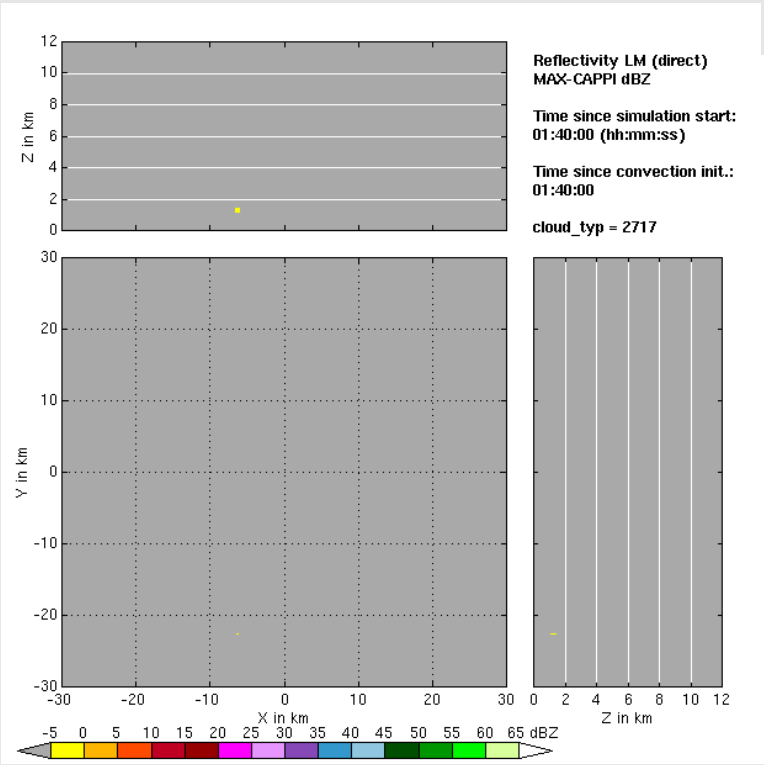
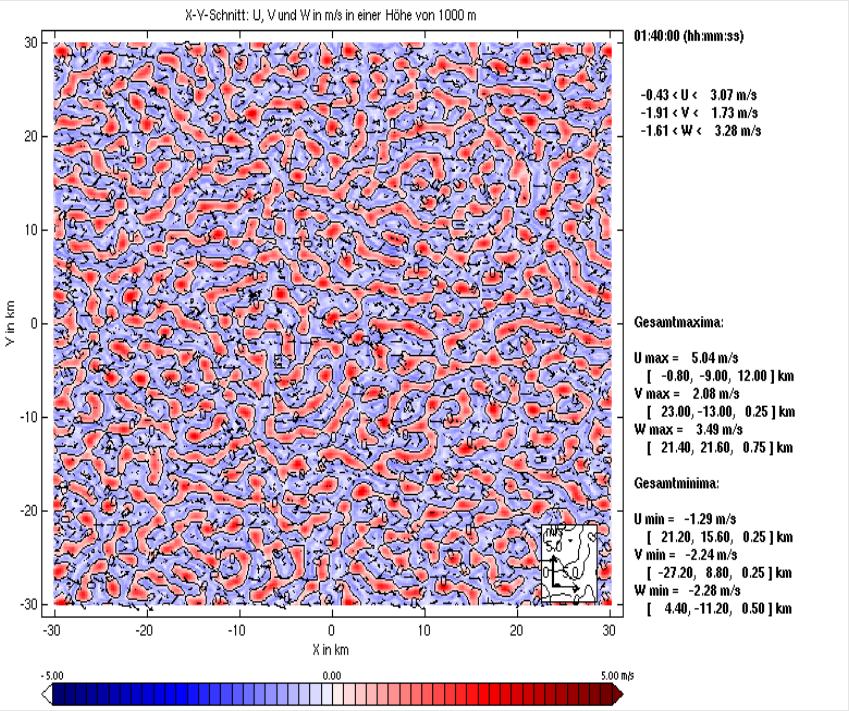


W in m/s at Z=1000 m



play

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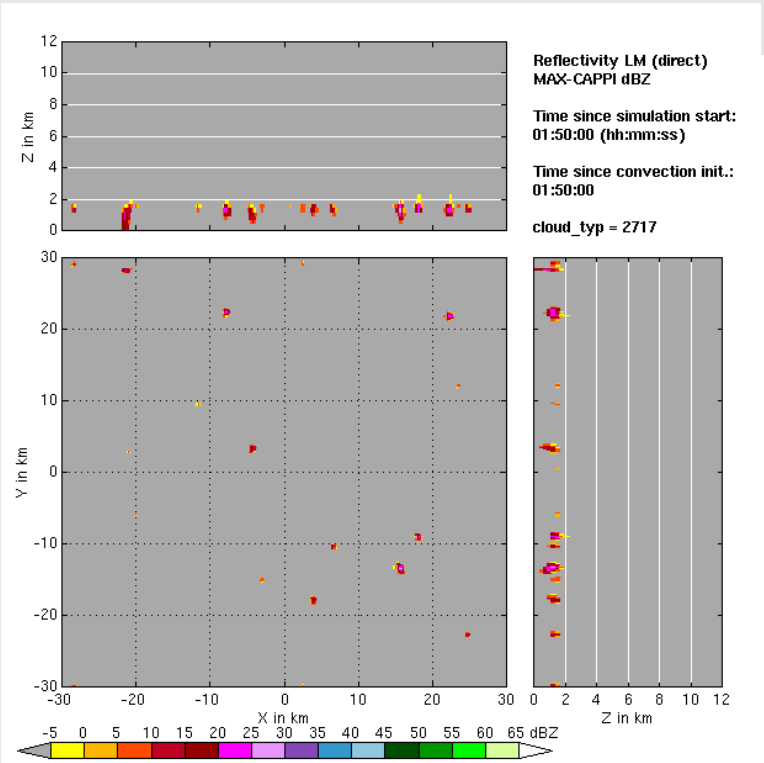
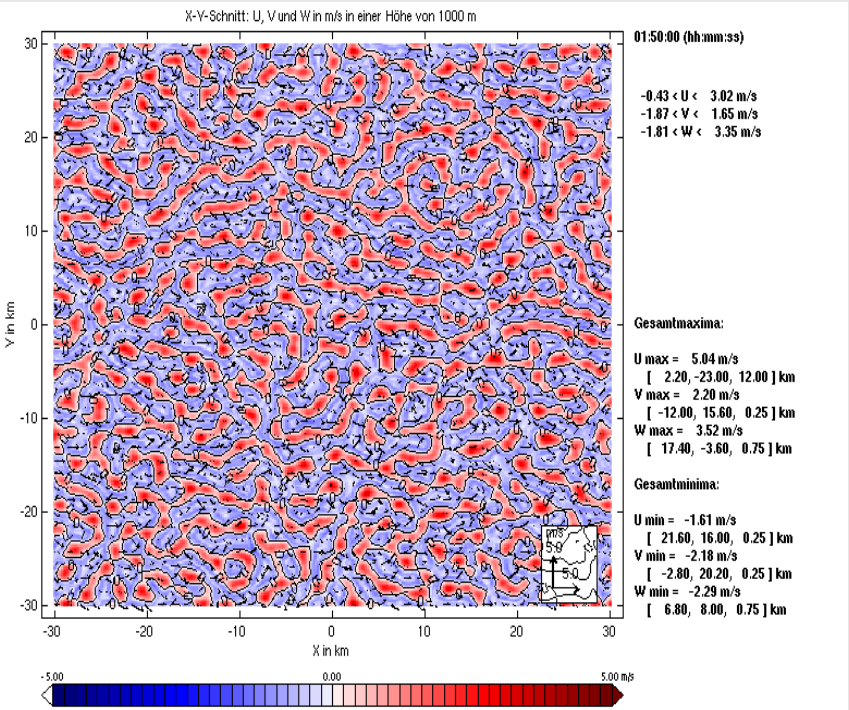


W in m/s at Z=1000 m



play

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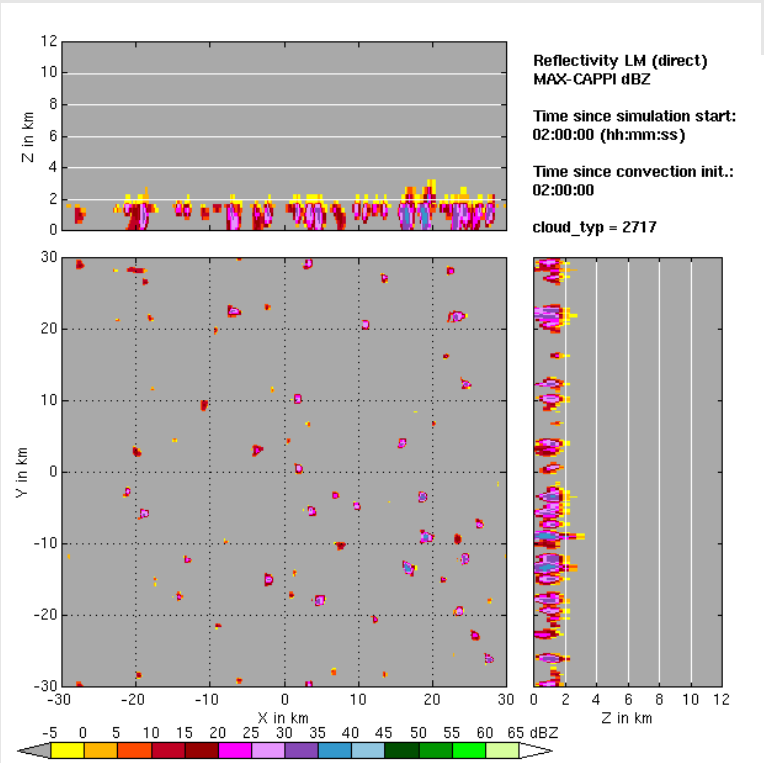
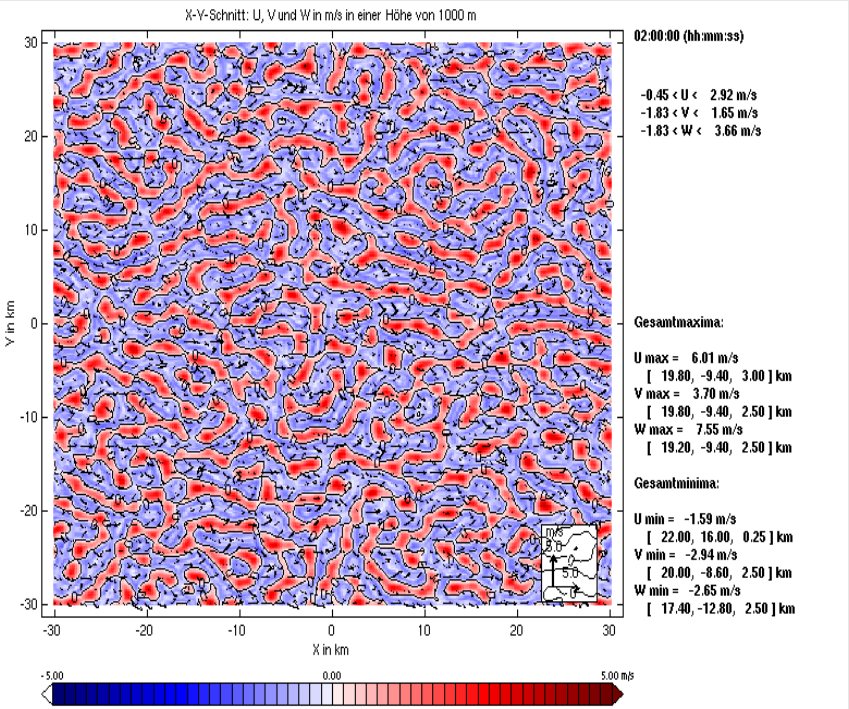
Max-Cappi Z in dBZ



