LMK: A Very Short Range Forecasting System

Goals and Methods

Structure of the project ‘LMK’

Development Work

LMK Testsuite

Final Remarks

Günther Doms, Michael Baldauf (FE 13)

LMK - (LM-Kürzestfrist)
‘Aktionsprogramm 2003’ of DWD

Goals

- Development of a model-based NWP system for very short range 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)

Method

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

Potential benefits from an explicit representation of convection

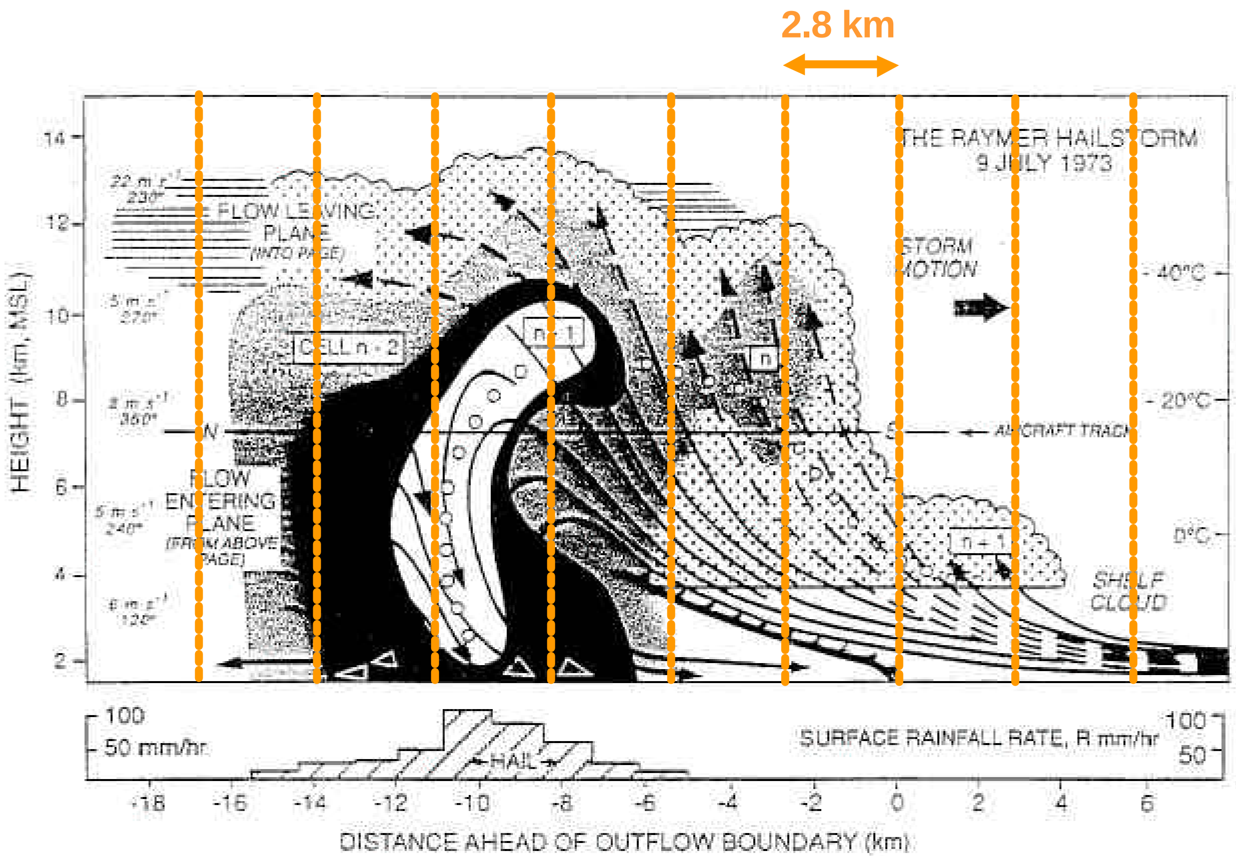
- no drawbacks from the use of parameterized convection (artificial closure conditions, stationarity, ...)
- time evolution (life-cycle) of convective cells is simulated
- transport of convective cells with the wind field (impact of shear)
- formation of new cells along gust-fronts (long-lasting cells, super- and multi-cells development)
- more detailed representation of cloud-microphysics
- thermodynamic interaction between updraft und downdraft
- scale-interaction and organization (Squall-Lines)

Related projects:

AROME, UK MetOffice, HIRLAM, WRF (BAMEX)

Deep moist convection

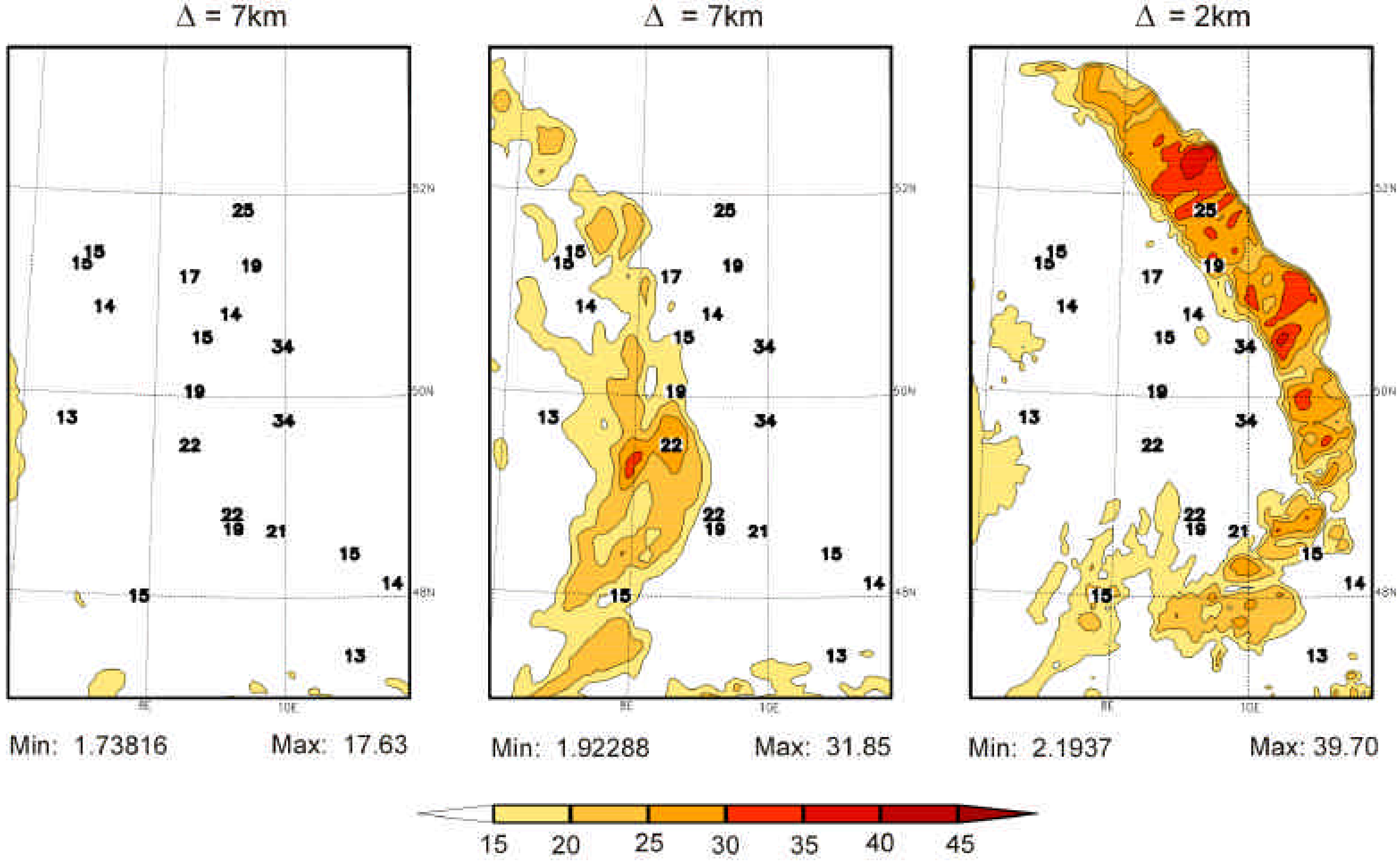
Schematic model from a Colorado storm case study
(Raymer Hailstorm)



