Development of the very short range forecast, meso-γ model LMK

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LMK (Lokal Modell - Kürzestfrist)
‘Aktionsprogramm 2003’ of DWD

Goals

- Development of a model-based NWP system for very short range (=‘*Kürzestfrist*’) forecasts (2-18 h) of severe weather events on the meso-γ scale, especially those related to
  - deep moist convection
    (super- and multi-cell thunderstorms, squall-lines, MCCs, rainbands,...)
  - interactions with fine-scale topography
    (severe downslope winds, Föhn-storms, flash floodings, fog, ...)

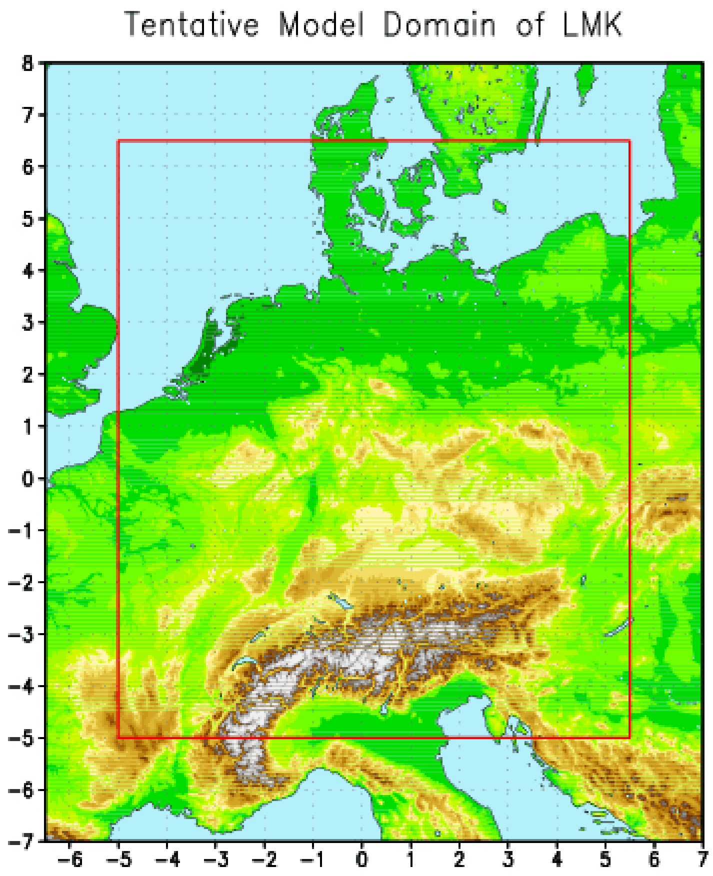
LMK - (LM-Kürzestfrist)

Methods

- Application of the LM at a grid-spacing of 2.8 km with about 50 vertical layers
  -> direct simulation of the coarser parts of deep convection (!?)
- 18-h forecasts, starting every 3-hours
  -> ensemble of forecasts (LAF-ensemble)
- ‘rapid-update’ data assimilation cycle
  - Continuous data assimilation based on nudging, short cut-off (< 1h)
  - Use of all available data, especially radar reflectivities.

LMK-Configuration

- center of the domain 10° E, 50° N
- 421 x 461 grid points
- grid length: dx = 2.8 km
- about 50 vertical layers, currently: lowest layer in 22 m above ground (planned: ~ 10 m above ground)
- boundary values from LM (LME) (dx = 7 km)



M7: Radar
M8: Latent Heat Nudging
M9: LMK 2.8 km & explicit convection
M10: Verification

M8: Latent Heat Nudging

- Thermodynamic feedback and interactions of LMK
- Improvements of the method
- Alternative methods (?)

Data assimilation: special requirements for LMK

- Assimilation of structures on the meso-γ -scale necessary (<-- deep convection)
  --> need for high resolution, rapidly updated data fields
  --> radar observations ('precipitation scan')
  horizontal resolution: Δr~1 km, $\Delta\varphi$~1°,
  temporal resolution: Δt~5 / 15 min (Germany/Europe))
  max. range: ~ 120 km
- assimilation method:
  - fast
  - relatively easy to implement
  --> Latent Heat Nudging

Basics of Latent Heat Nudging

Differences (or ratios) between (radar) measured and simulated precipitation rates are interpreted as a lack/surplus of latent heat along the trajectory of a condensed particle.

$$\frac{RR_{obs}}{RR_{sim}} = \frac{\int (LH_{sim} + LH_{corr})\, dz}{\int LH_{sim}\, dz}$$

Basic assumption of LHN: this relation is valid in a vertical model column
vertical structure of latent heating <--> temperature increments
(optional: moisture increments, e.g. by conservation of relative humidity)