W in m/s at Z=1000 m



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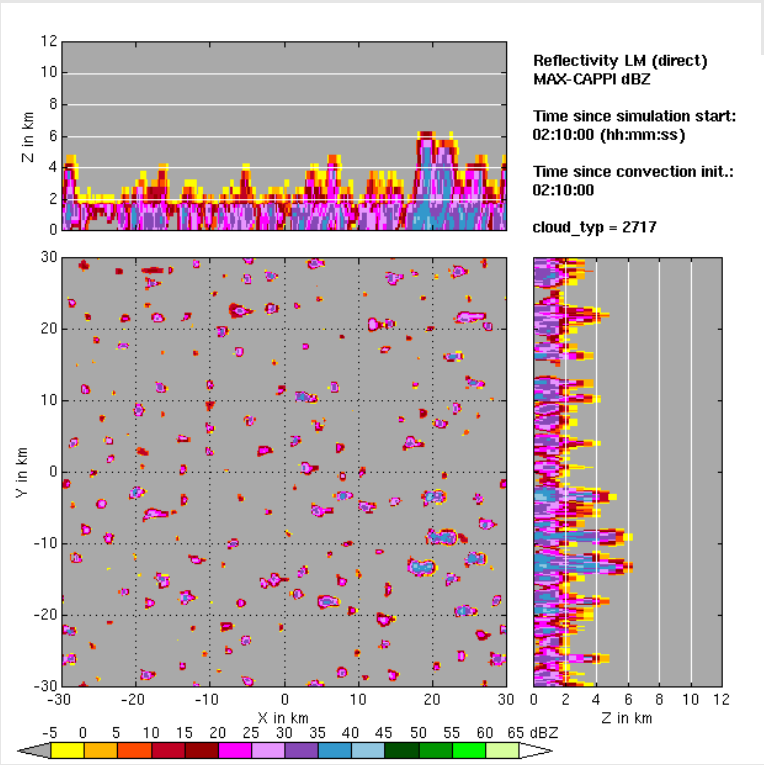
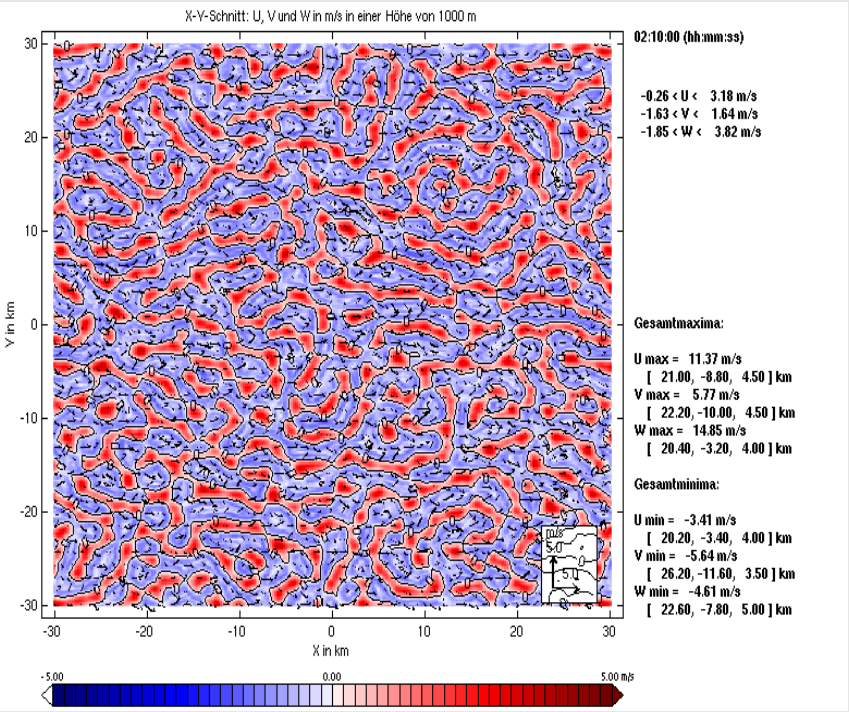


W in m/s at Z=1000 m



play

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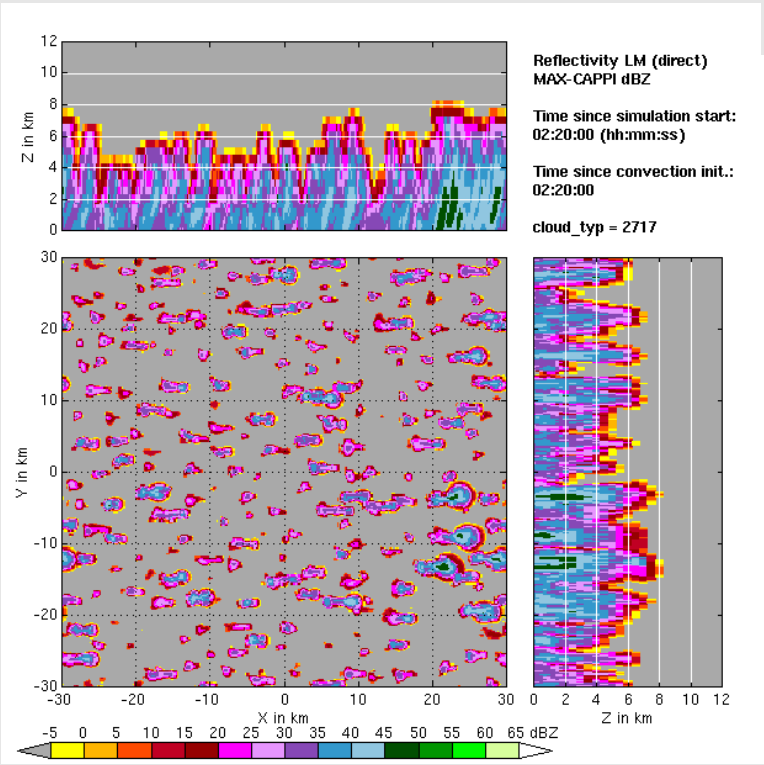
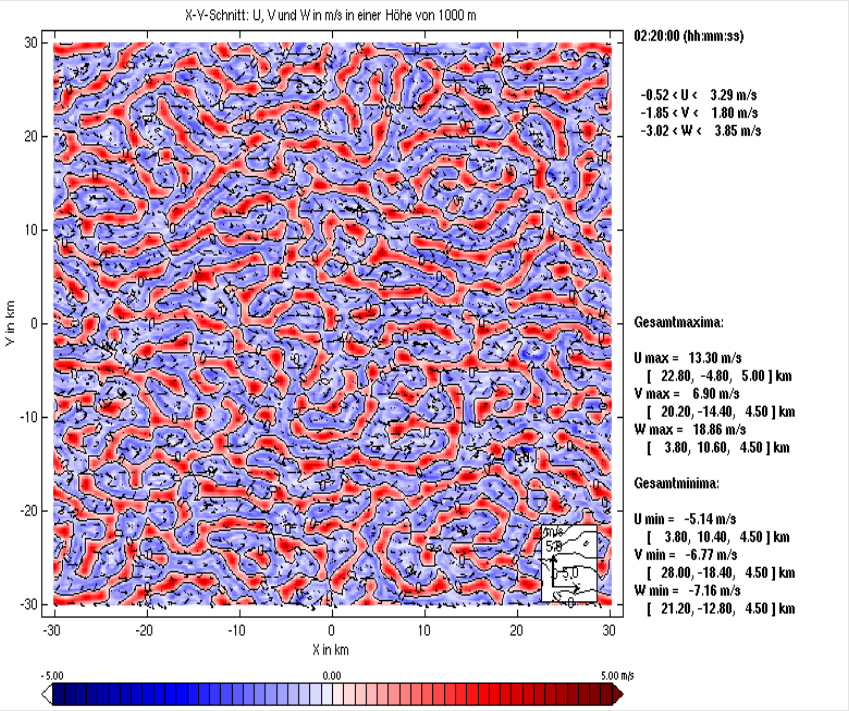


W in m/s at Z=1000 m



play

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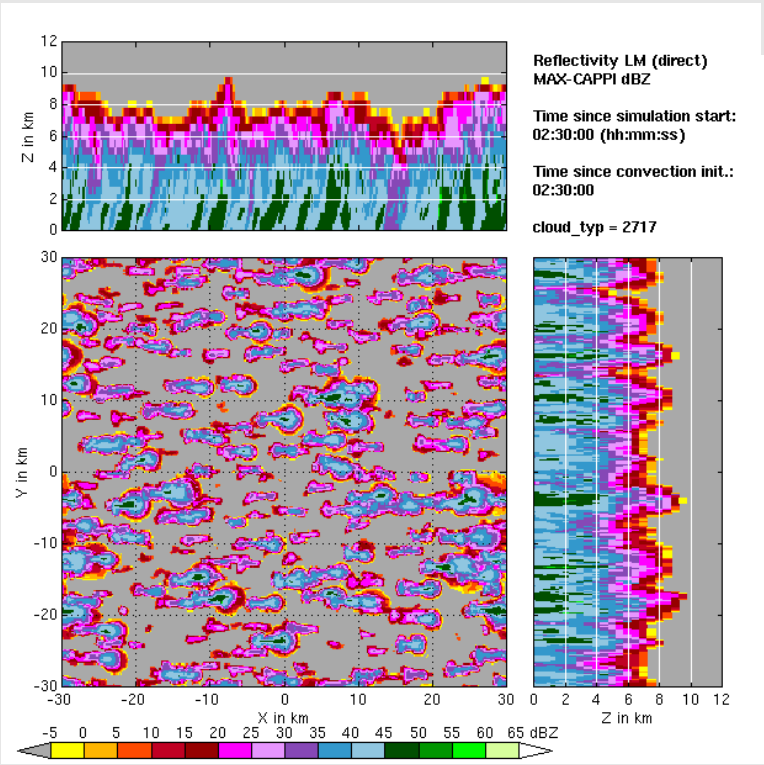

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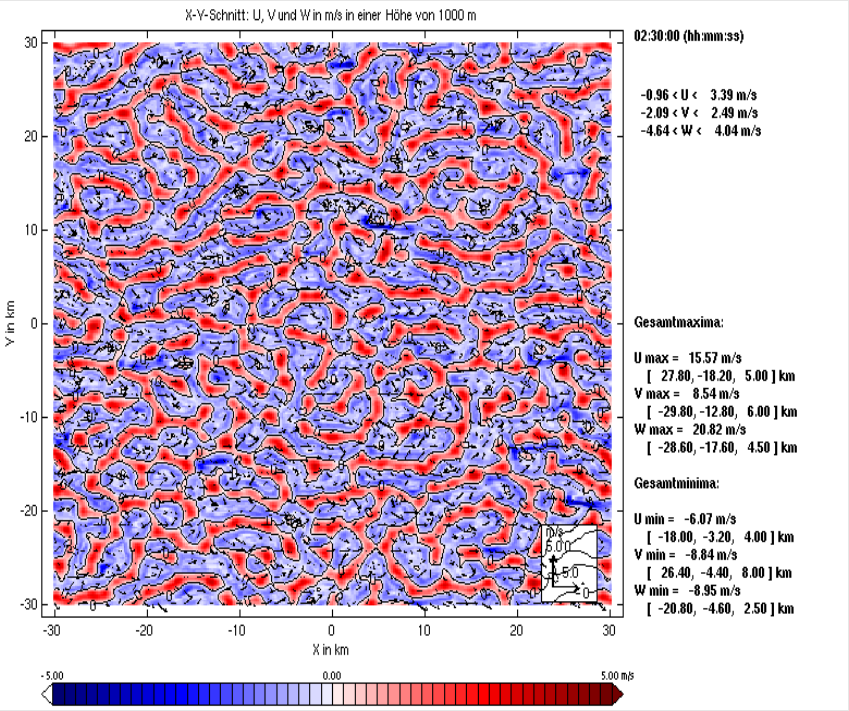