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

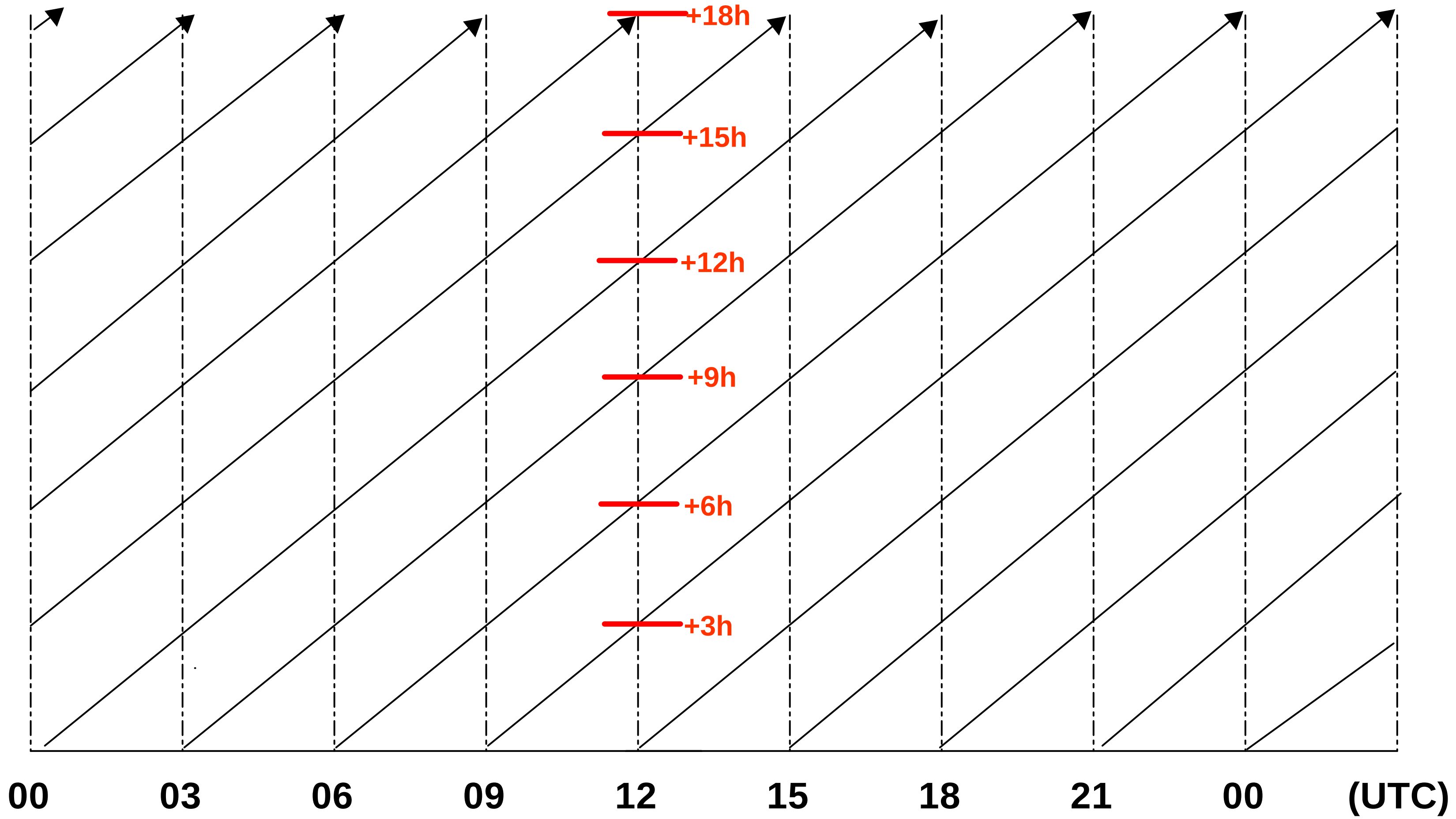
with convective parameterization

without convective parameterization



vmax and obs. wind gusts (m/s) 2 June 1999 00UTC +17h

LMK Assimilation and forecast cycle (LAF-Ensemble)



LMK: new forecast every 3 hours

LMK will require not only adjustments of existing schemes but also the development of new components

- Further developments in the method to assimilate radar data (Latent heat nudging, LHN)
- 5-min radar composits (DX-data) including quality control
- Development of an efficient time-integration scheme allowing for high-order spatial discretization
  - modified metrics, new 'symmetric' thermodynamics, BCs, cov. metrics
- Full 3-d budget equations for precipitating hydrometeors
- Development of new physics schemes for kilometer-scale simulations (graupel and hail microphysics, 3-d turbulence, shallow convection)
- Development of new tools for model validation and verification using remote-sensing data
  (pseudo-satellite and pseudo-radar products, Lidar, cloud-radars)
- Development of products and methods to interpret model results from deterministic forecasts (on stochastic scales) and to estimate the predictability (probabilistic products)

LMK Project Structure

Work Packages	Mentors /Project staff members	Tasks
M7: Radar Data	Michael Buchhold (FE 12) Kathleen Helmert	- Quality control of 5-min DX-data - European DX composit - Assimilation of radar winds
M8: Latent Heat Nudging (LHN)	Christoph Schraff (FE 12) Klaus Stephan	- Thermodynamic feedback and interactions of LHN - Improvements of the method - Alternative methods (?)
M9: LM 2.8 km & explicit convection	Michael Baldauf (FE 13) Jochen Förstner Thorsten Reinhardt	- Numerical schemes - Physical parameterization - Lateral and upper boundaries - Case studies and intercomparison - LMK Testsuite
M10: Verifikation and Validation	Uli Damrath (FE 15) Claus-Jürgen Lenz	- Traditional verifikation (Syn/Temp) - Use of pseudo-satellite and pseudo-radar tools - New methods (pattern recognition, upscaling, ...