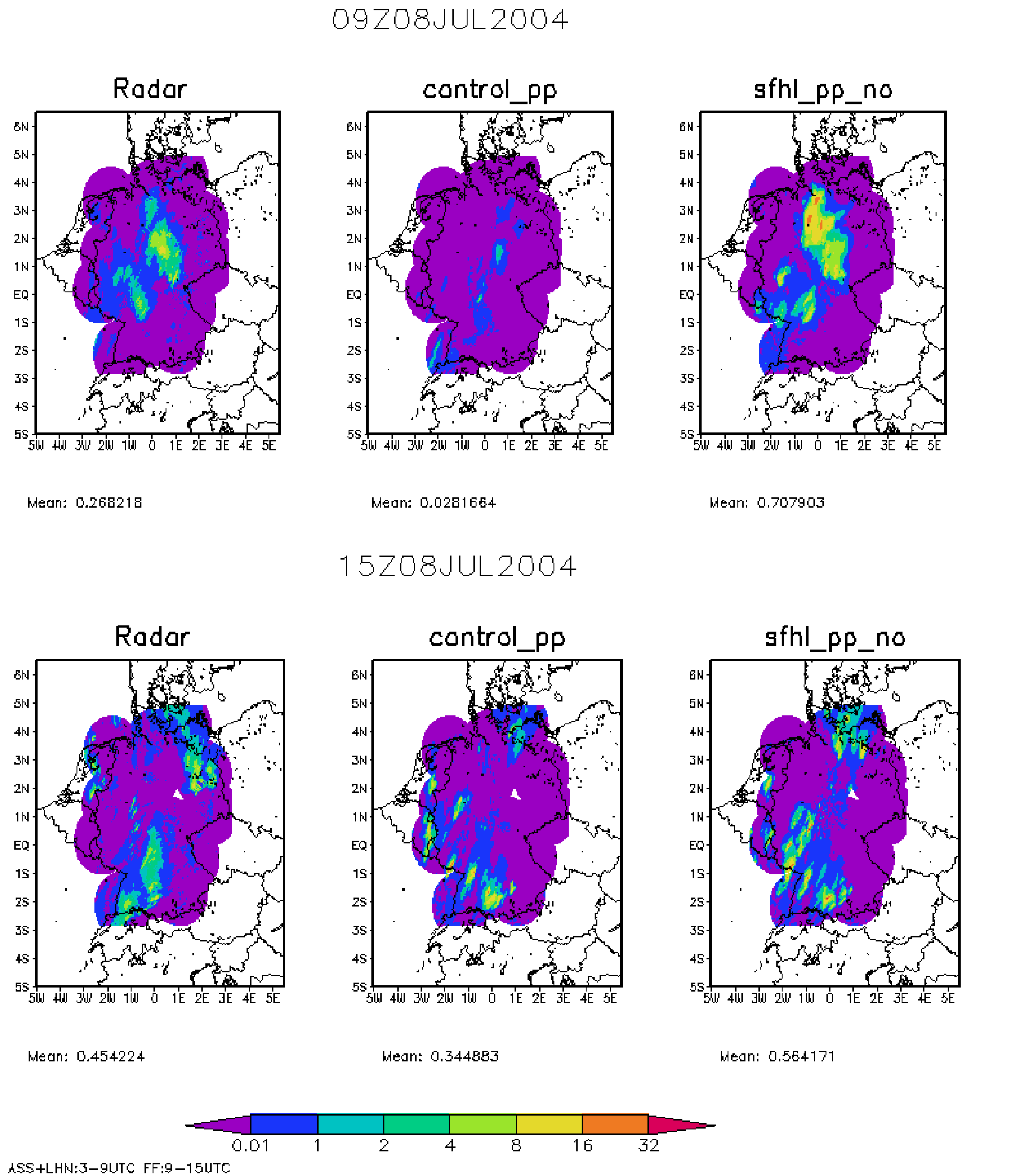
$$\Delta T_{LHN} = \frac{RR_{obs} - RR_{sim}}{RR_{sim}} \Delta T_{LH\,sim}$$

$$\frac{\partial T}{\partial t} = \ldots + \left.\frac{\partial T}{\partial t}\right|_{LHN} + \left.\frac{\partial T}{\partial t}\right|_{Nudging}$$

First results when we started to look at the interactions of LHN and the prognostic precipitation scheme

left: radar image,
middle: control run without LHN
right: simulation with LHN

top: at the end of assimilation (6h)



bottom: at the end of free forecast (6h)

Latent Heat Nudging (LHN) – Basic questions

- ***LHN <--> prognostic precipitation ?***
  problem: different basic assumptions
    - assumption LHN:
      precipitation process is local in time and space (horizontal)
    - prognostic precipitation:
      drifting of the precipitation by several grid lengths and over several time steps

    --> 'feedback problem'

  <u>main solutions:</u>
  1.) apply LHN increments only in the growth stage of the convective cell
  2.) use of an undelayed reference precipitation (e.g. diagnostic precipitation scheme) as an intermediate step

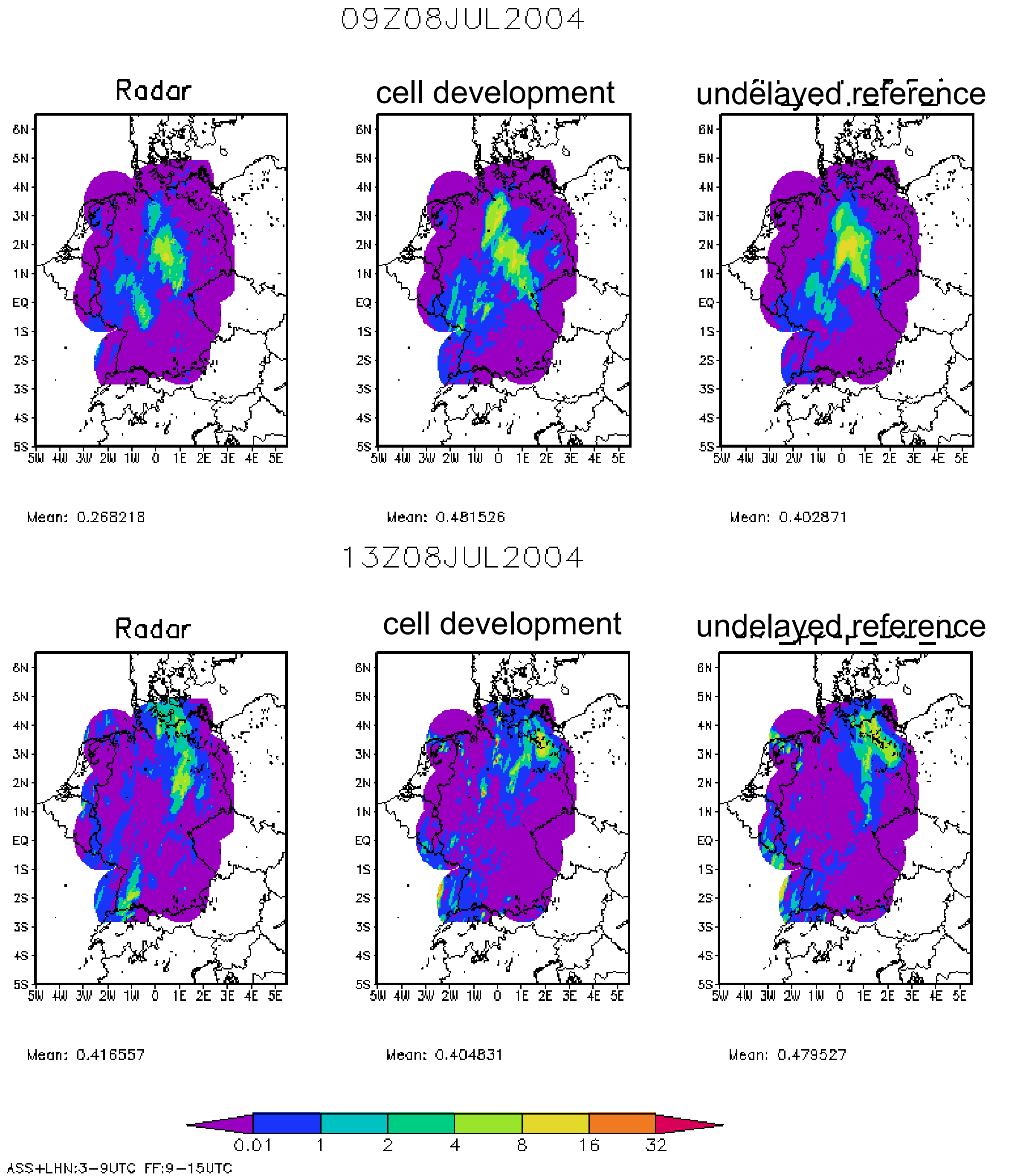
- ***What are the reasons for the short memory time of LHN ?***
  -> expansion of gravity waves
  <u>solution:</u>
  problem is largely reduced by application of prognostic precipitation instead of the diagnostic precipitation scheme