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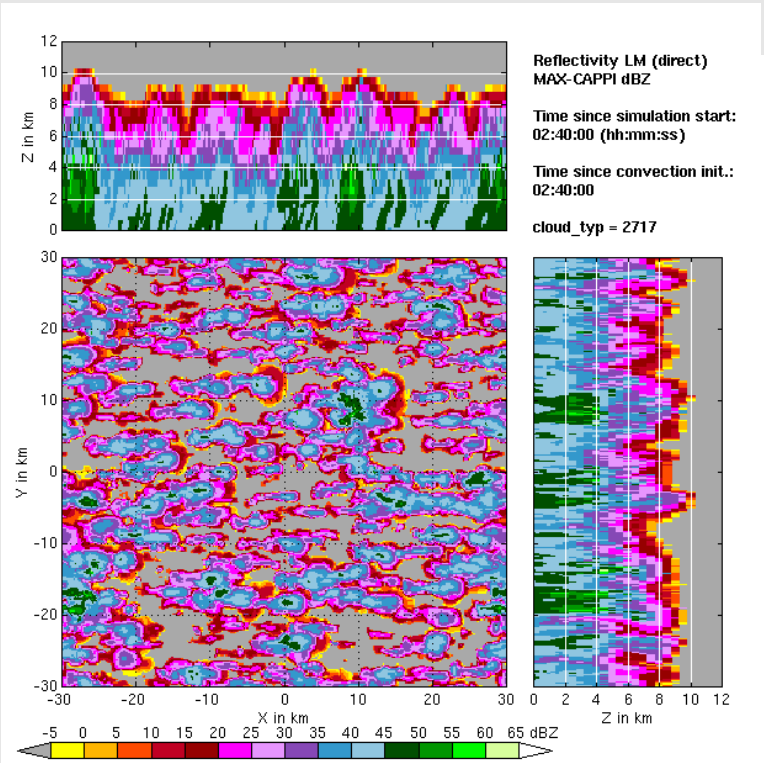
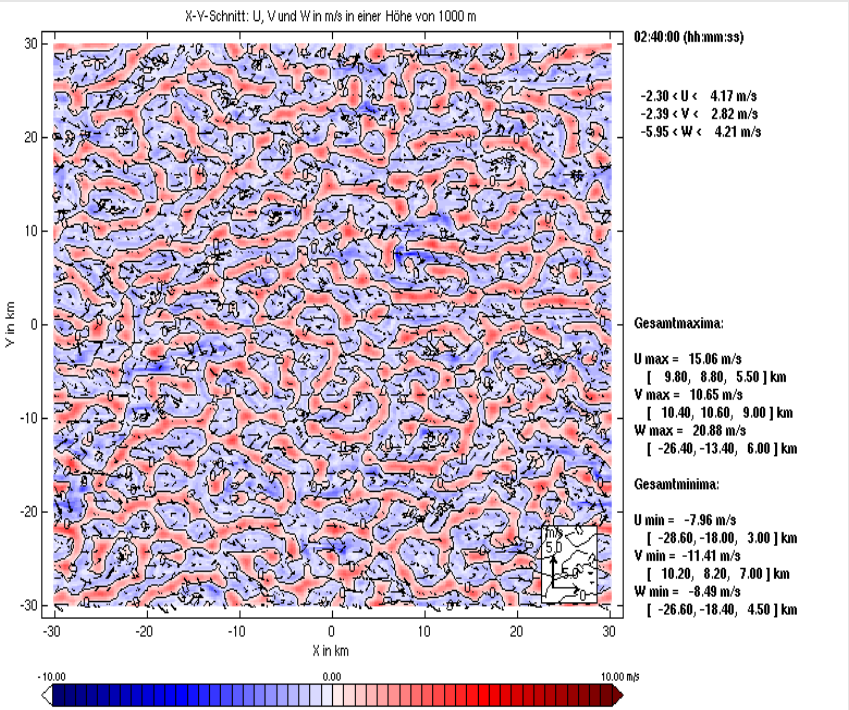


W in m/s at Z=1000 m



play

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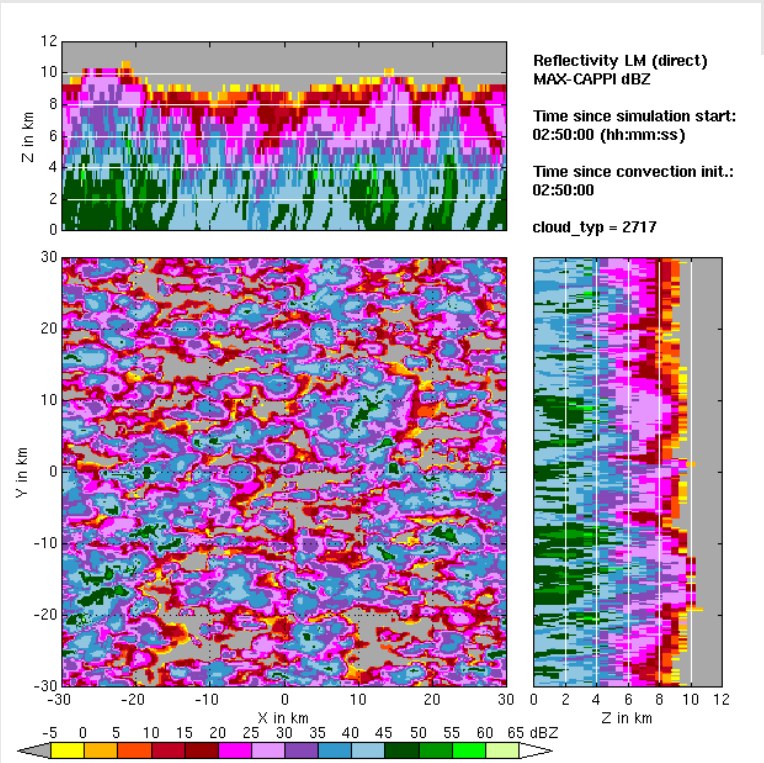
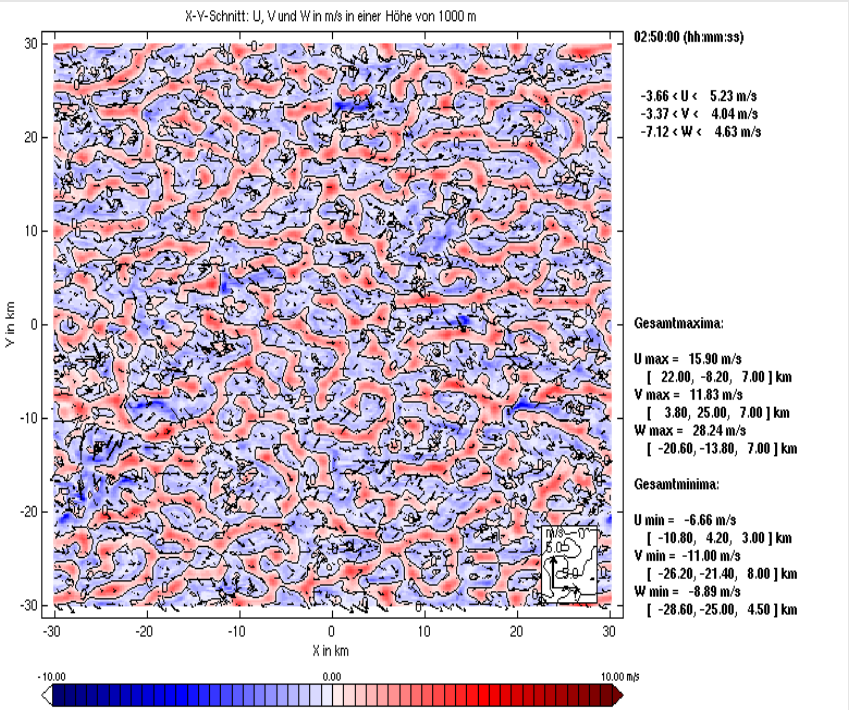
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

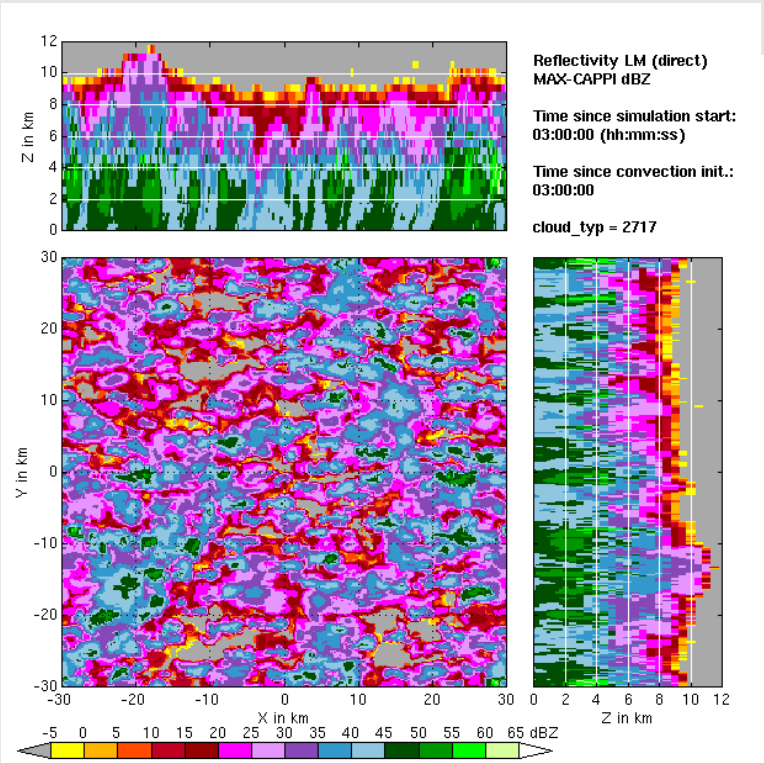


play

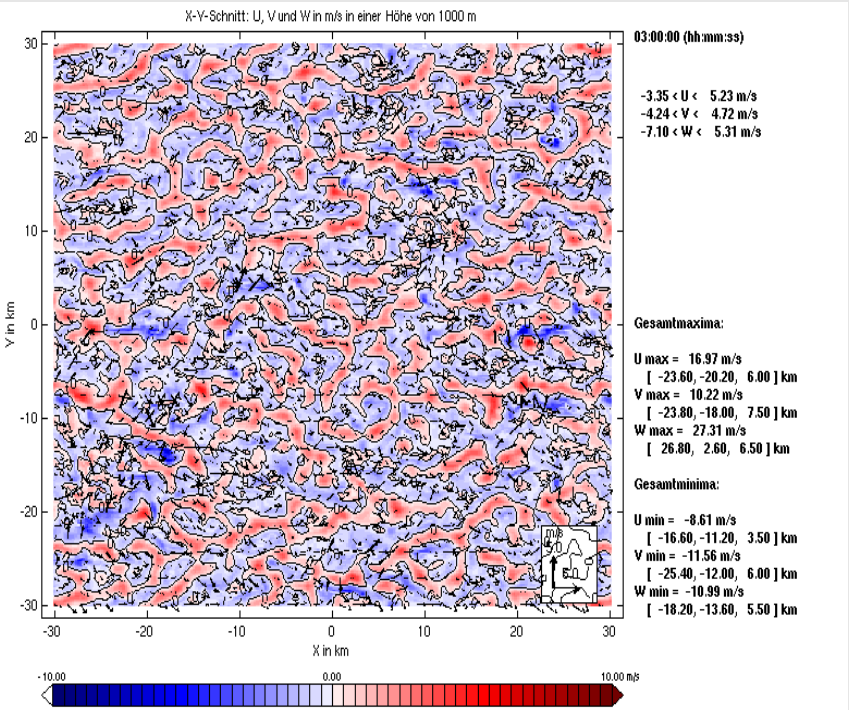
2. experiment: ”moist” run with $\Delta X = 200$ m

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

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

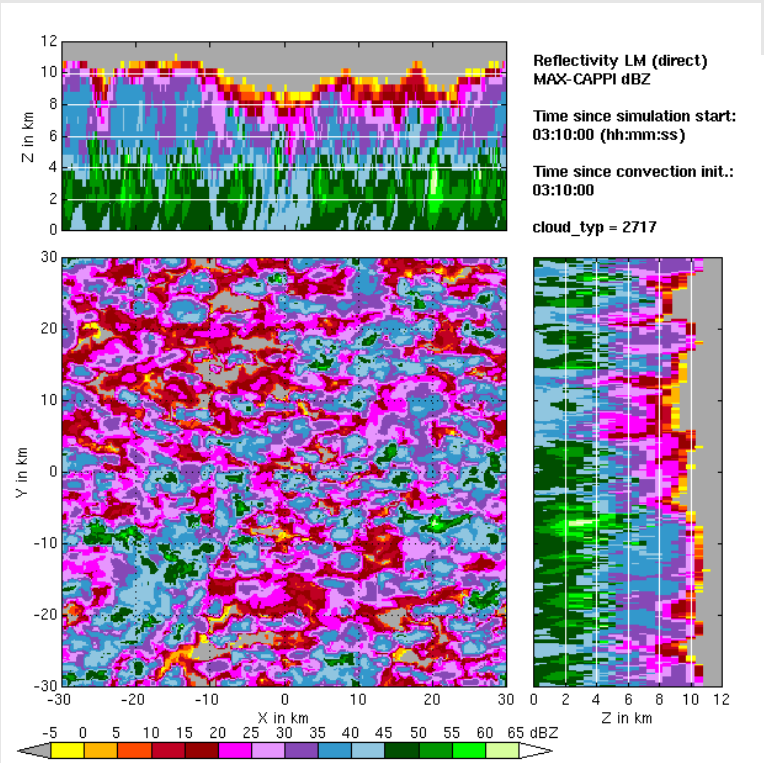


play

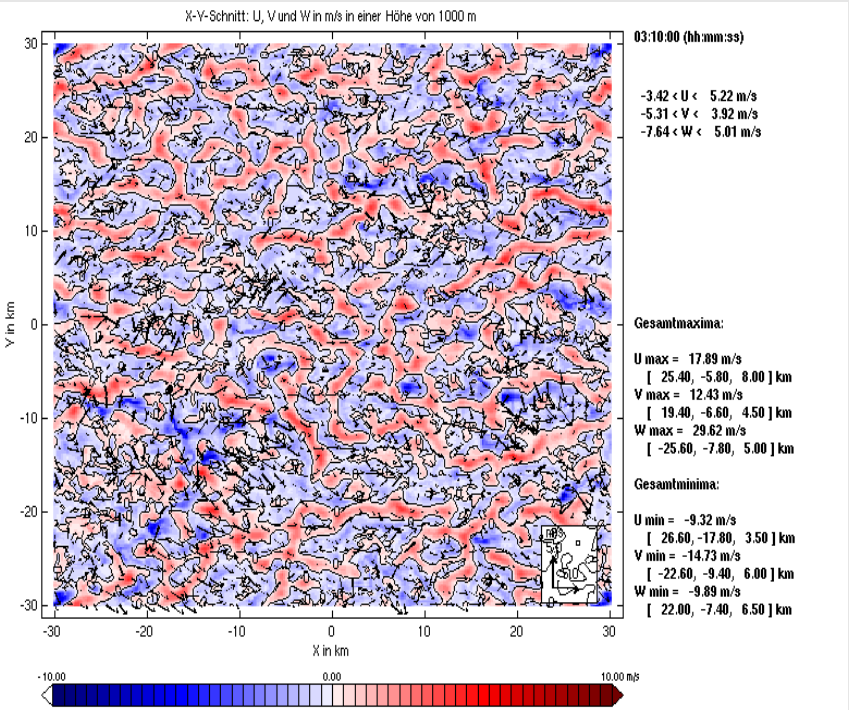
2. experiment: ”moist” run with $\Delta X = 200$ m