Plus ~ 10 permanent staff members at 10 -20 %

Current Activities

- **Radar Data**
  - Generation of a DX composite for the DWD network
  - Quality control
  - Clutter corrections

- **Latent Heat Nudging (LHN)**
  - Diagnostic studies ->
    Reasons for the short memory time of LHN?
  - Use of DX data
  - Code transfer to LM
  - LHN <--> prognostic precipitation ?
    problem: different basic assumptions

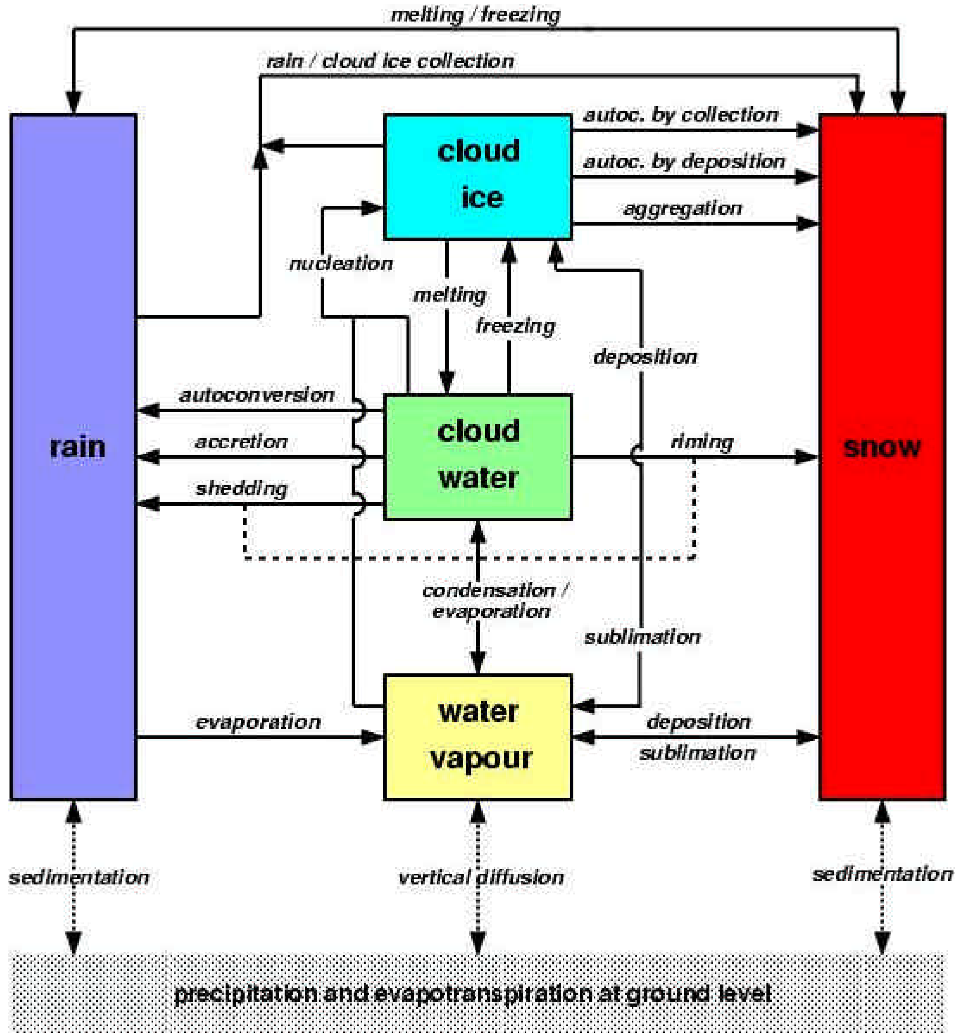
Current Activities (2)

- **Dynamics, Numerics, Boundary Data**
  - New ‘symmetric thermodynamics’ within the RK3 solver
  - Lateral boundary conditions: ‘pressure drop’ (solved)
  - LBC’s for prognostic precipitation
  - Update of LM2LM (SLEVE coordinate, ex. Param for data assimilation)
  - Idealized cases

- **Physical Parameterization**
  - Implementation of 3-d turbulence for the RK3 solver
  - Test and evaluation of the new Graupel-Scheme
  - Development of a shallow convection scheme
  - Sensitivity tests for radiation update frequency

- **Verification and Validation**
  - Synop Verification of LMK testsuites
  - Pseudo-satellite and pseudo-radar products

Parametrization of cloud microphysical processes



$$\frac{\partial q_x}{\partial t} + \mathbf{v}_h \cdot \nabla q_x + w\frac{\partial q_x}{\partial z} - \frac{1}{\rho}\frac{\partial P_x}{\partial z} = S_x$$

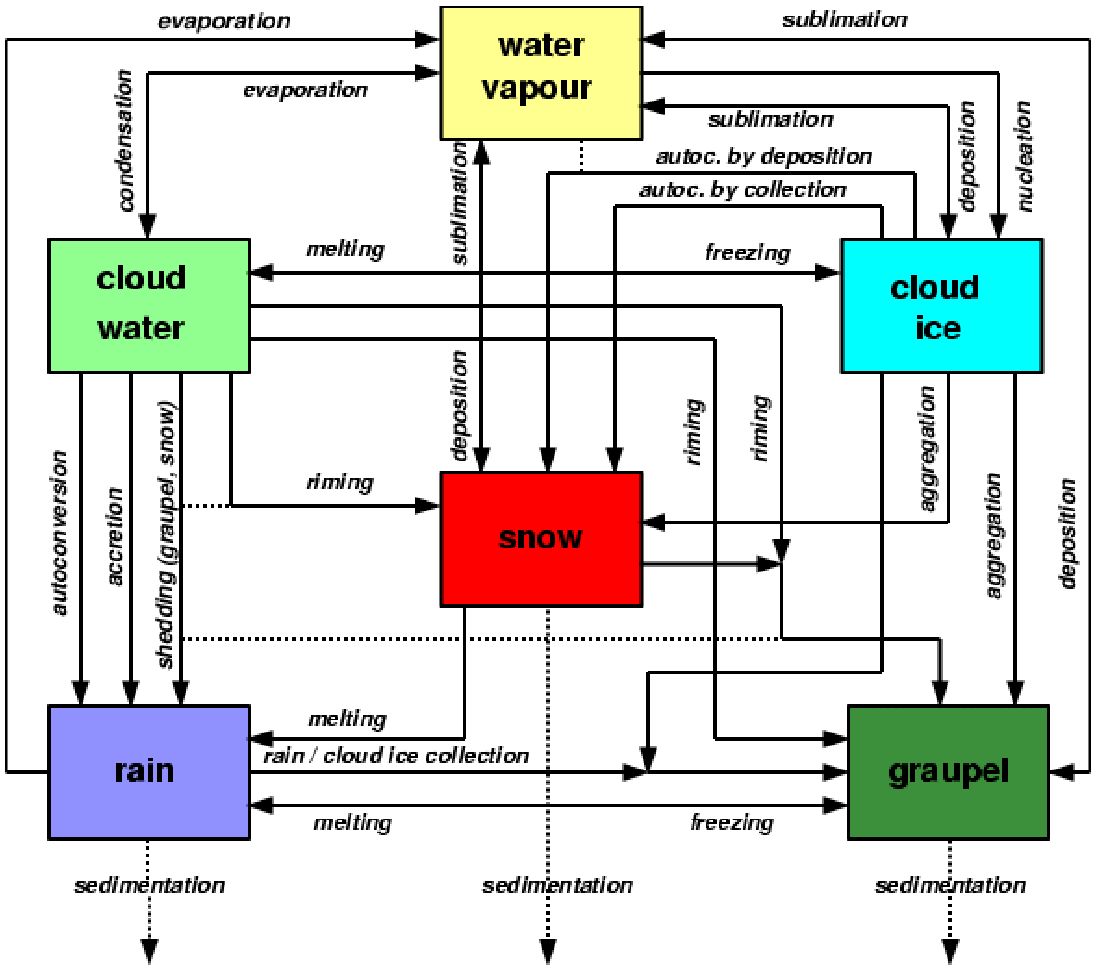
Full 3-d budget equations connect microphysics to flow field
- horizontal and vertical transport of precipitation is important