model run with undelayed reference precipitation and consideration of temporal cell development

hourly sum of precipitation

<u>Above:</u> at the end of the assimilation period

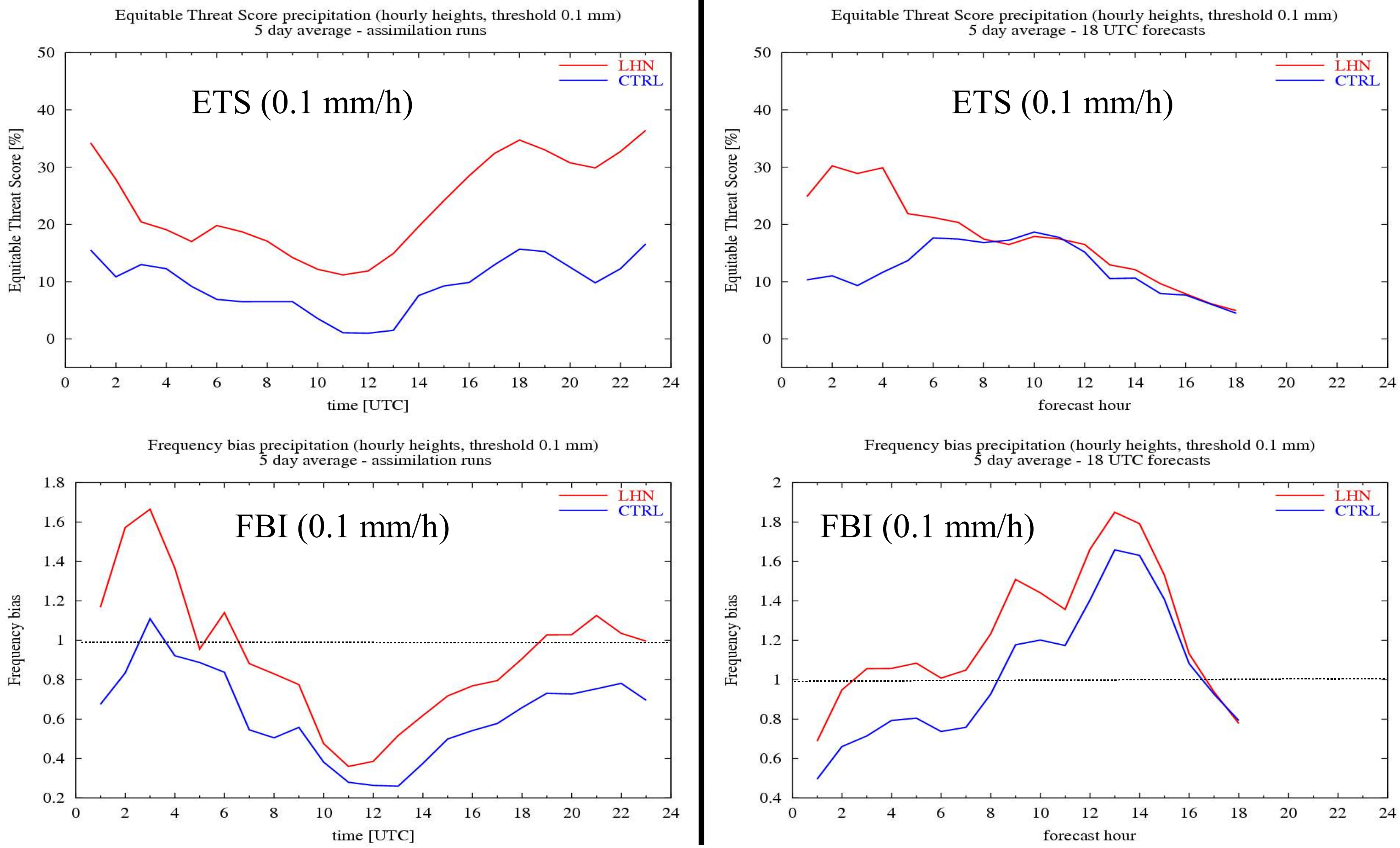
<u>Below:</u> after 4 hours of free forecast



Assimilation run for a 5 day period (07/07/2004 0 UTC to 12/07/2004 0 UTC)

Assimilation

Free forecast (18 UTC)



M7: Radar
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M9: LMK 2.8 km & explicit convection

- Numerical schemes
- Physical Parameterisations
- Boundary conditions
- case studies
- LMK Testsuite

M9: LMK 2.8 km and explicit convection

LMK - Dynamics

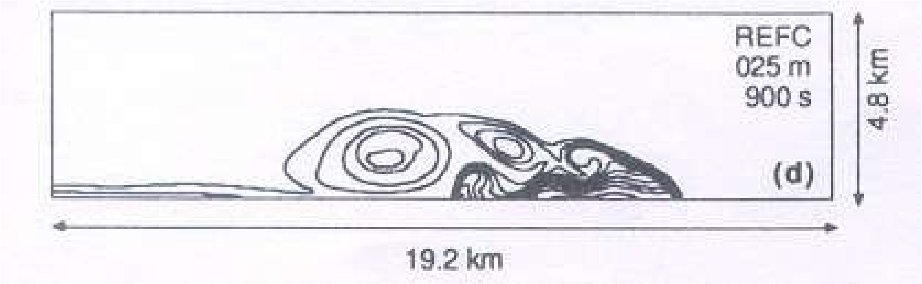
- Model equations: non-hydrostatic, full compressible, advection form
- Base state: hydrostatic
- Prognostic variables: cartesian wind components u, v, w
  pressure perturbation p‘, Temperature T (or $T' = T - T_0$)
  humidity var. q_v, q_c, q_i, q_r, q_s, q_g ('prognostic precip.')
  TKE
- Coordinate systems: rotated geographical coordinates
  generalized terrain-following height coordinate
  user-defined vertical stretching