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

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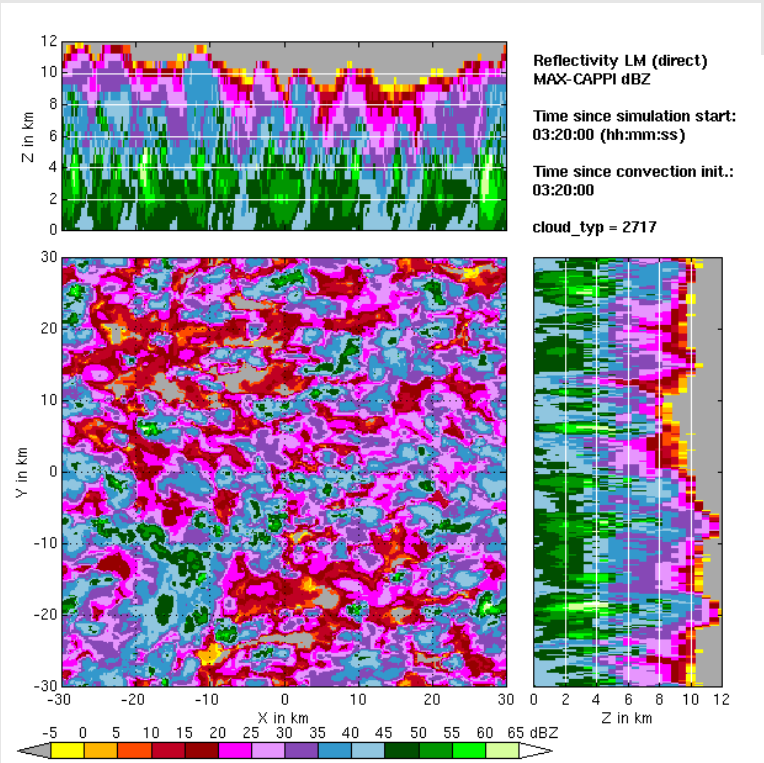
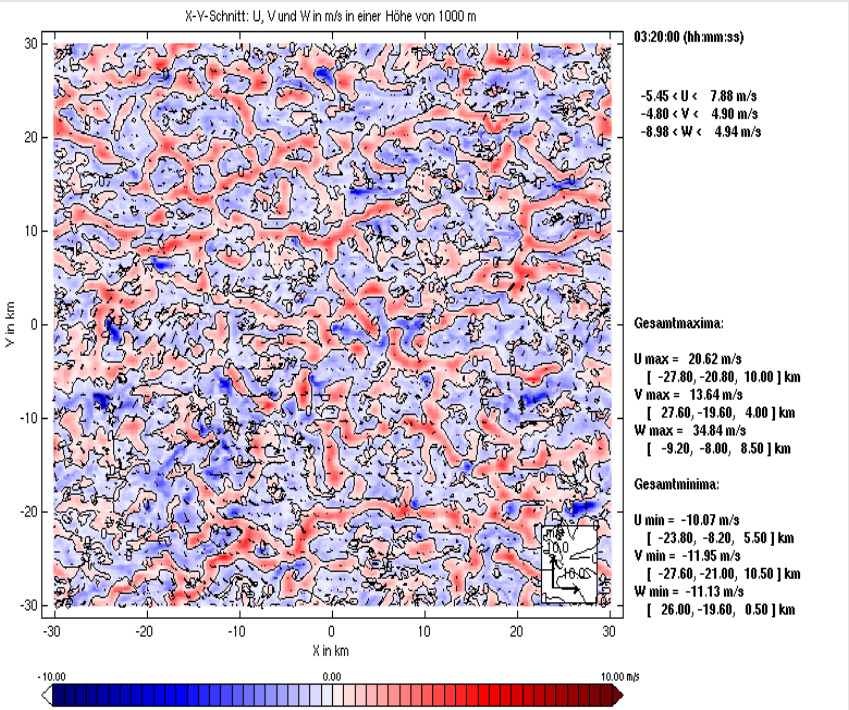
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



play

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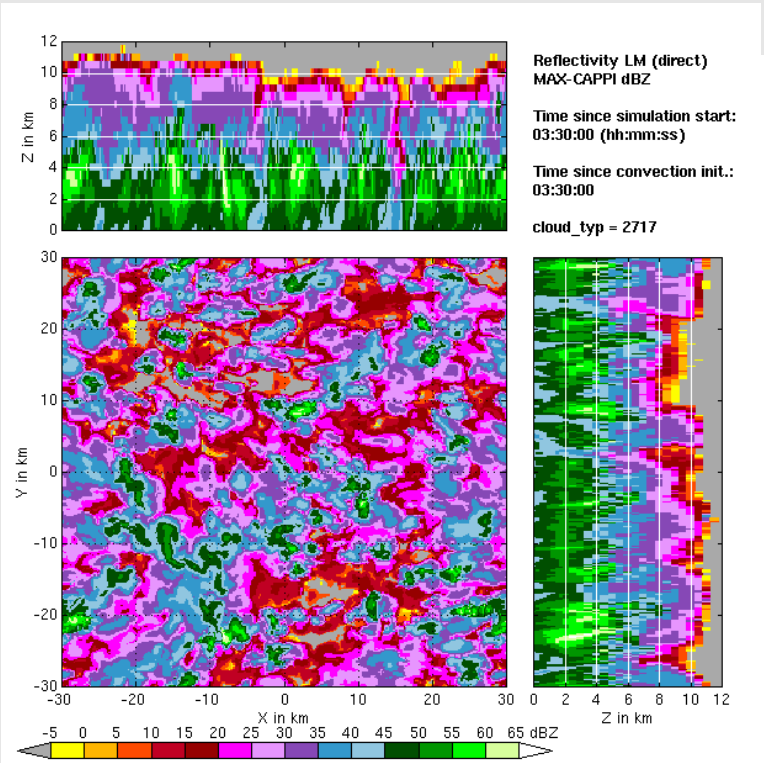
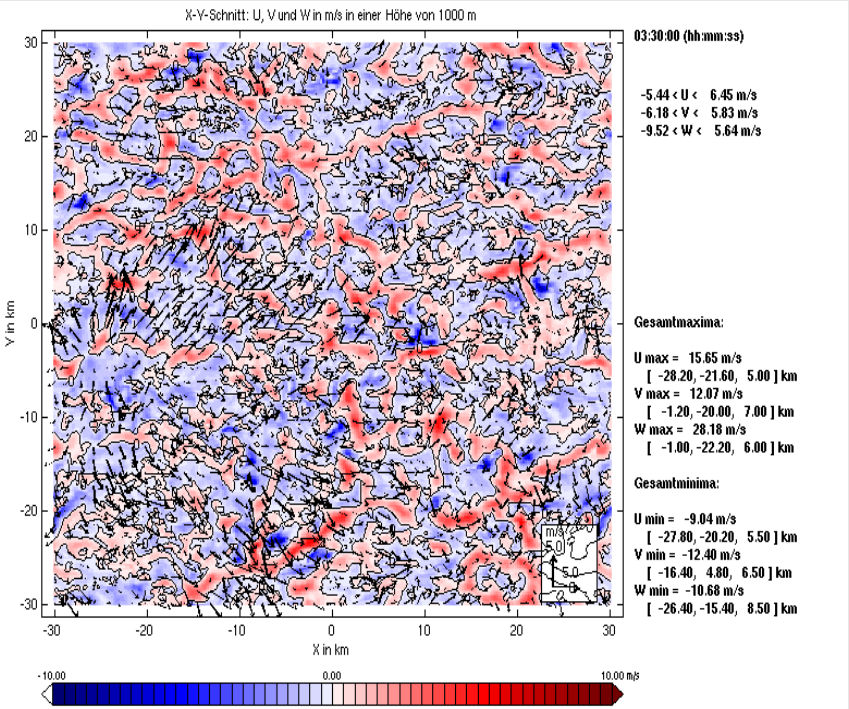
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



play

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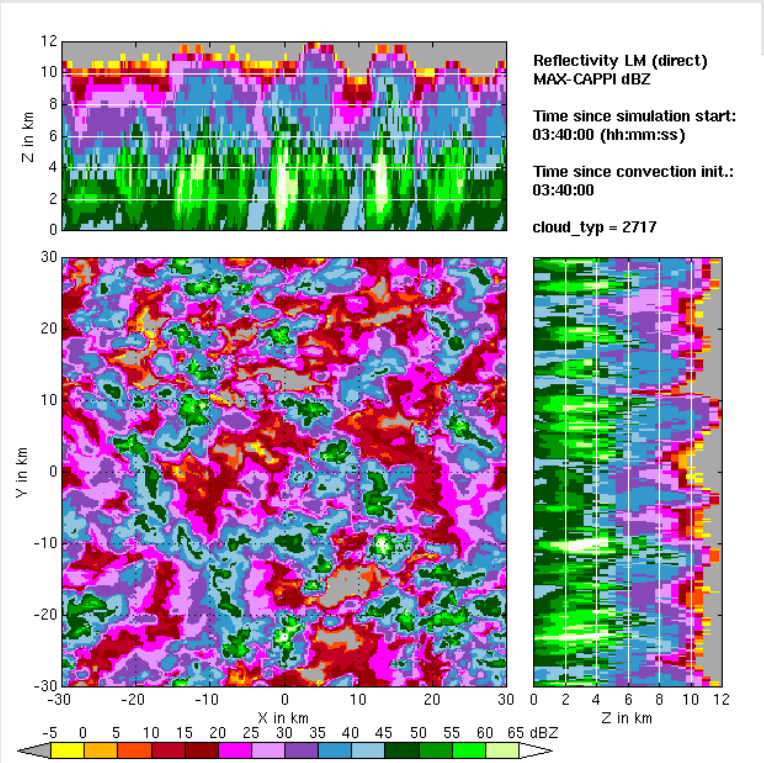
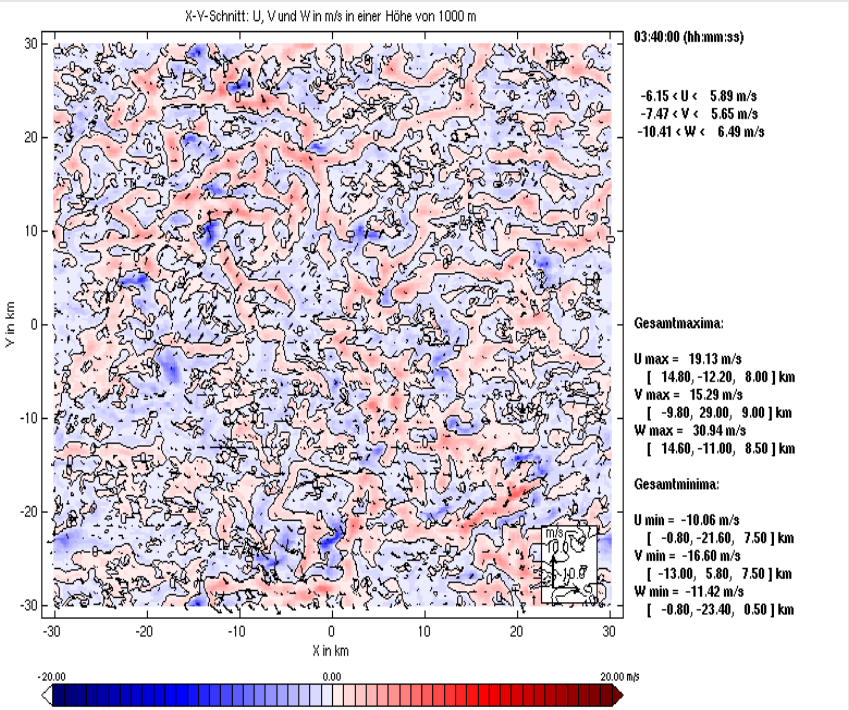
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m