The current LM (Class-5) scheme is designed for stratiform clouds

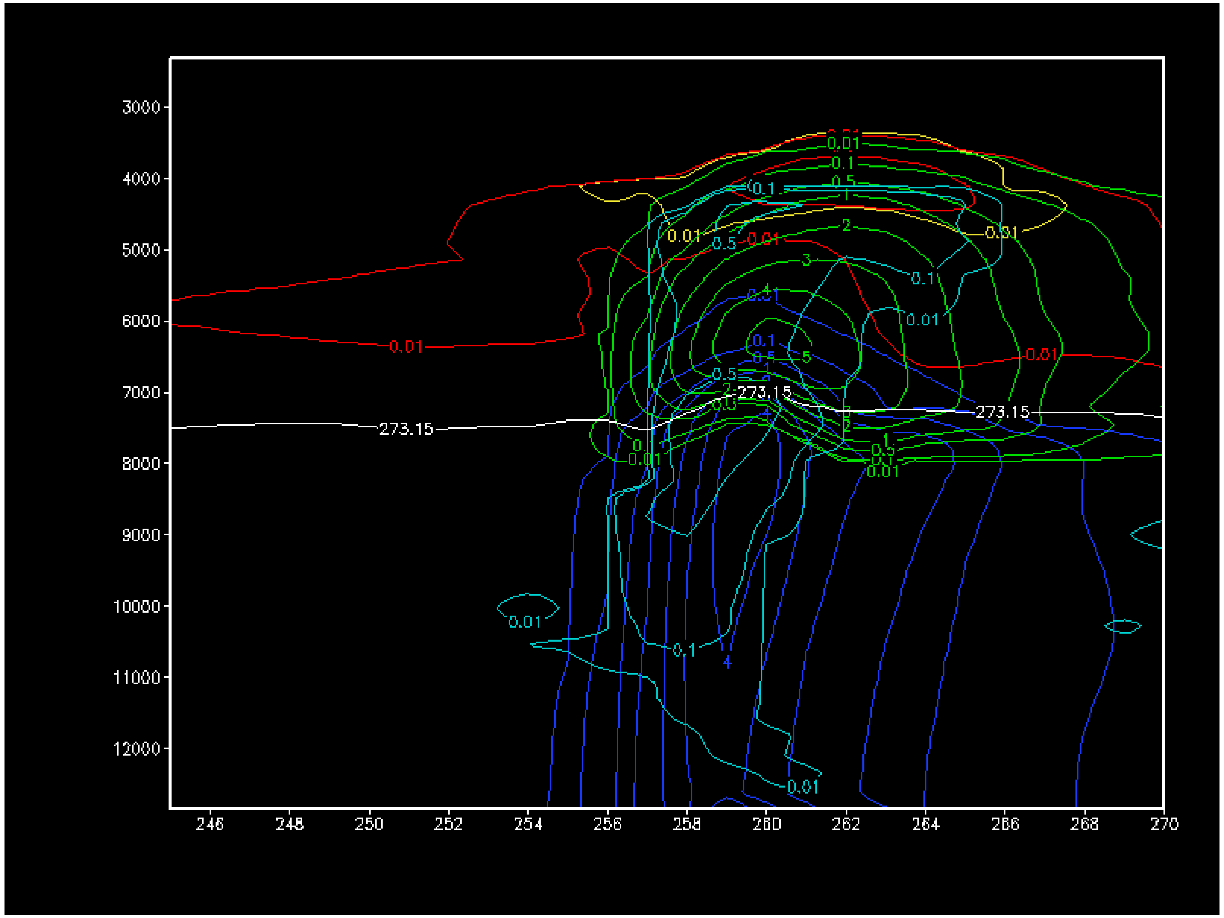
Application to convective clouds requires adjustments and extension to include graupel (hail):
- Formulation of a Class-6 scheme

Implementation of a double moment ice scheme for research and benchmark (A.Seifert, NCAR)

LMK Graupel-Schema



- New microphysical processes related to graupel are formulated and parameterized
- Full 3-d budget equation
  - advection with the 3-d wind
  - sedimentation and source/sinks are treated with a quasi-implicit predictor-corrector method
- Prototype version
  - tests and evaluation
  - adjustments of parameters
  - completeness



LMK test-simulation with the new graupel scheme

10. June 2003 12 UTC + 9 h

West-east vertical cross section through a deep convective cell (equidistant in level space) (mixing ratio in g/kg)

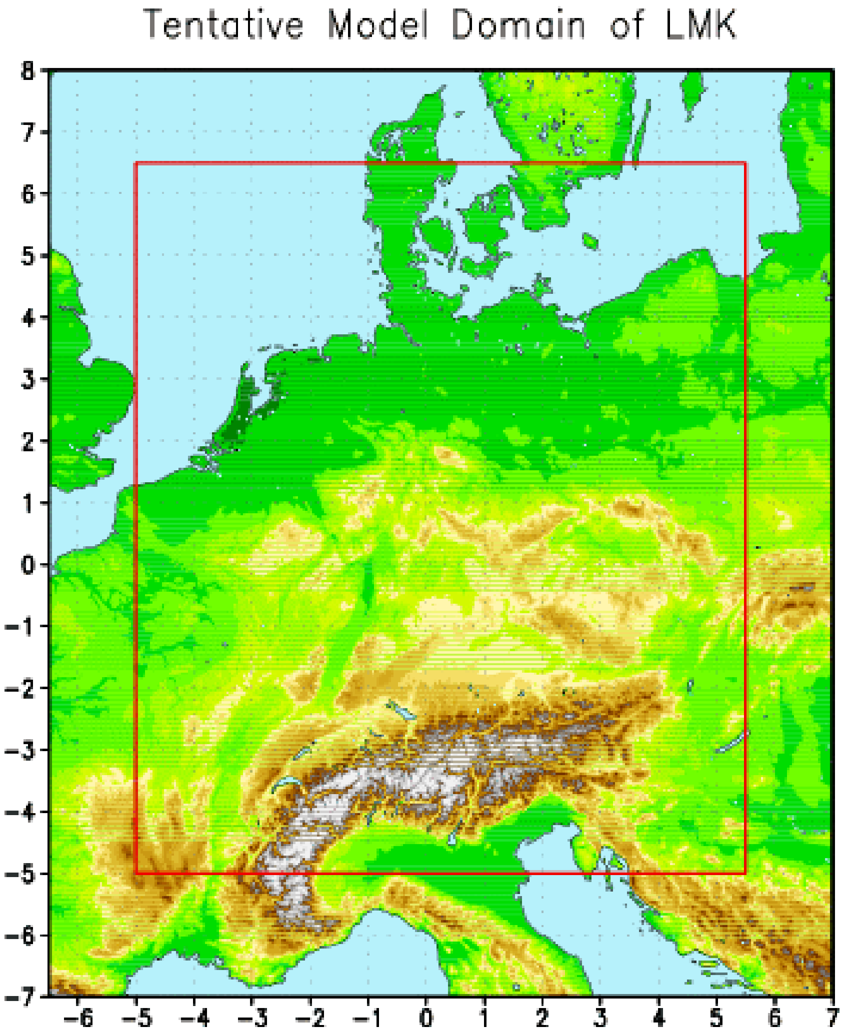
light blue: cloud water
yellow: cloud ice
dark blue: rain water
red: snow
green: graupel

Ongoing sensitivity tests for both convective and stratiform cases

Testsuite 1

- LMK-Domain, dx=2.8 km, 50 layers, dt=16 sec.
- Leapfrog-time-integration
- horizontal advection with centered differences 2. order
- diagnostic precipitation scheme with cloud ice (itype_gscp=3)
- prognostic TKE-Vertical diffusion (itype_turb=3, itype_tran=2)
- without convection parametrization
- period: Dez. 2003 - Feb. 2004