LMK- Numerics

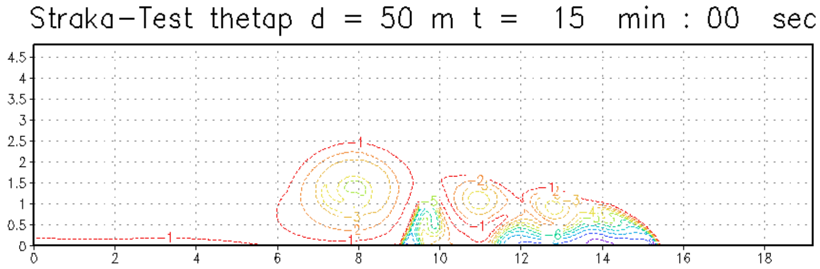
- Grid structure: horizontal: Arakawa C
  vertical: Lorenz
- time integrations: time-splitting between fast and slow modes:
  3-timelevels: Leapfrog (+centered diff.) (Klemp, Wilhelmson, 1978)
  2-timelevels: Runge-Kutta: 2. order, 3. order, 3. order TVD
- Advection: for u,v,w,p',T:
  - hor. advection: upwind 3., 4., 5., 6. order (Wicker, Skamarock, 2002)
  - for q_v, q_c, q_i, q_r, q_s, q_g, TKE:
  - Courant-number-independent (CNI)-advection:
  - (Motivation: no constraint for w <--deep convection!)
  - Euler-schemes:
    - with PPM advection (Skamarock, 2004)
    - Bott (1989) (2., 4. order)
  - Semi-Lagrange (trilinear, triquadr., tricubic) (Staniforth, Côté, 1991)
- Smoothing: 3D divergence damping
  horizontal diffusion 4. order

Test of the dynamical core: density current (Straka et al., 1993)

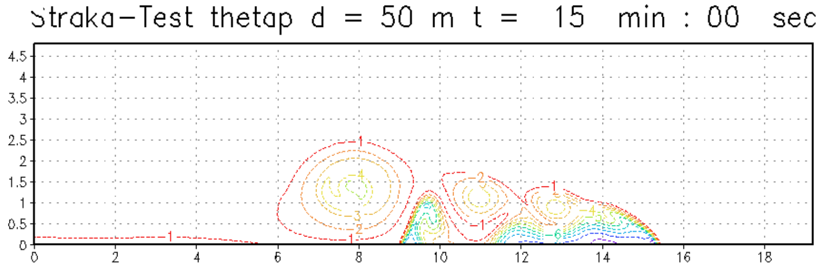
θ' after 900 s. (Reference)
by Straka et al. (1993)



RK3 + upwind 5. order



RK2 + upwind 3. order



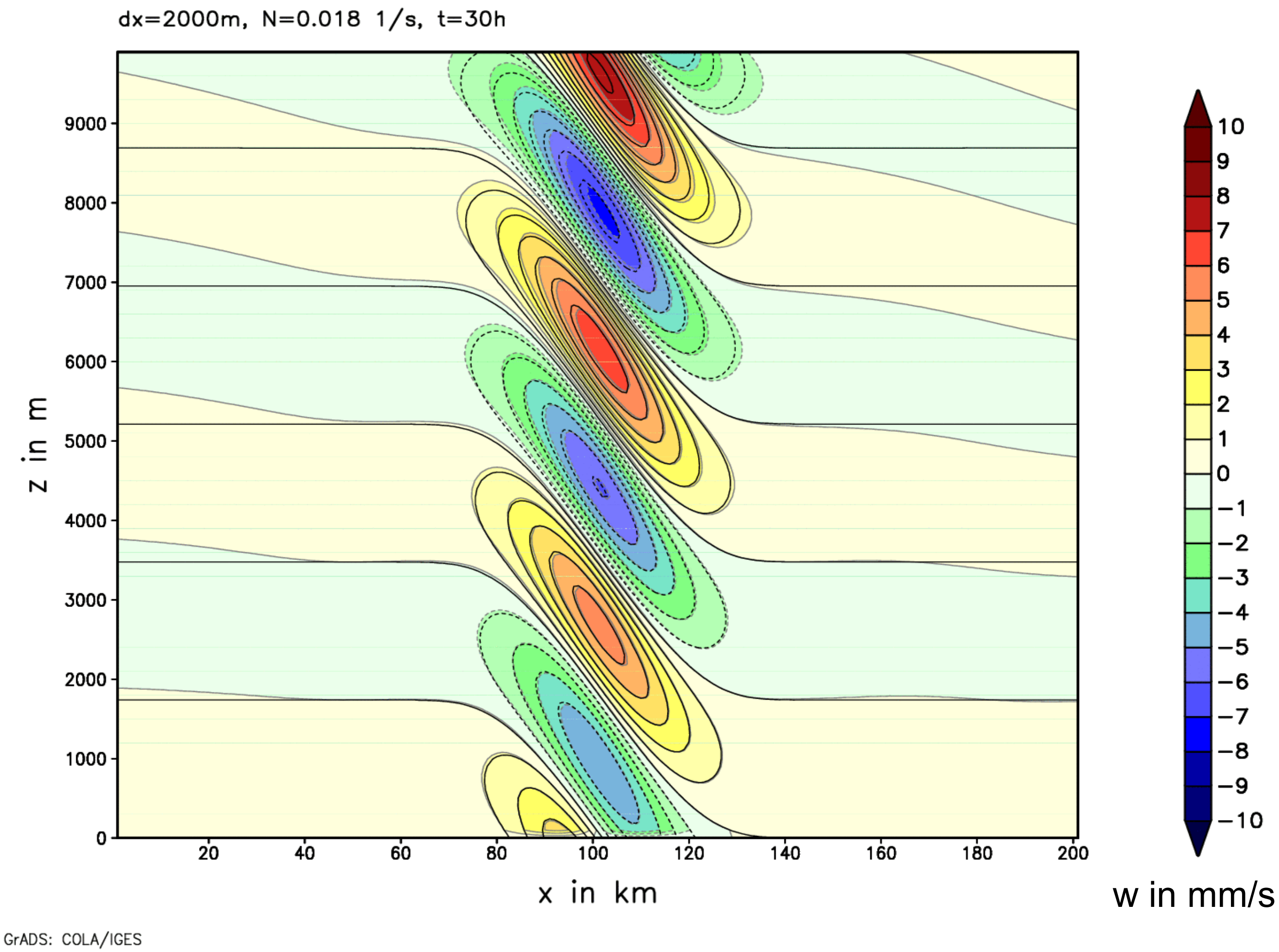
Test of the dynamical core: linear, hydrostatic mountain wave