play

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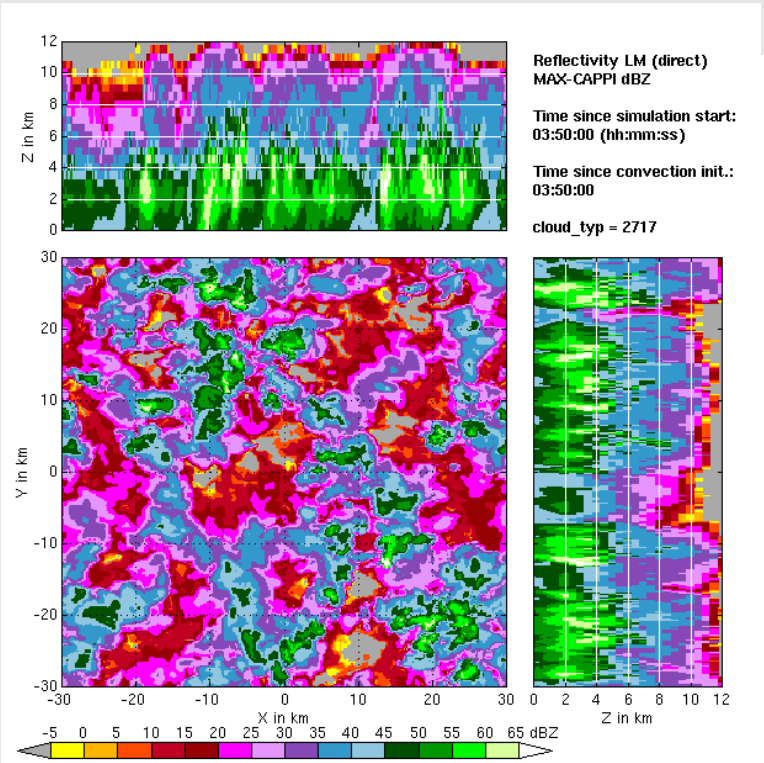
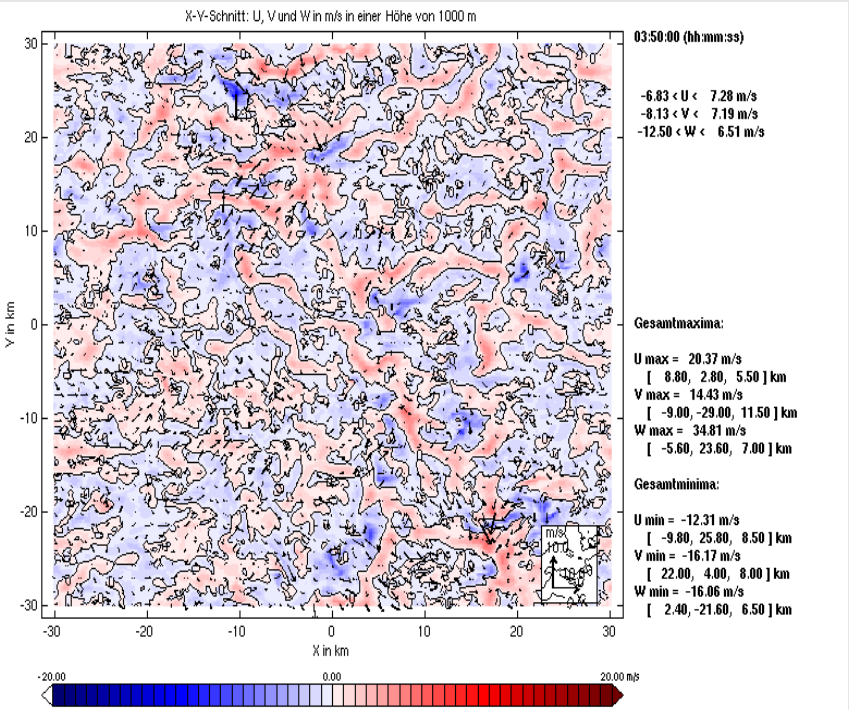
301 x 301 grid points, domain size 60 x 60 km

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

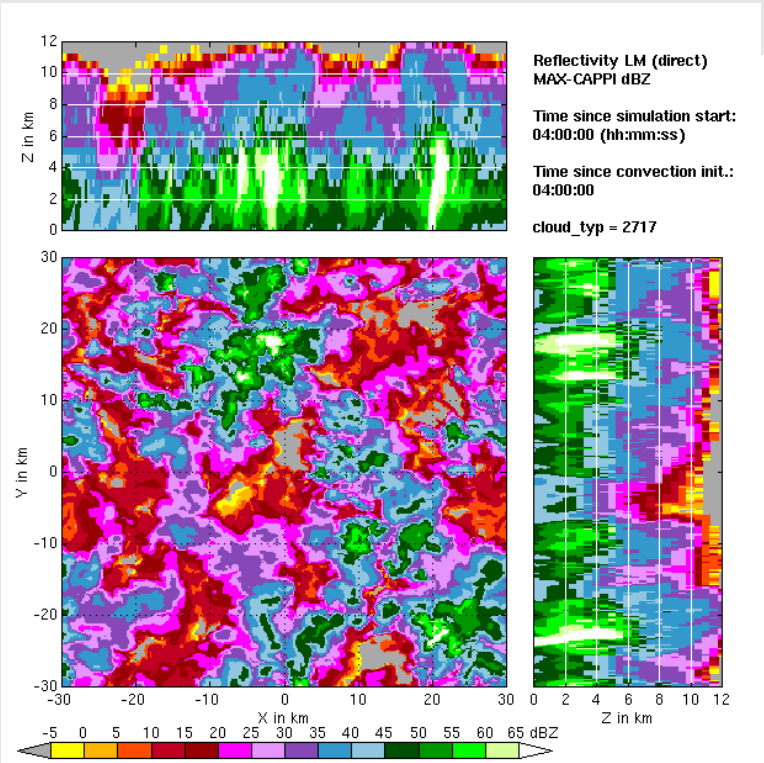


play

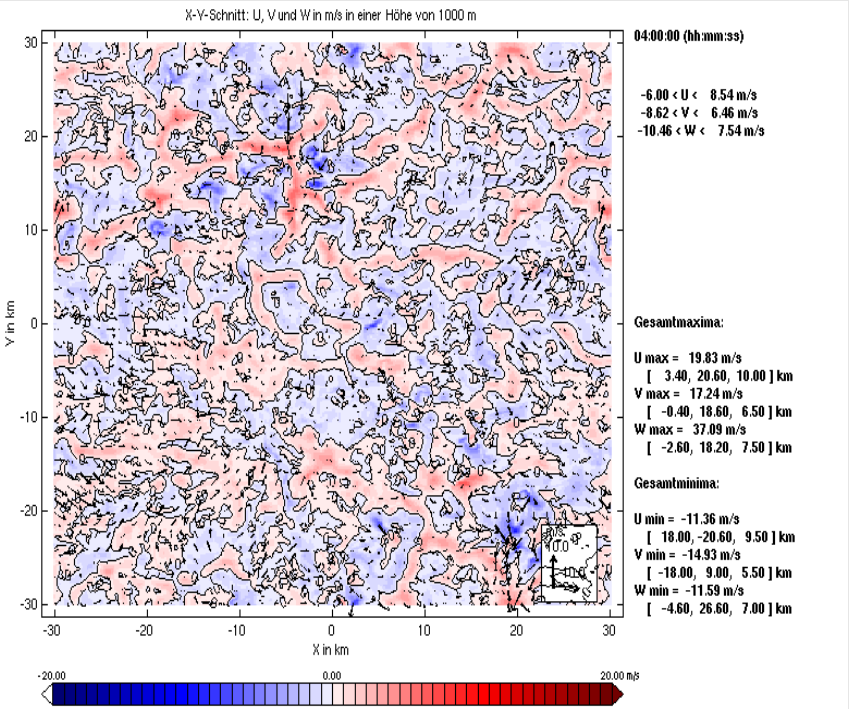
2. experiment: ”moist” run with $\Delta X = 200$ m

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

Max-Cappi Z in dBZ



W in m/s at Z=1000 m

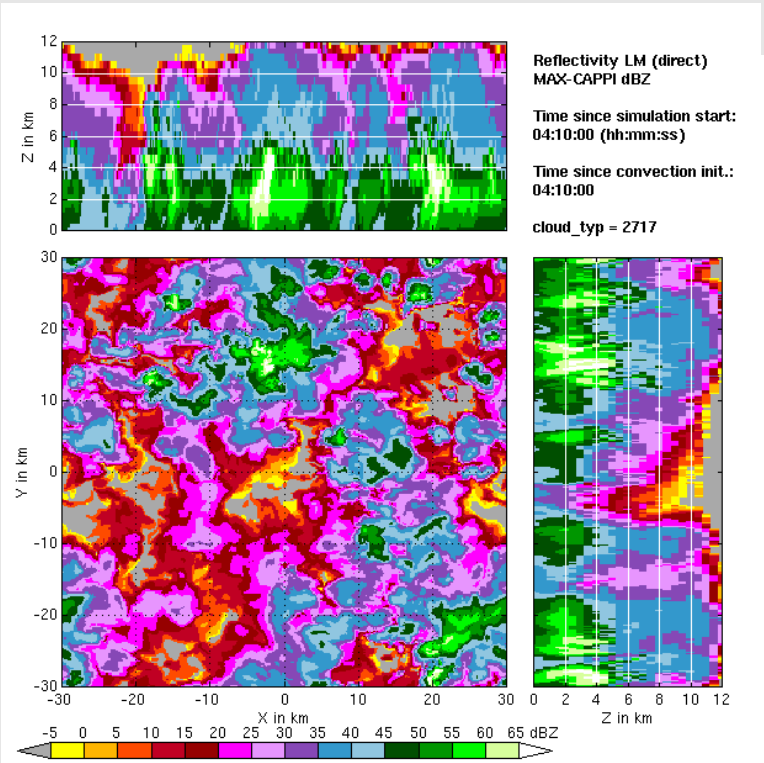


play

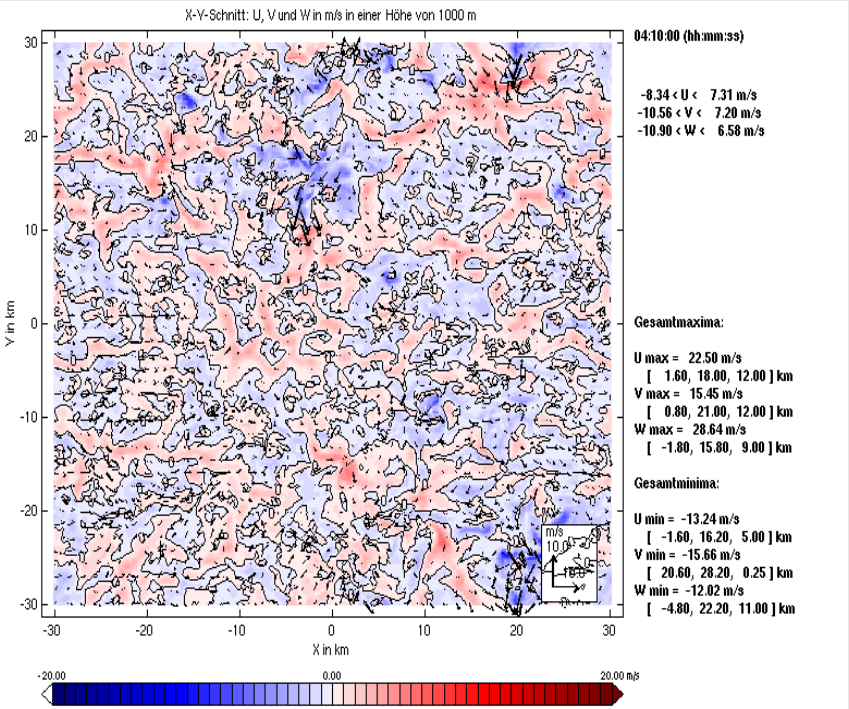
2. experiment: ”moist” run with $\Delta X = 200$ m