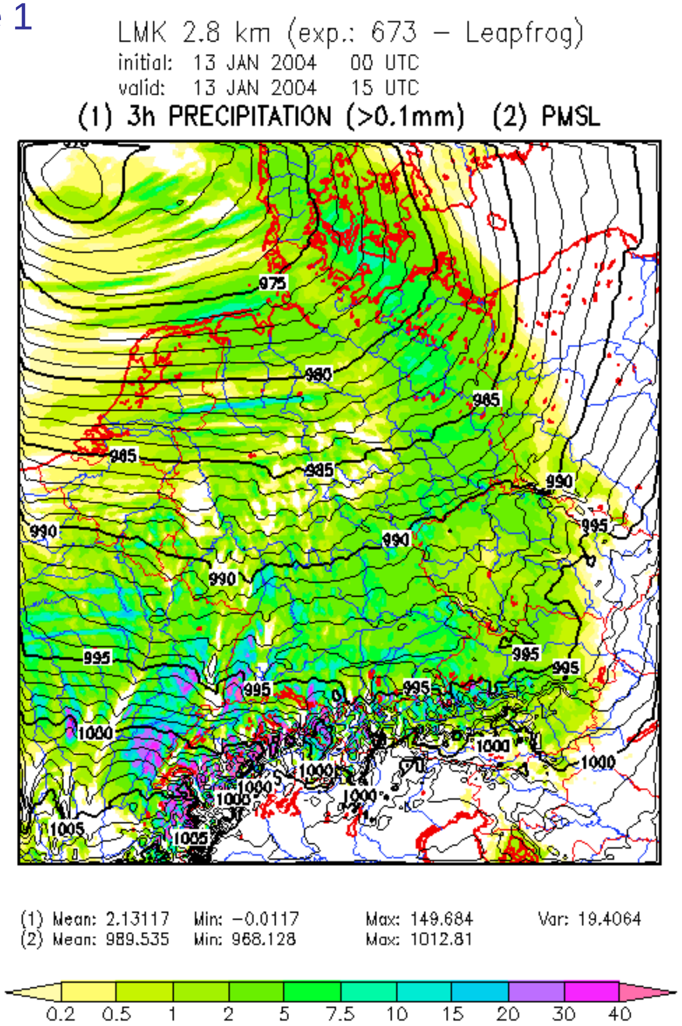
Testsuite 1

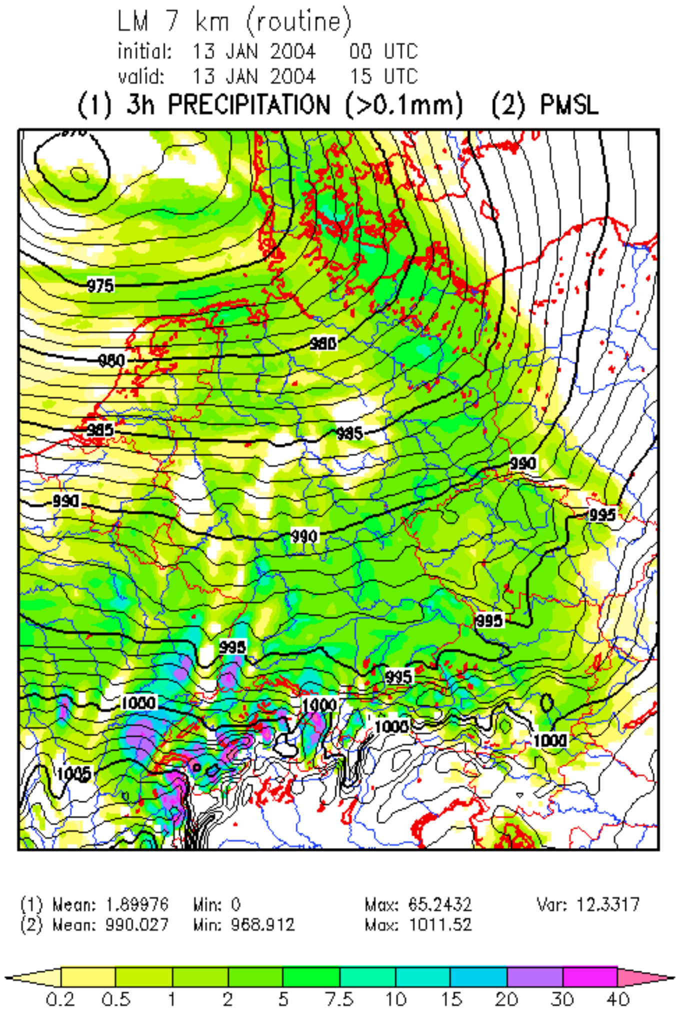


- 2.8 km grid spacing
- 421 x 461 grid points
- 50 layers

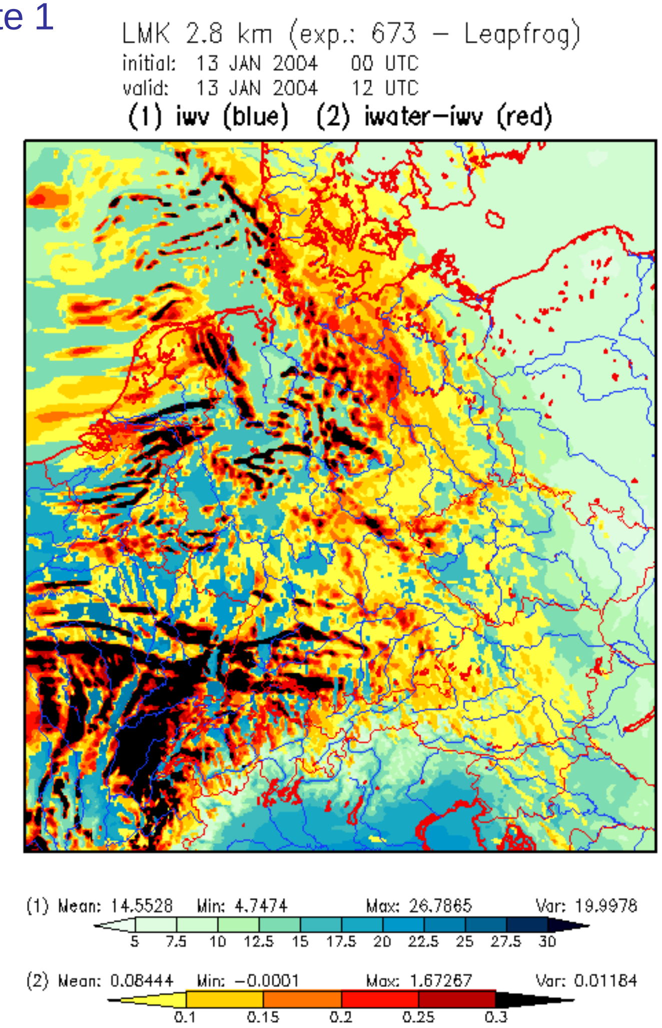
Mode configuration as LM, but:
- convection scheme switched off
- no data assimilation