Gaussian hill
Half width = 40 km
Height = 10 m
U0 = 10 m/s
isothermal stratification

dx=2 km
dz=100 m
T=30 h

analytic solution:
black solid lines

simulation:
colours + grey lines

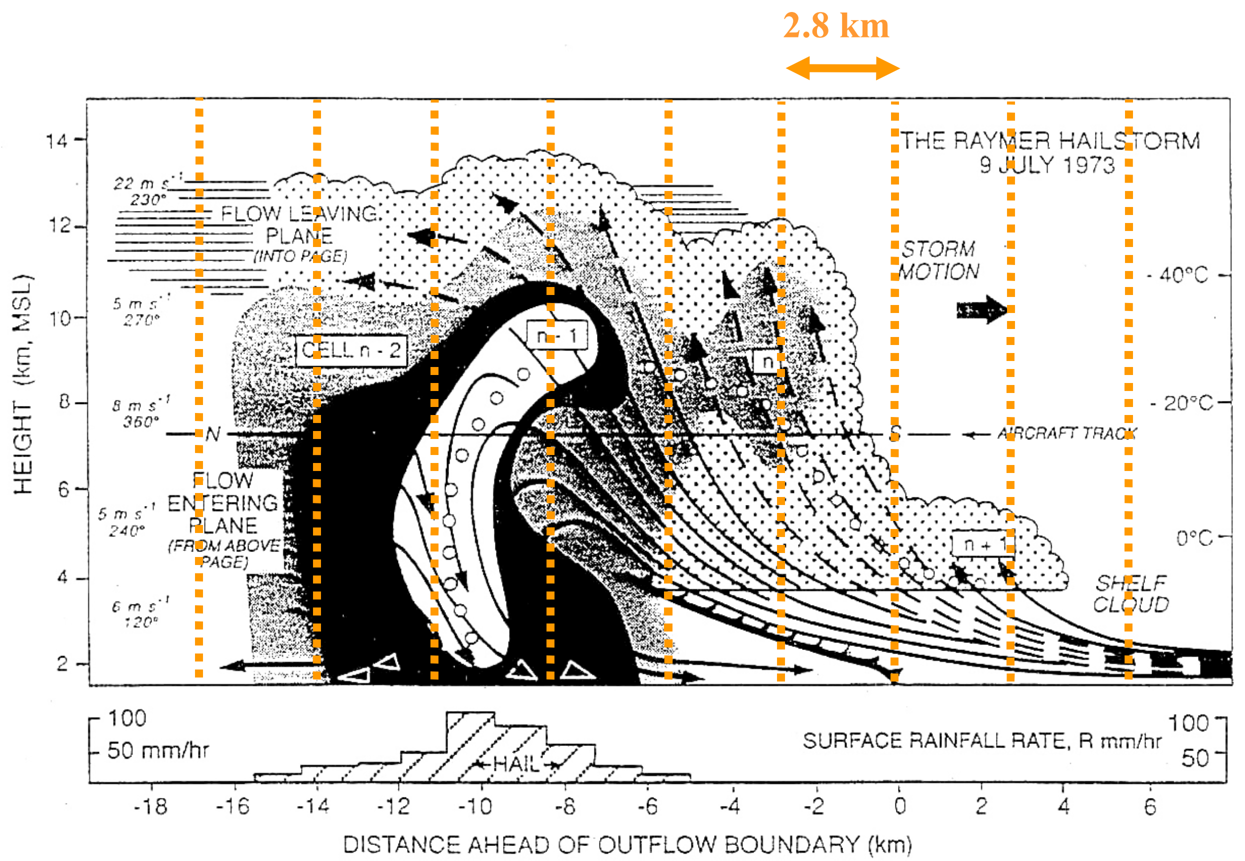


LMK- physics

- turbulence: 1D, 1-equation model (prognostic TKE)
  3D, 1-equation-model, full coordinate transformations
  'moist turbulence' (buoyancy production of TKE
  altered by condensation processes)
- cloud microphysics: 6-class-scheme (q_v, q_c, q_i, q_r, q_s, new: graupel q_g)
  6-class/2-moments-scheme (for research/benchmark purposes)
- radiation: 2-flux-scheme (Ritter, Geleyn, 1992)
  update frequency?
- soil-vegetation-model 2 levels --> 7 levels (planned)
- convection: - no cumulus convection parametrization
  - ‚simple' shallow convection:
  apply only shallow convection part from Tiedtke (1989)
  only for cloud 'heights' < 250 hPa

Deep moist convection

Schematic model from a Colorado storm case study (Raymer Hailstorm)