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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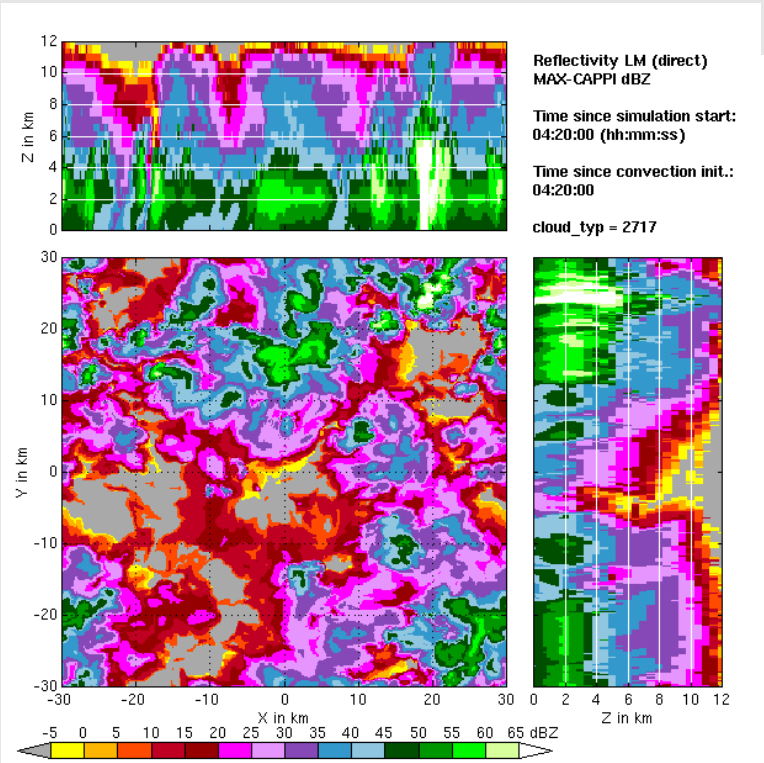
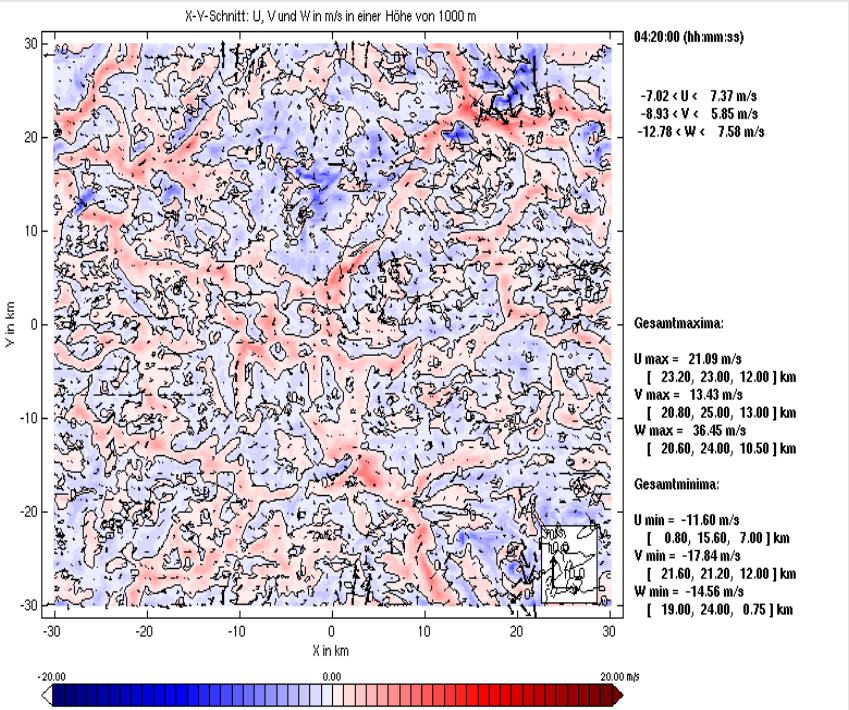


W in m/s at Z=1000 m



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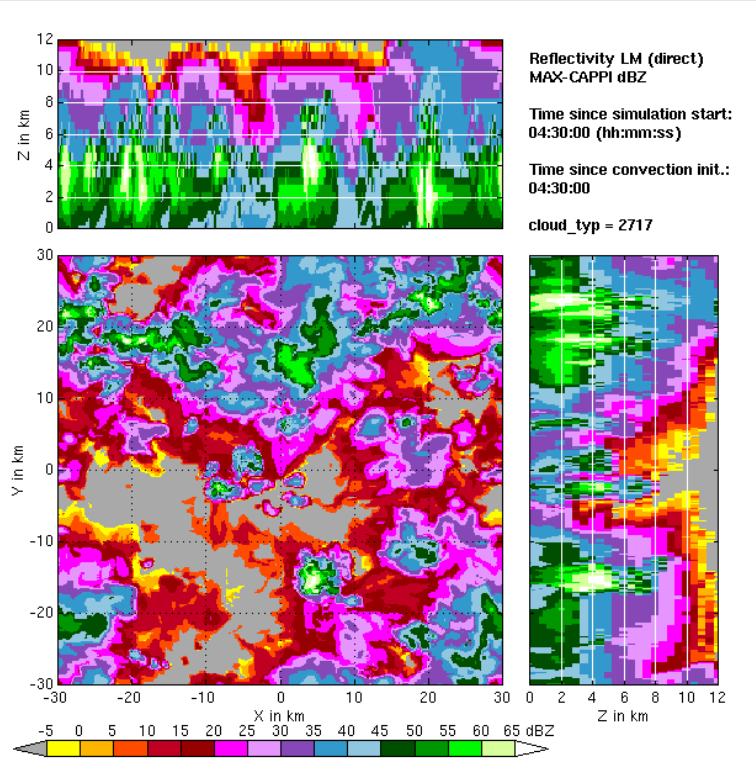
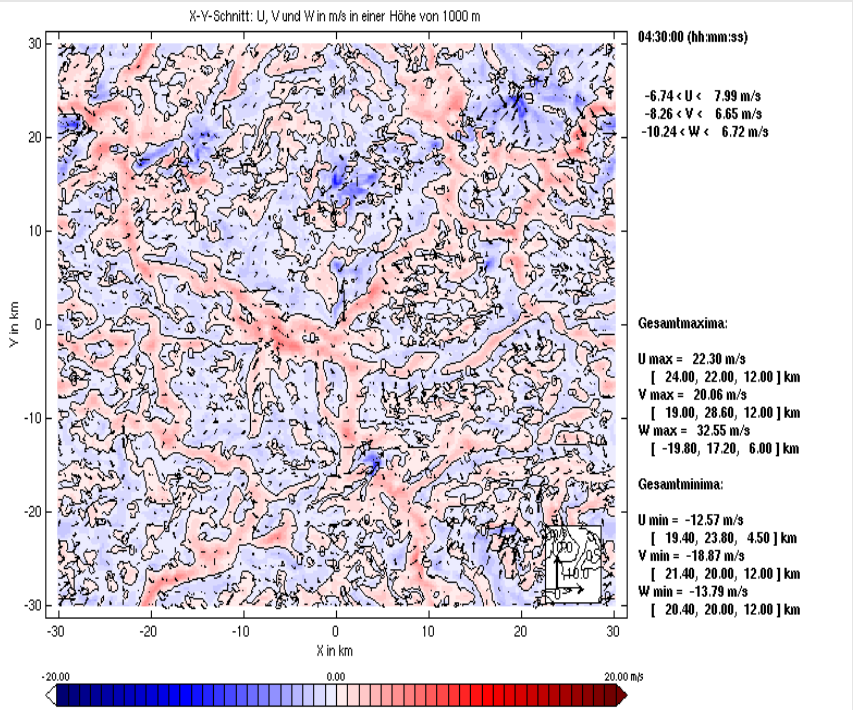


W in m/s at Z=1000 m



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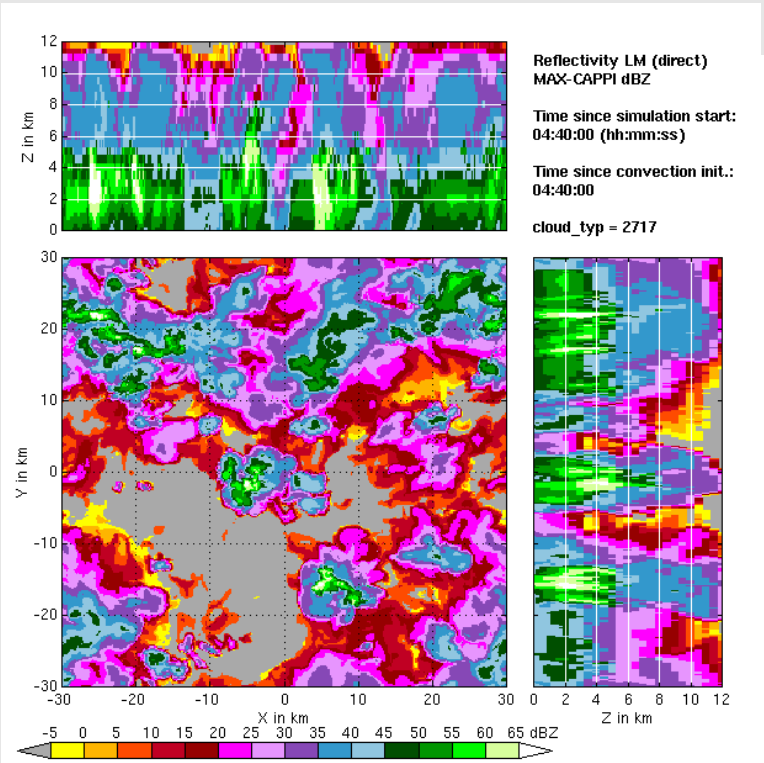
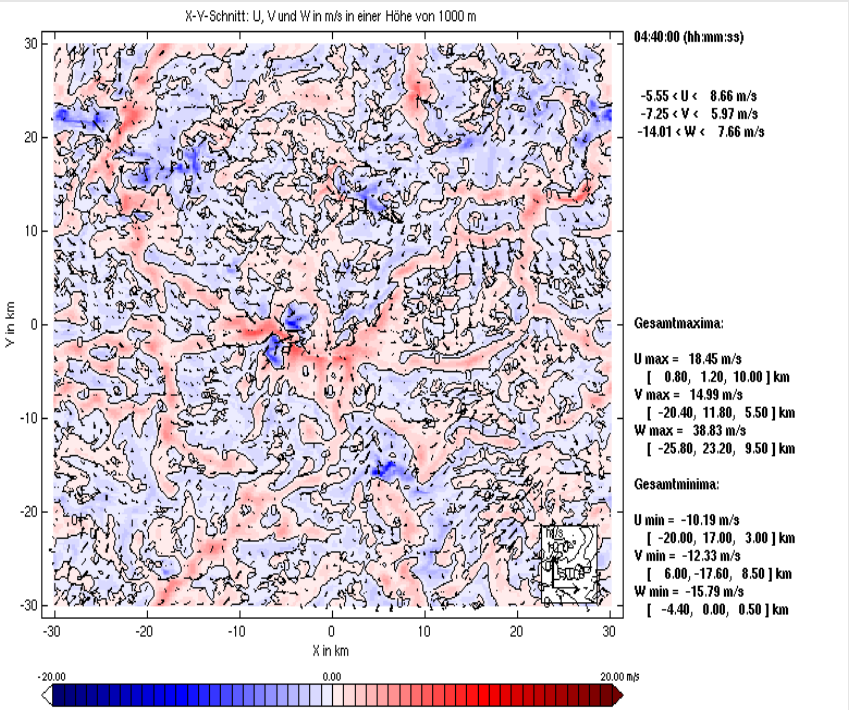