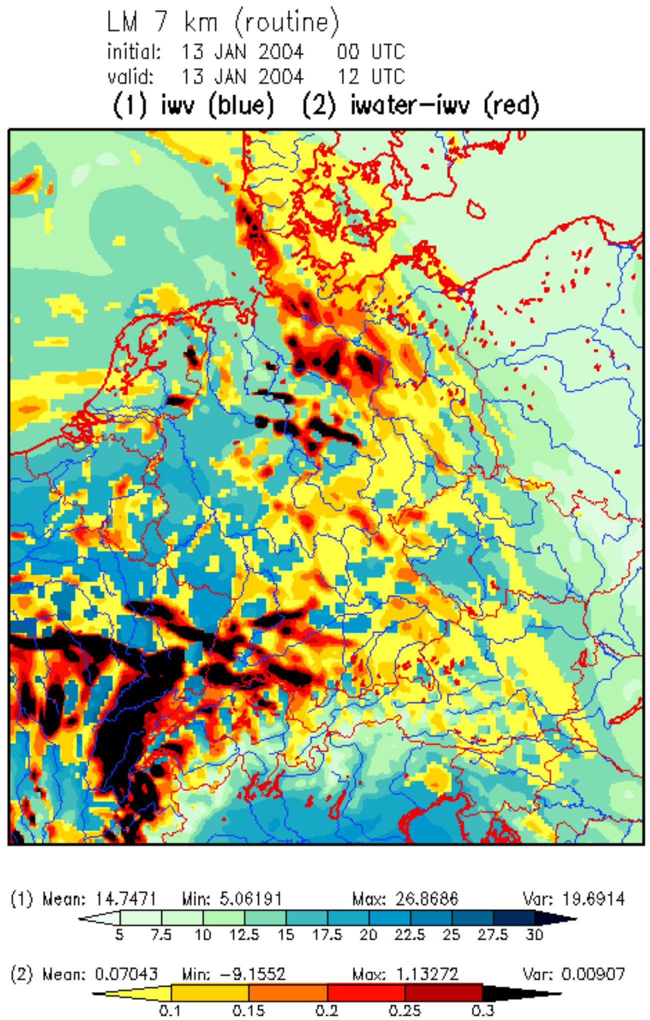
Testsuite 1


LMK 2.8 km (exp.: 673 – Leapfrog)
initial: 13 JAN 2004 00 UTC
valid: 13 JAN 2004 15 UTC
(1) 3h PRECIPITATION (>0.1mm) (2) PMSL
(1) Mean: 2.13117 Min: –0.0117 Max: 149.684 Var: 19.4064
(2) Mean: 989.535 Min: 968.128 Max: 1012.81
0.2 0.5 1 2 5 7.5 10 15 20 30 40

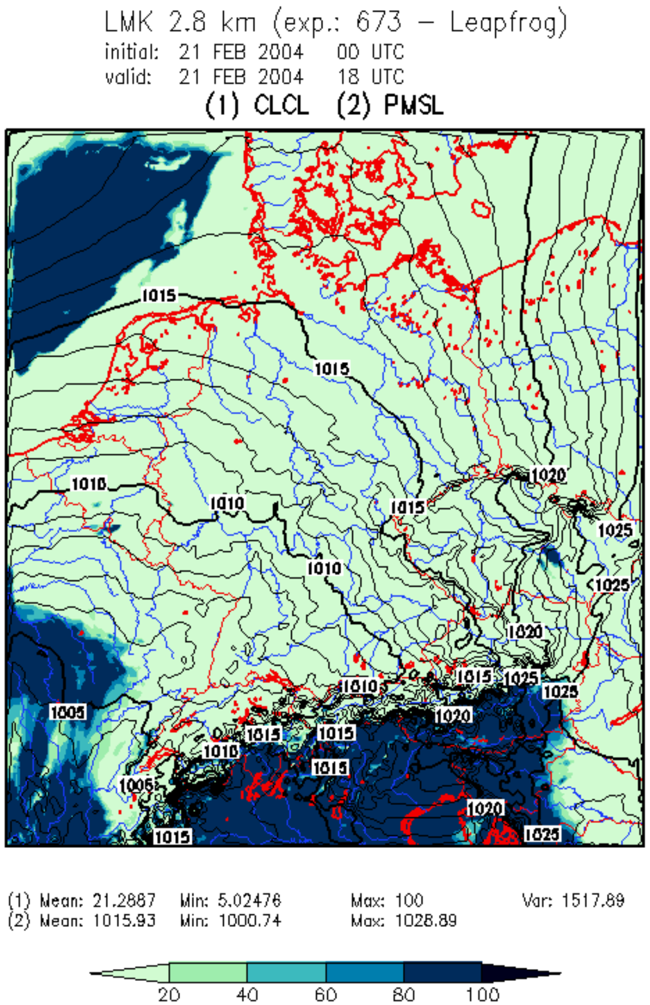

LM 7 km (routine)
initial: 13 JAN 2004 00 UTC
valid: 13 JAN 2004 15 UTC
(1) 3h PRECIPITATION (>0.1mm) (2) PMSL
(1) Mean: 1.89976 Min: 0 Max: 65.2432 Var: 12.3317
(2) Mean: 990.027 Min: 968.912 Max: 1011.52
0.2 0.5 1 2 5 7.5 10 15 20 30 40

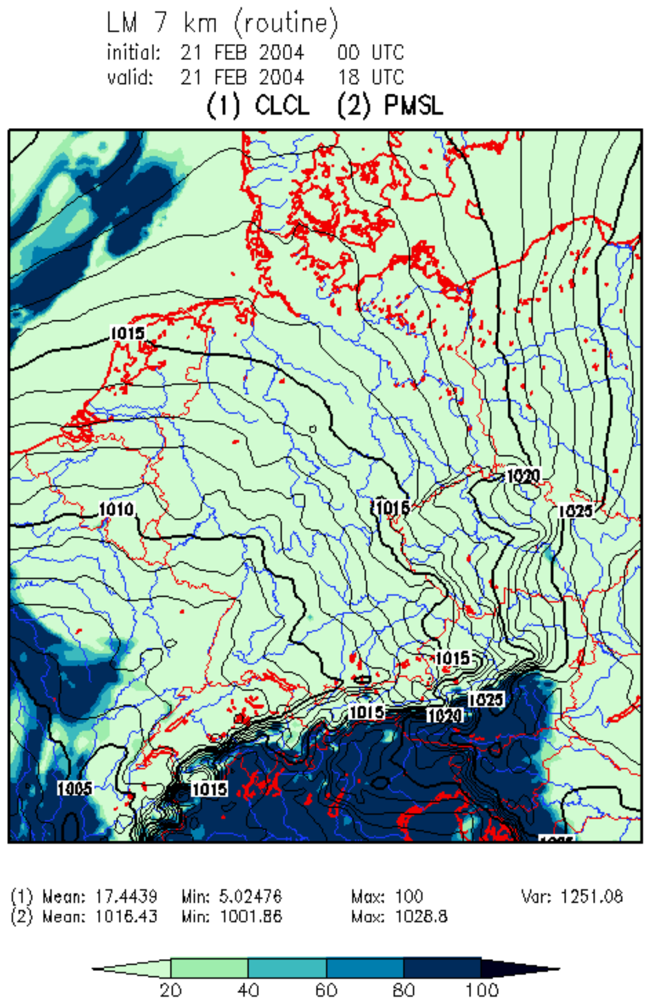
Testsuite 1


LMK 2.8 km (exp.: 673 – Leapfrog)
initial: 13 JAN 2004 00 UTC
valid: 13 JAN 2004 12 UTC
(1) iwv (blue) (2) iwater-iwv (red)
(1) Mean: 14.5528 Min: 4.7474 Max: 26.7865 Var: 19.9978
5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30
(2) Mean: 0.08444 Min: -0.0001 Max: 1.67267 Var: 0.01184
0.1 0.15 0.2 0.25 0.3