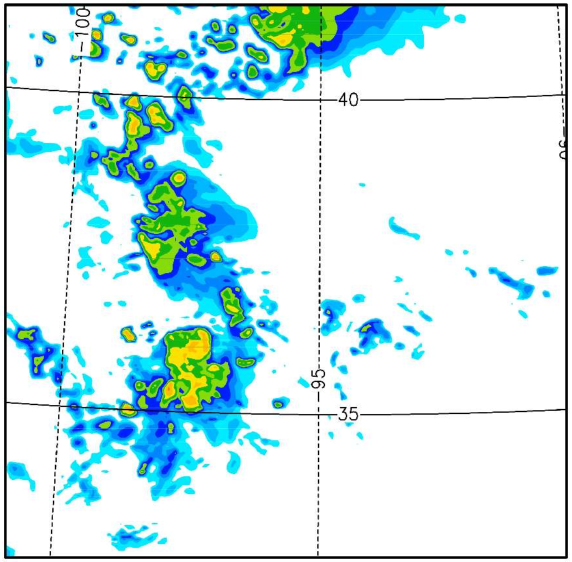


from: R. A. Houze, Jr.: Cloud Dynamics
International Geophysics Series Vol. 53

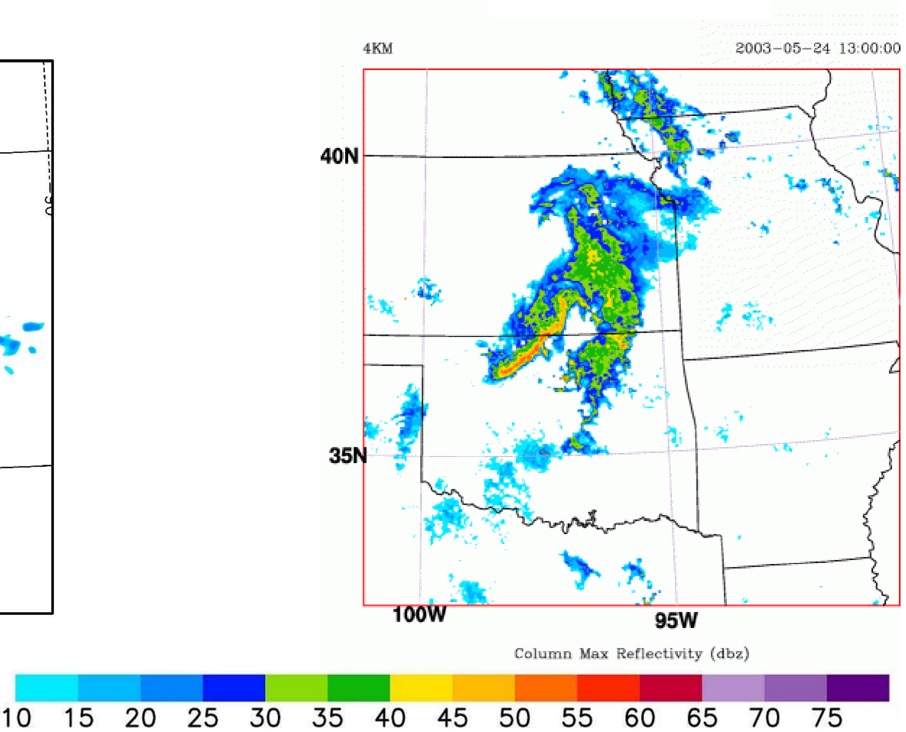
Example of explicit convection in LMK: BAMEX-test case

Max. radar reflectivity 24.05.2003 13 UTC

LMK, dx=4 km
Graupel scheme
Init. from GME, dx=60 km



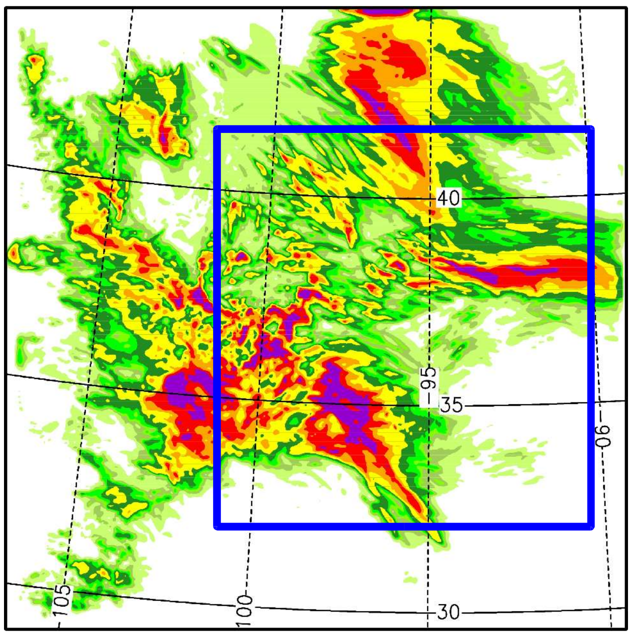
Observation



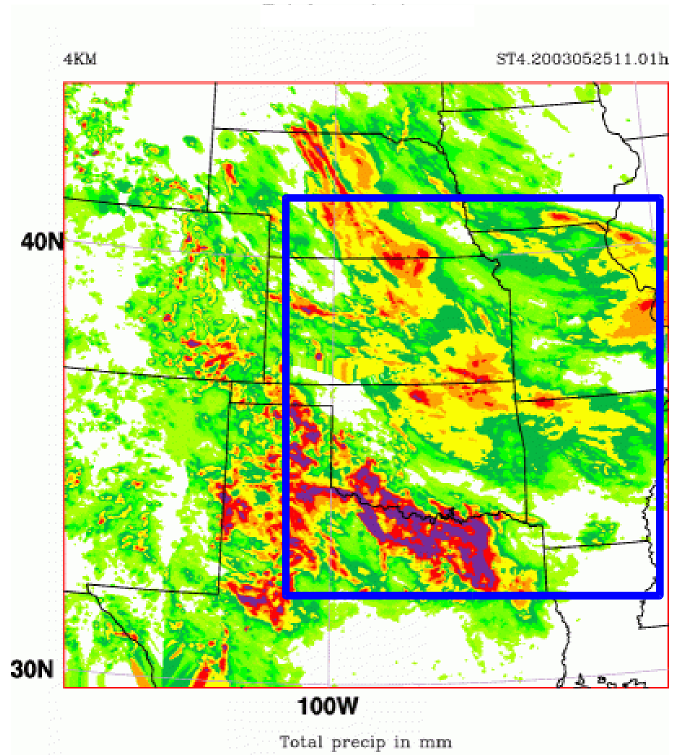
Example of explicit convection in LMK: BAMEX-test case