W in m/s at Z=1000 m



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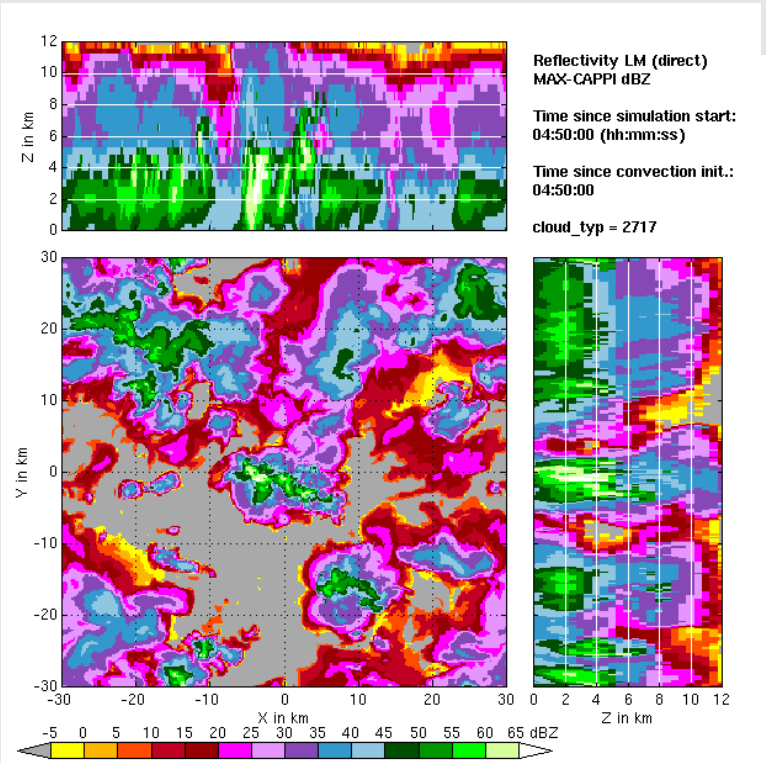
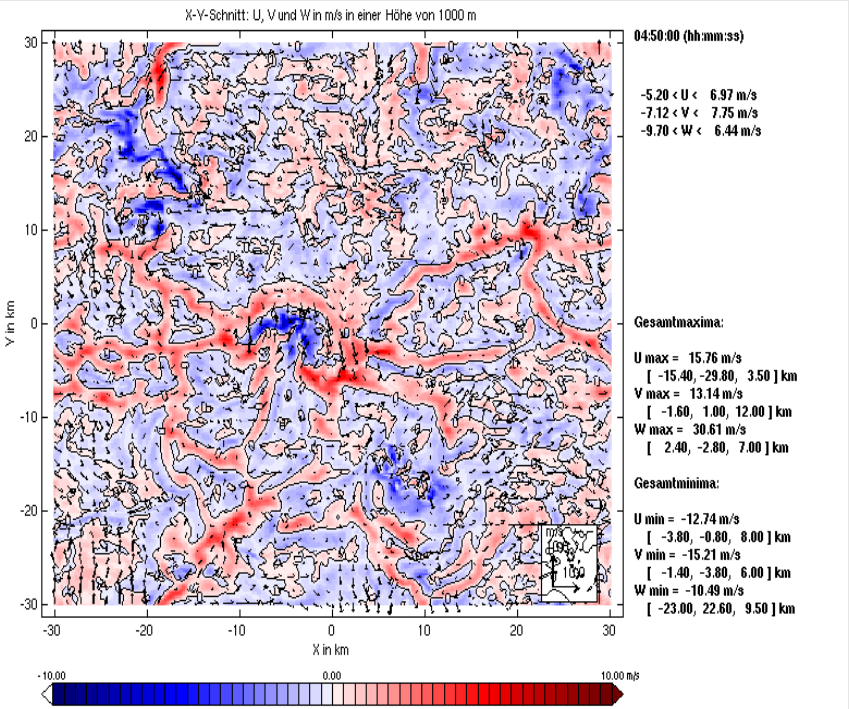


W in m/s at Z=1000 m



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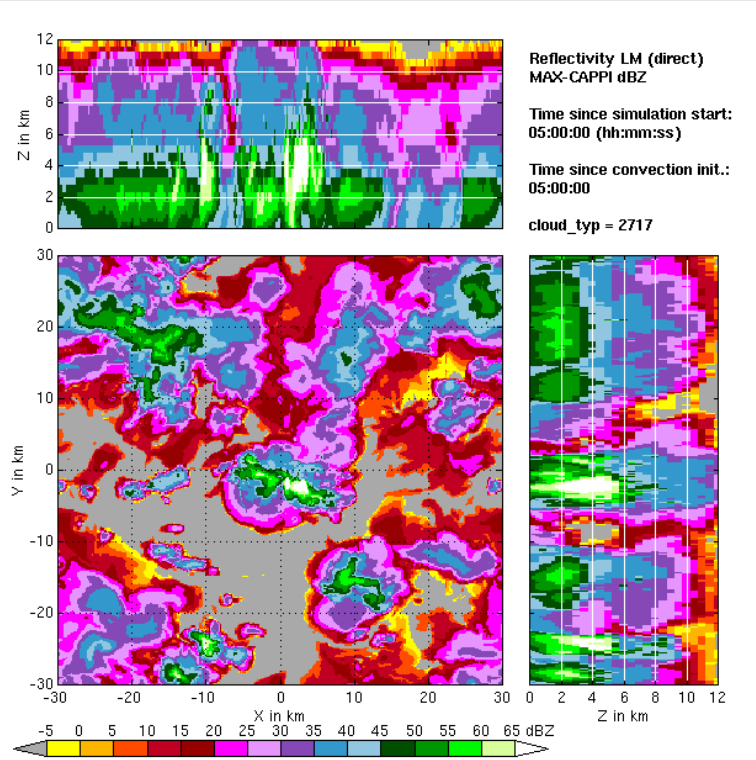
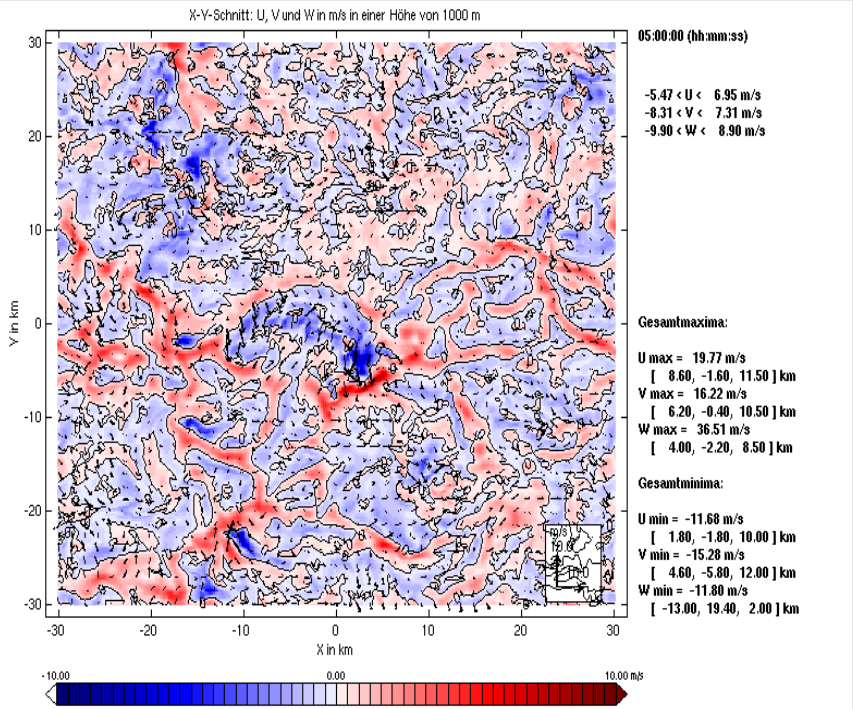


W in m/s at Z=1000 m

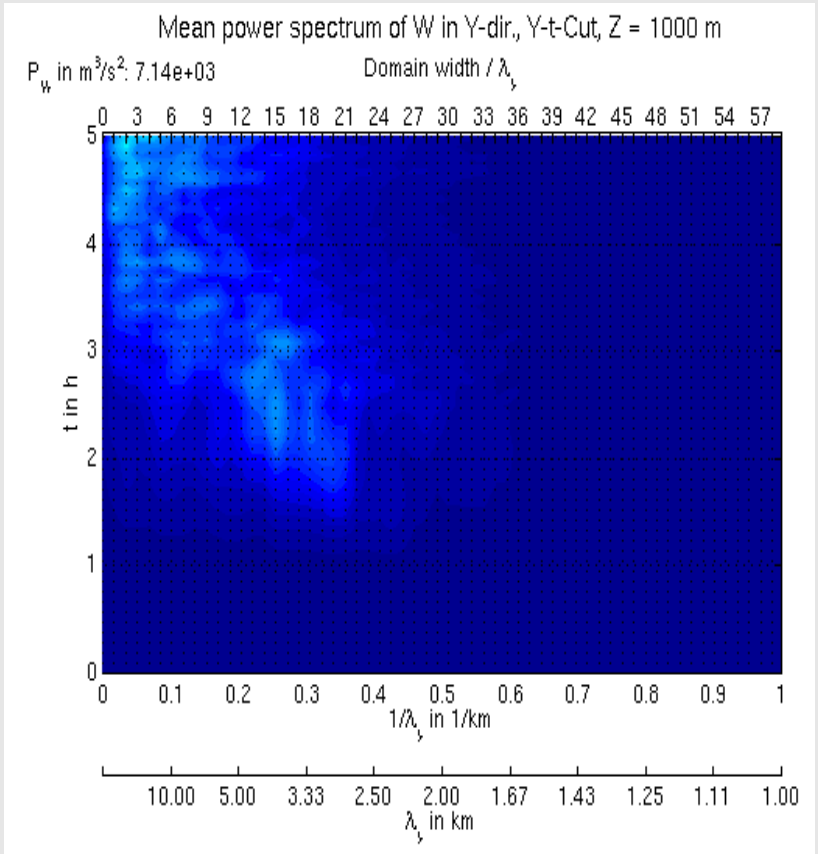


revert

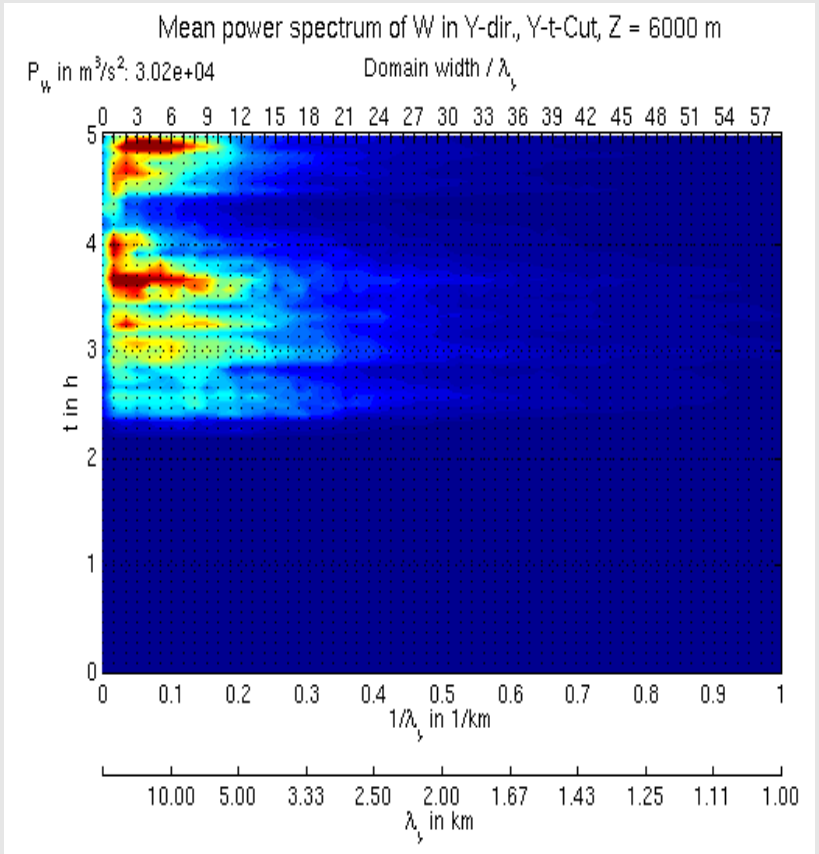
Horizontal and vertical scales?

Power spectra of *W* in *Y*-dir. as Hovmöller-Plots

Z = 1000 m

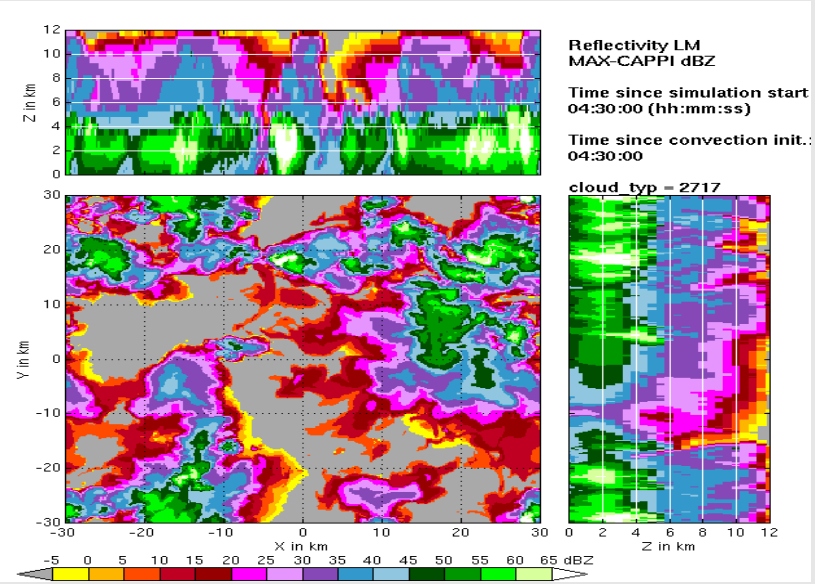


Z = 6000 m



Resolution dependency?