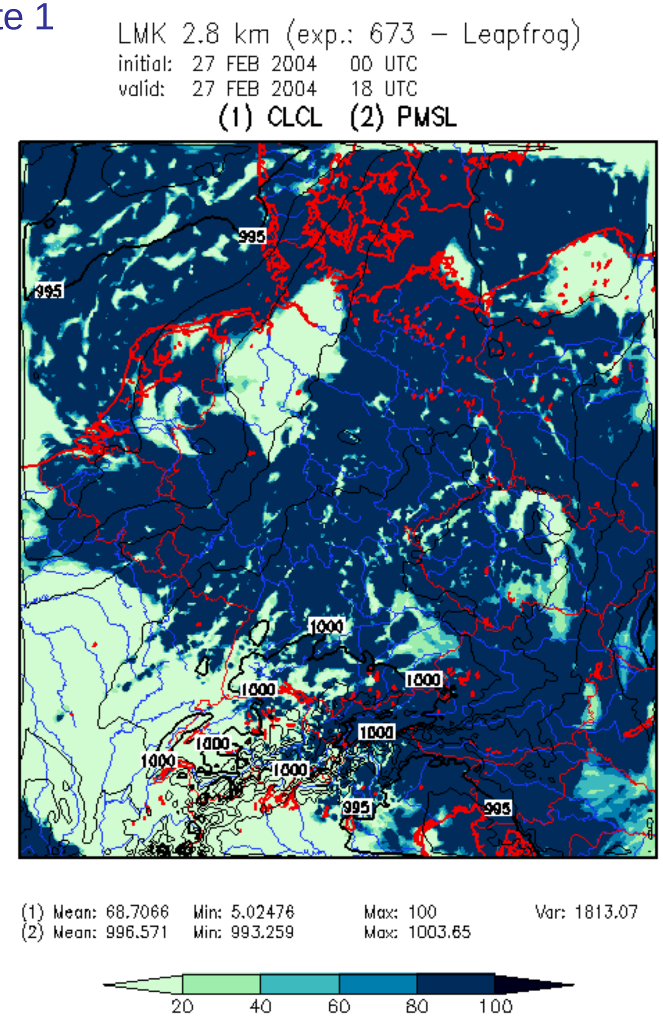

LM 7 km (routine)
initial: 13 JAN 2004 00 UTC
valid: 13 JAN 2004 12 UTC
(1) iwv (blue) (2) iwater-iwv (red)
(1) Mean: 14.7471 Min: 5.06191 Max: 26.8686 Var: 19.6914
5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30
(2) Mean: 0.07043 Min: -9.1552 Max: 1.13272 Var: 0.00907
0.1 0.15 0.2 0.25 0.3

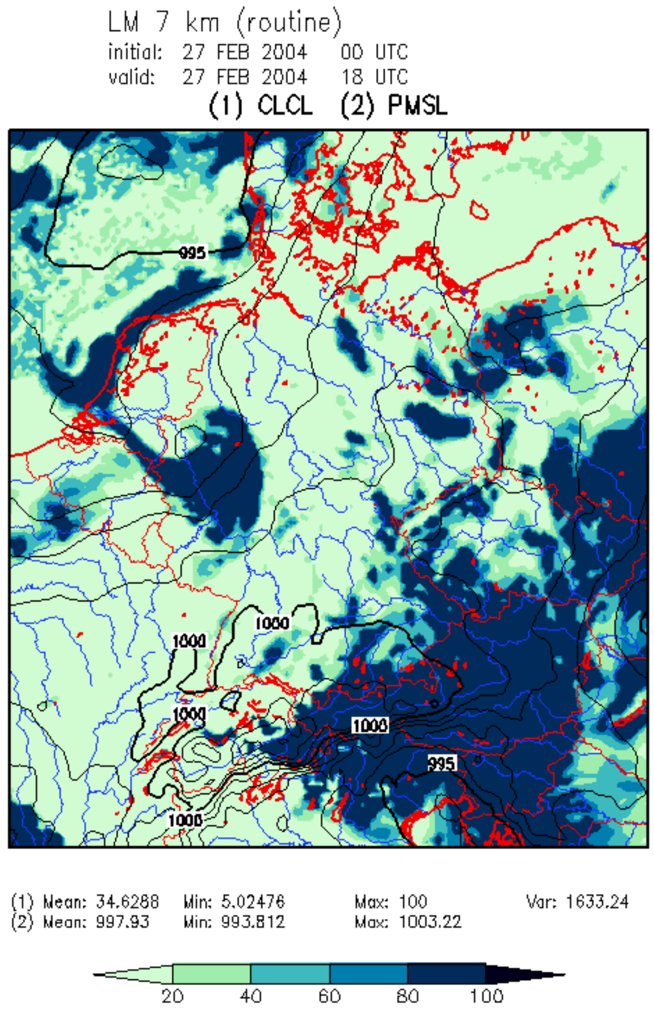
Testsuite 1


LMK 2.8 km (exp.: 673 – Leapfrog)
initial: 21 FEB 2004 00 UTC
valid: 21 FEB 2004 18 UTC
(1) CLCL (2) PMSL
(1) Mean: 21.2887 Min: 5.02476 Max: 100 Var: 1517.89
(2) Mean: 1015.93 Min: 1000.74 Max: 1028.89
20 40 60 80 100


LM 7 km (routine)
initial: 21 FEB 2004 00 UTC
valid: 21 FEB 2004 18 UTC
(1) CLCL (2) PMSL
(1) Mean: 17.4439 Min: 5.02476 Max: 100 Var: 1251.08
(2) Mean: 1016.43 Min: 1001.86 Max: 1028.8
20 40 60 80 100