35-h-precipitation 23.05.2003 12 UTC +12h..+47h

LMK, dx=4 km

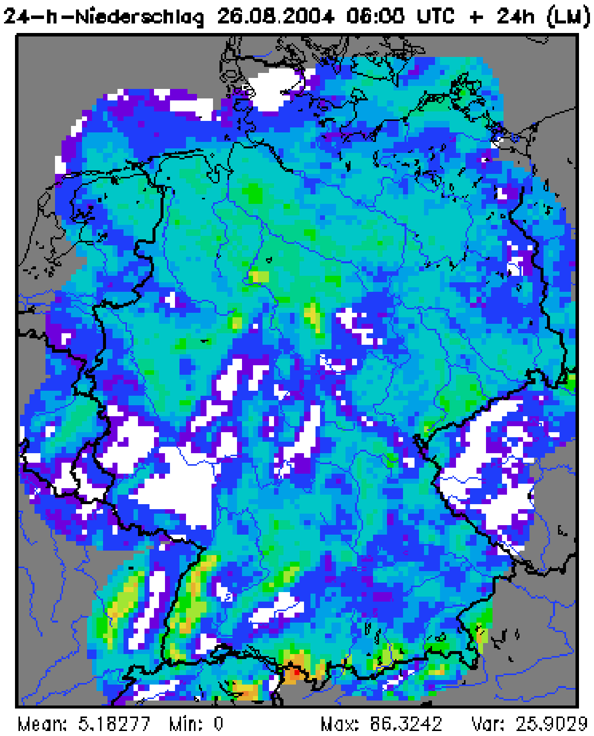


observation

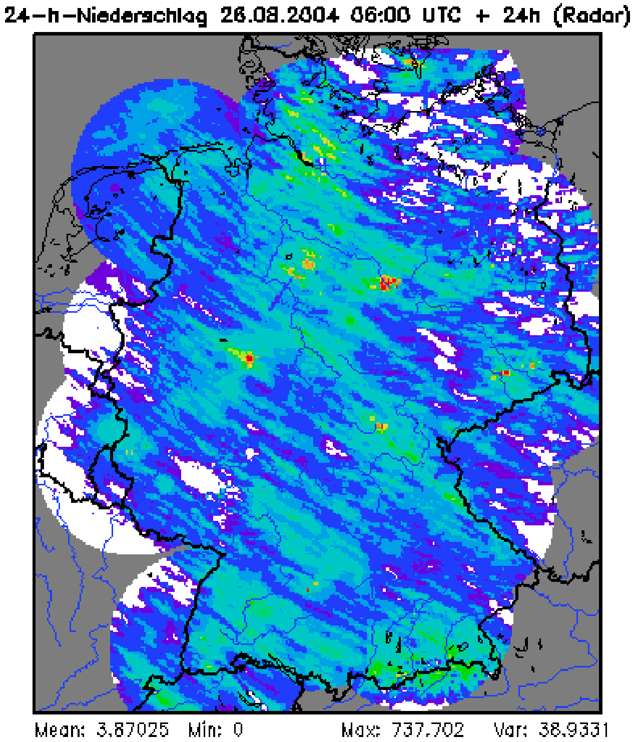


Example for explicitly resolved convection in LMK (case '26.08.2004')

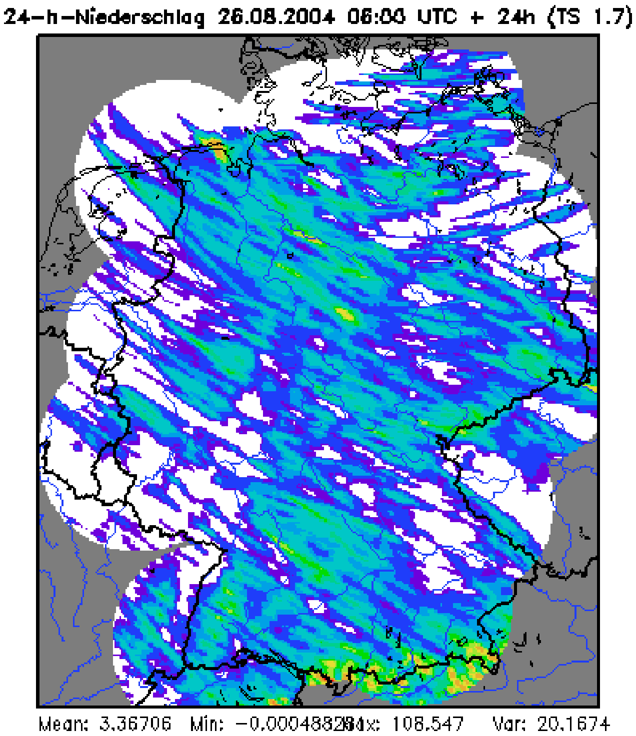
LM



Radar

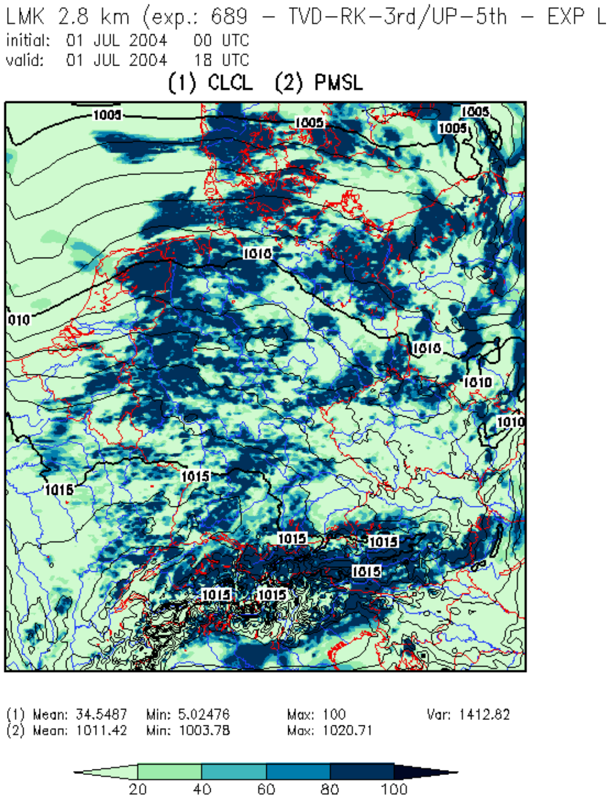


LMK, Testsuite 1.7

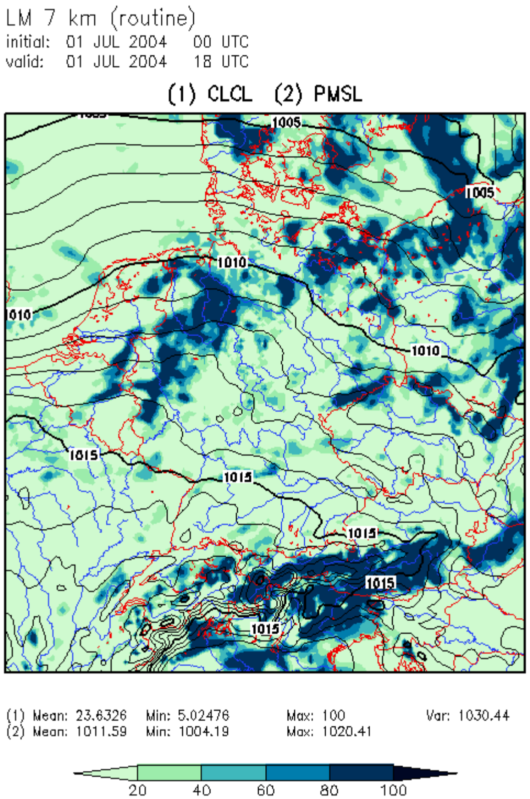


Need for a shallow convection parameterization:

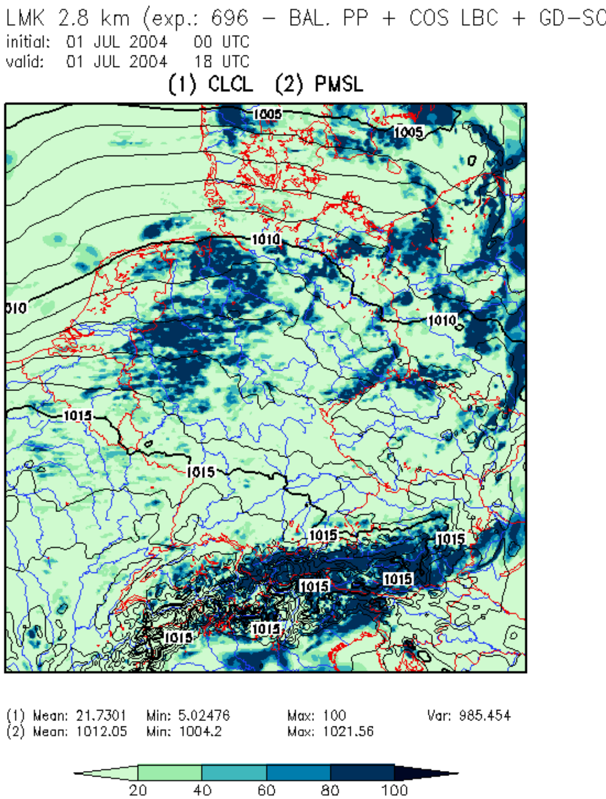
Testsuite 1-5
without shallow convection
pressure jump problem



operational LM
the ‚truth‘ (?)