$\Delta X = 200$ m



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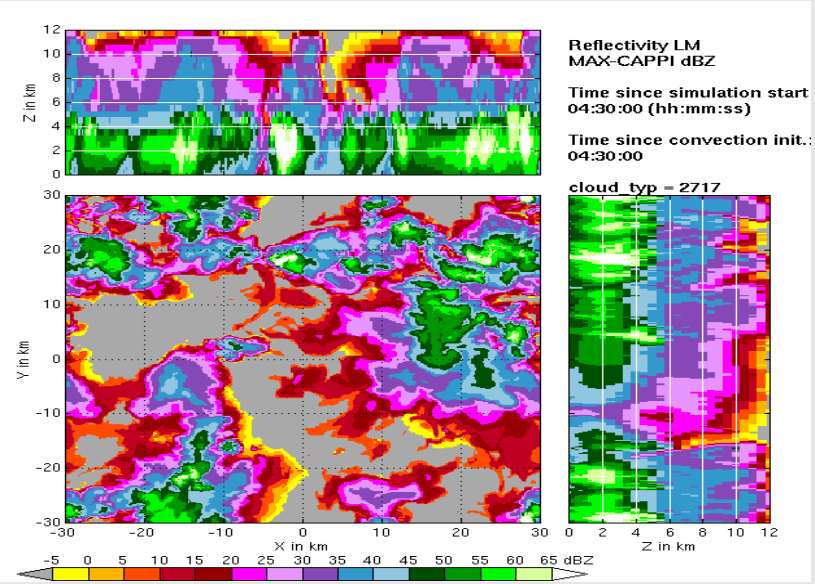
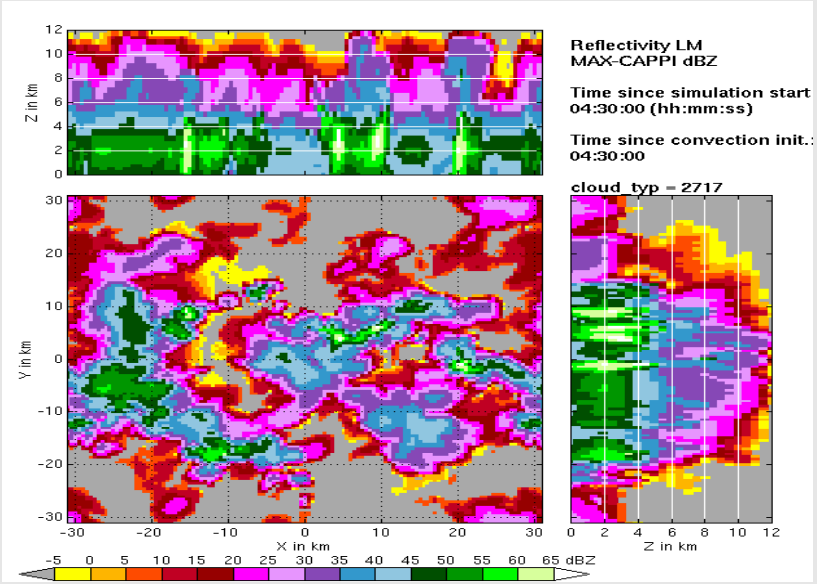
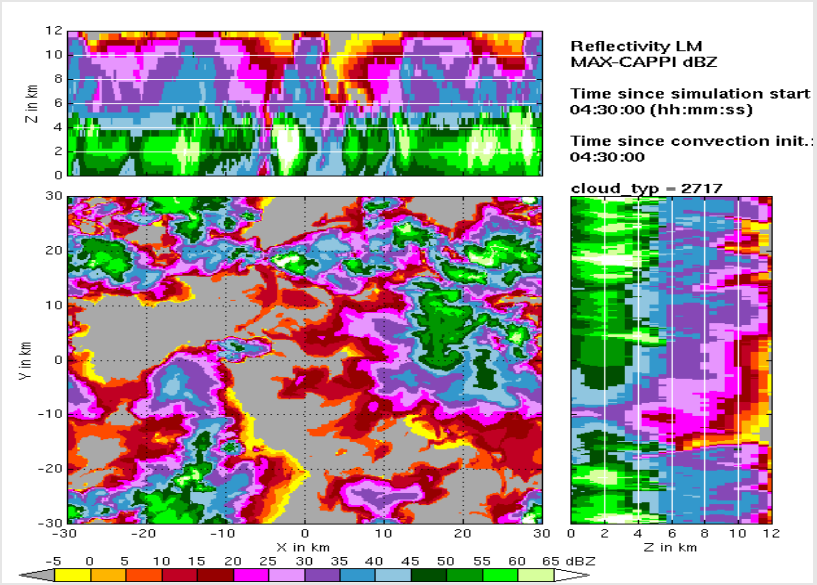


$\Delta X = 500$ m

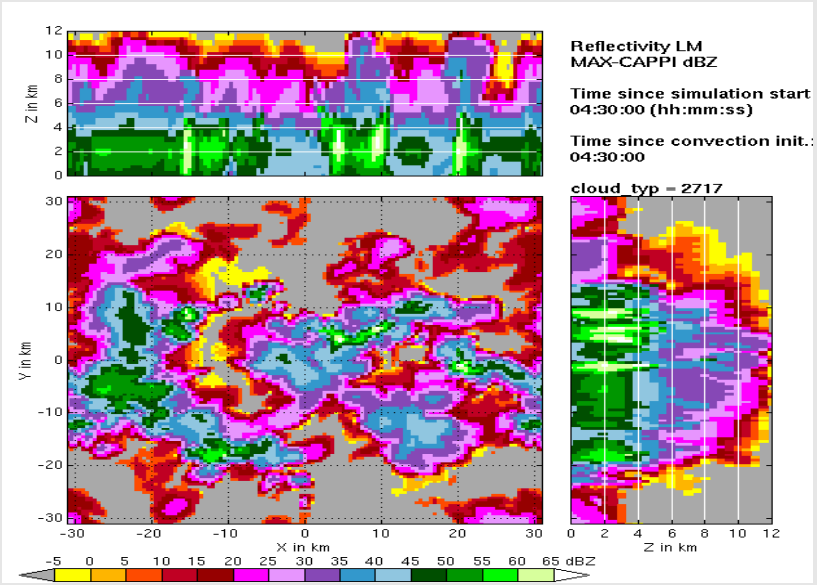


Resolution dependency?

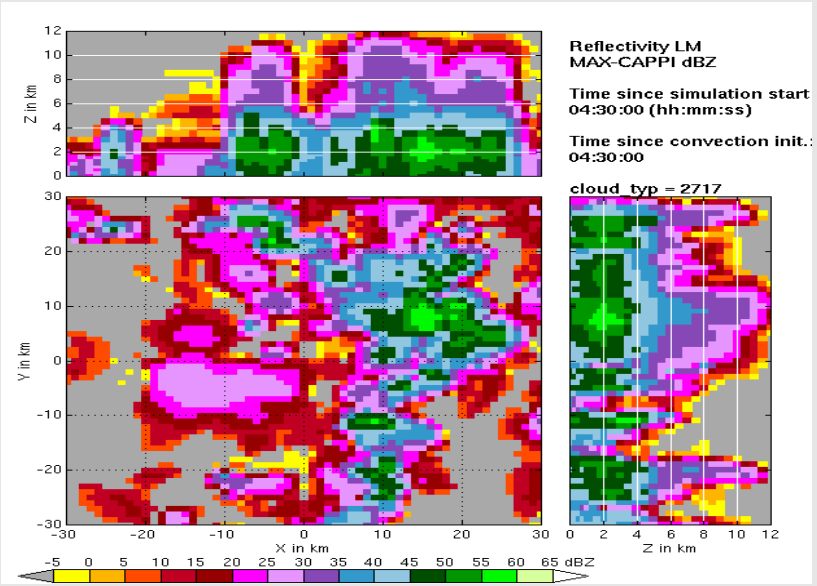
$\Delta X = 200$ m



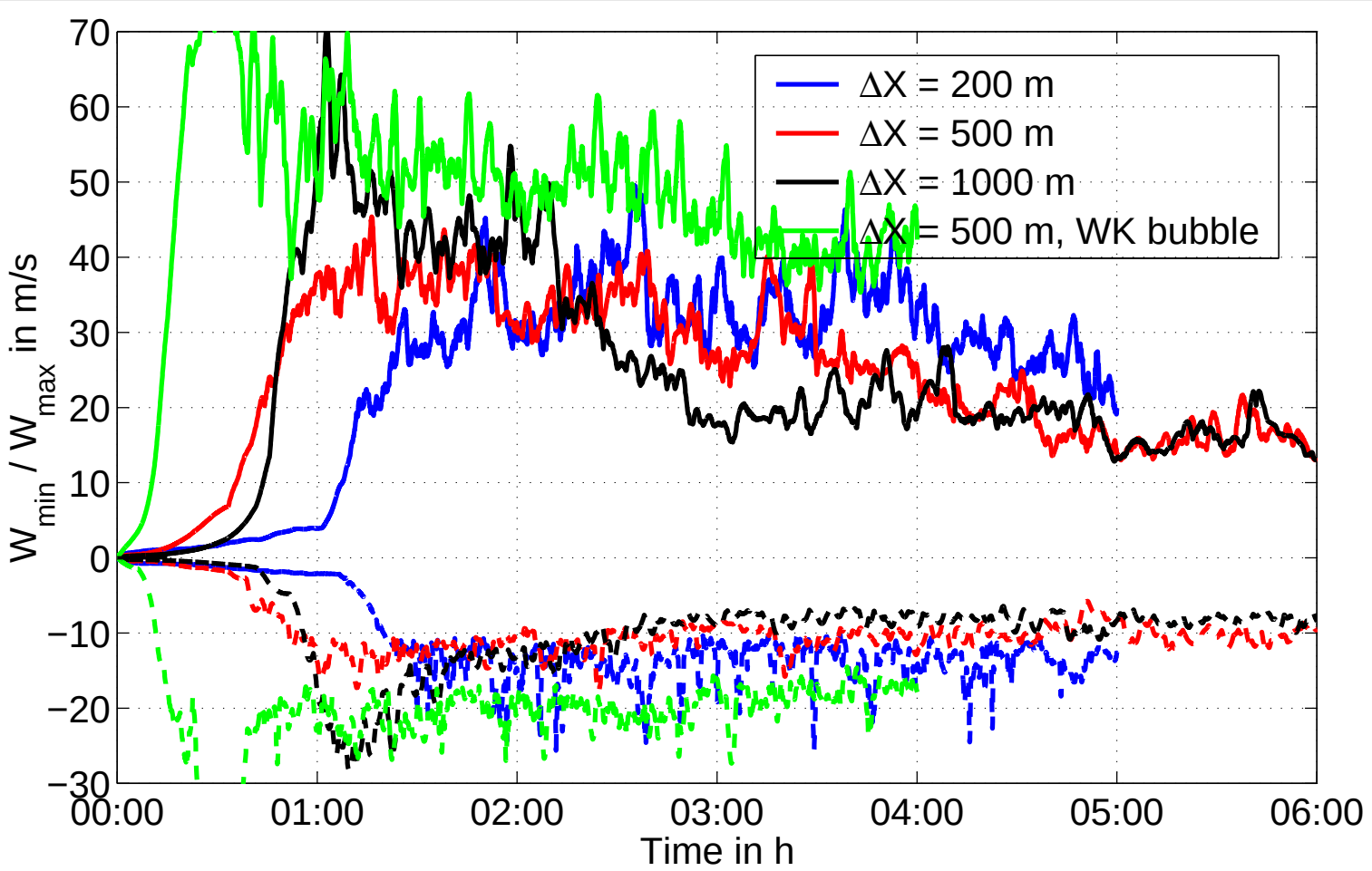
$\Delta X = 500$ m



$\Delta X = 1000$ m



Resolution dependency?



Conclusions

- Shallow convection: simulation of thermals realistic up to $\Delta X = 200$ m. Coarser resolution leads to unrealisticly 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, a model resolution of 500 m seems adequate.

- Conversely: $\Delta X = 1000$ m seems to be problematic concerning explicit simulation of convection: shallow convection too strong, deep convective modes only partly resolved, initial deep updrafts too strong (insufficient turbulent mixing?).

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