Testsuite 1-6
with simple shallow
convection param.



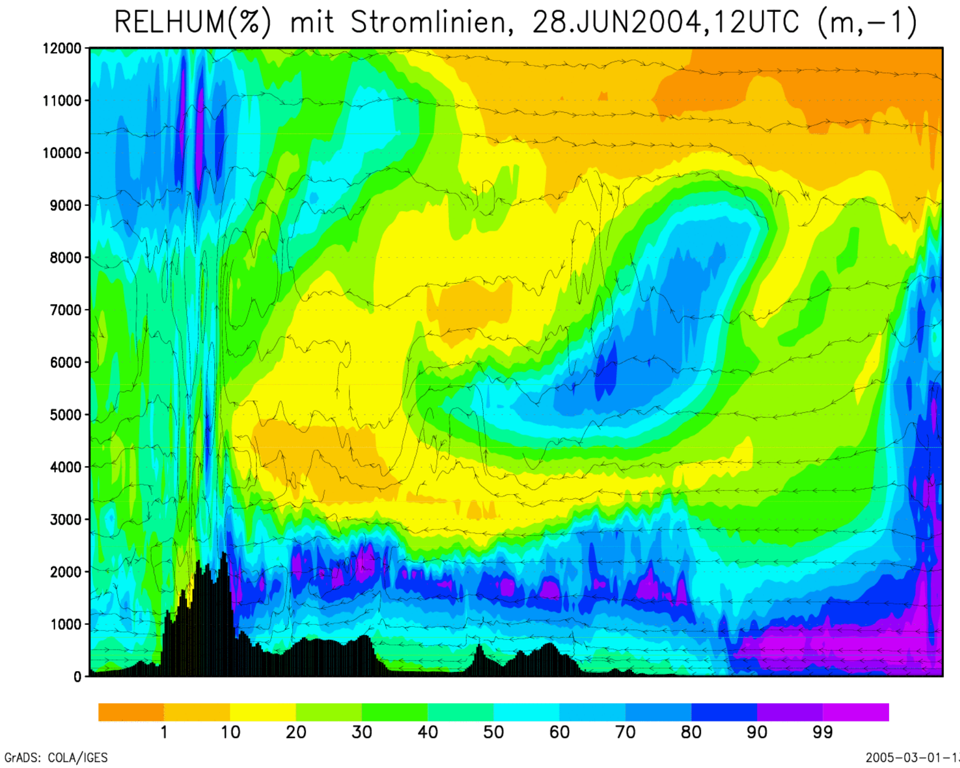
Shallow convection

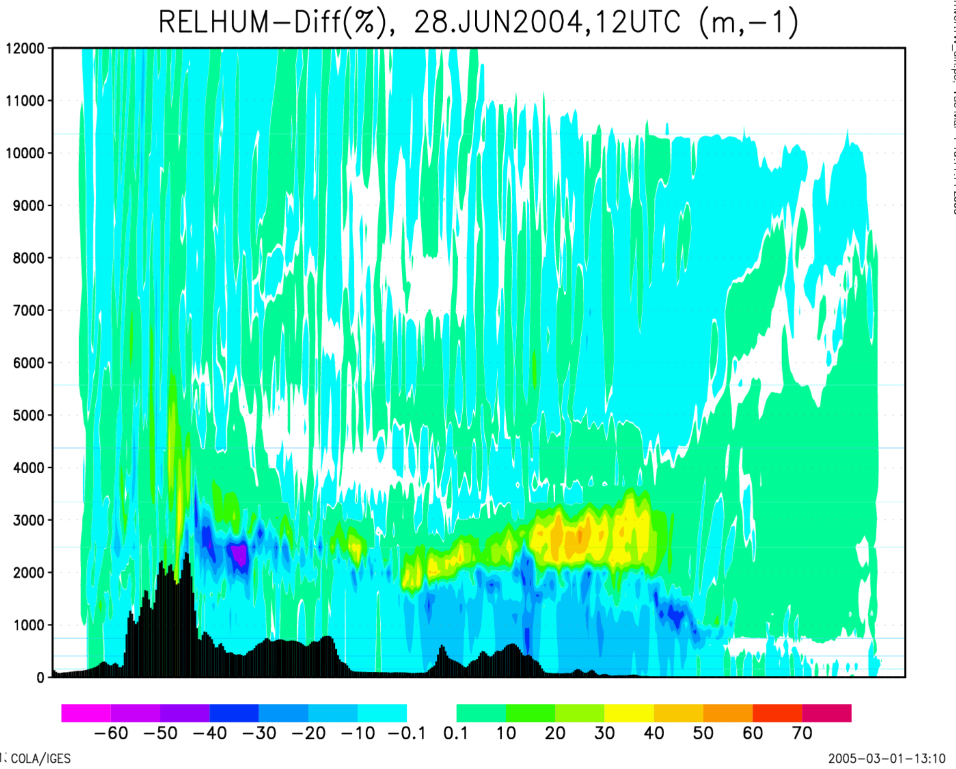
N-S-crosssection

based on Tiedtke-scheme

rh(with shallow convection)

Diff.: rh(with sh. conv) - rh(without sh. conv.)





Project LMK: Milestones

- **Summer 2003**
  Start of the project LMK
- **End 2003**:
  First test-suite with LM at high resolution is running.
- **End 2004:**
  Prototype version of the LMK-System with data assimilation but without LHN running.
- **Summer/Autumn 2005:**
  Prototype version of the LMK-System with LHN is running in a quasi-operational mode.
  Further testing and evaluation of new numerical schemes and physical parameterizations.
- **Early 2006:**
  Start of a pre-operational test-phase.
  Fine-Tuning and final evaluation of all components of the system.
- **End 2006:**
  Start of the operational application.