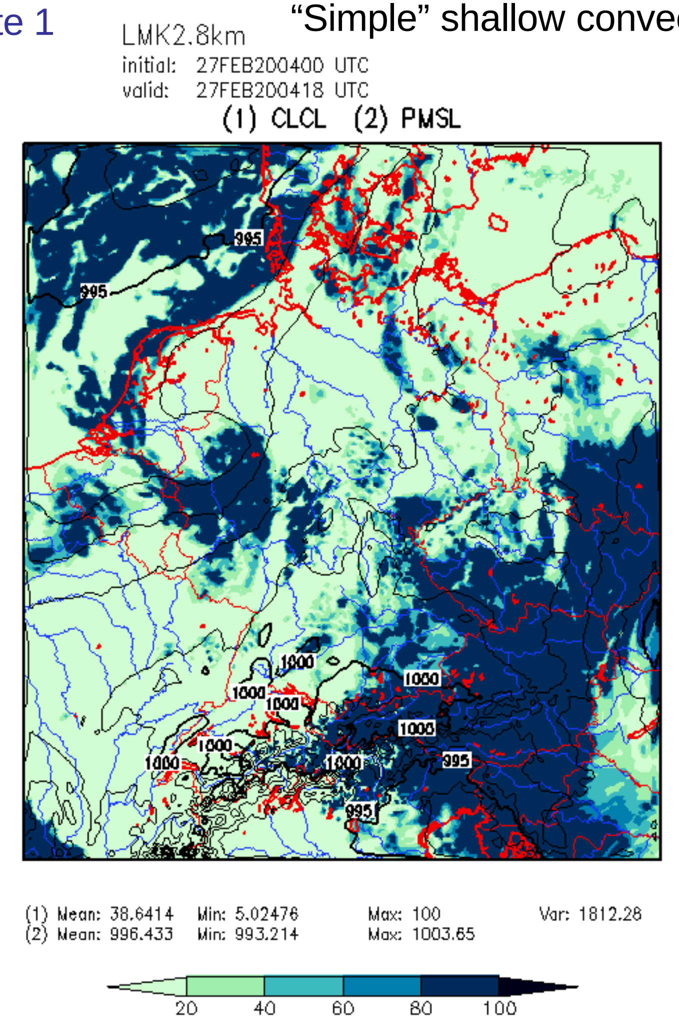
Testsuite 1

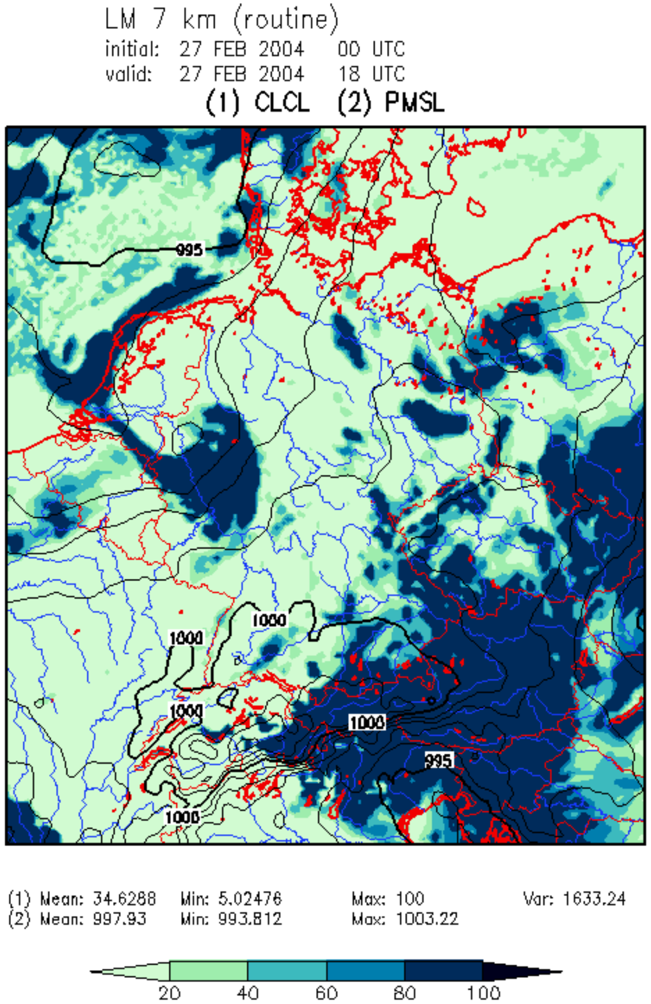

LMK 2.8 km (exp.: 673 – Leapfrog)
initial: 27 FEB 2004 00 UTC
valid: 27 FEB 2004 18 UTC
(1) CLCL (2) PMSL
995
1000
(1) Mean: 68.7066 Min: 5.02476 Max: 100 Var: 1813.07
(2) Mean: 996.571 Min: 993.259 Max: 1003.65
20 40 60 80 100


LM 7 km (routine)
initial: 27 FEB 2004 00 UTC
valid: 27 FEB 2004 18 UTC
(1) CLCL (2) PMSL
995
1000
(1) Mean: 34.6288 Min: 5.02476 Max: 100 Var: 1633.24
(2) Mean: 997.93 Min: 993.812 Max: 1003.22
20 40 60 80 100

Testsuite 1

“Simple” shallow convection



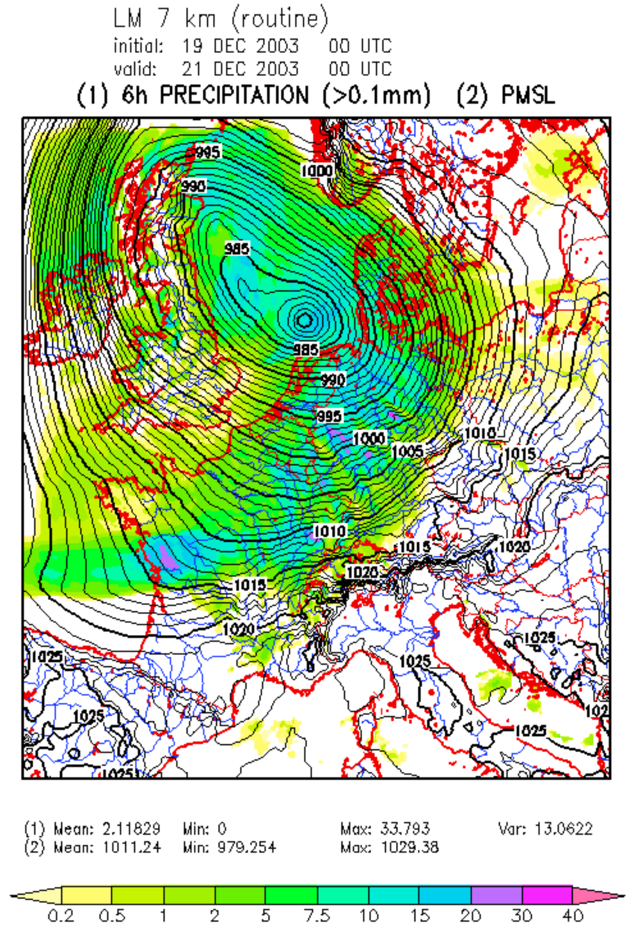


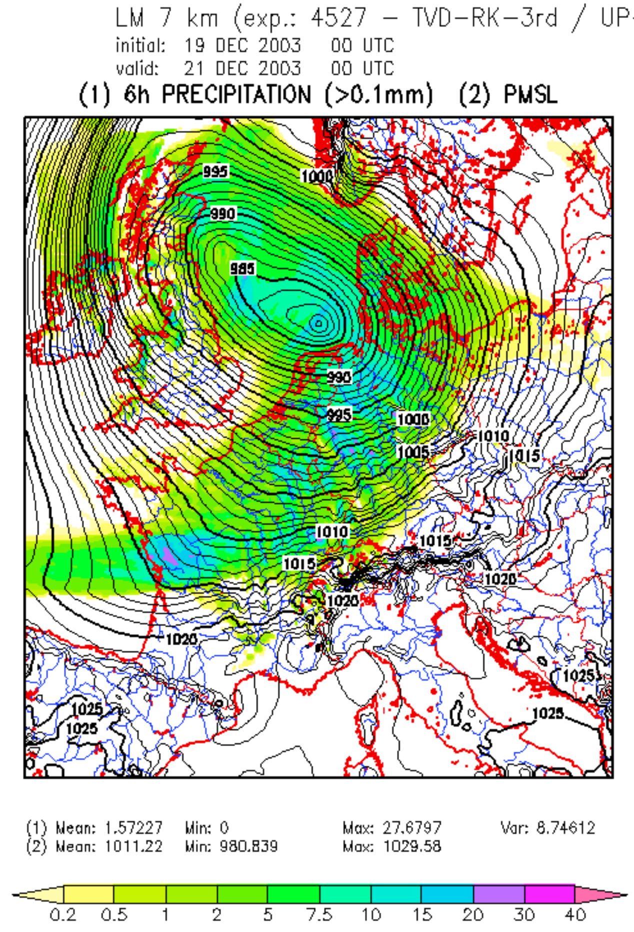
Testsuite 2

- LM-Domain, dx=7km, 35 layers
- RK3-TVD time integration, 5th-order advection, dt=72 sec
- new metrics
- diagnostic turbulence
- GME initial conditions
- period: Dez. 2003

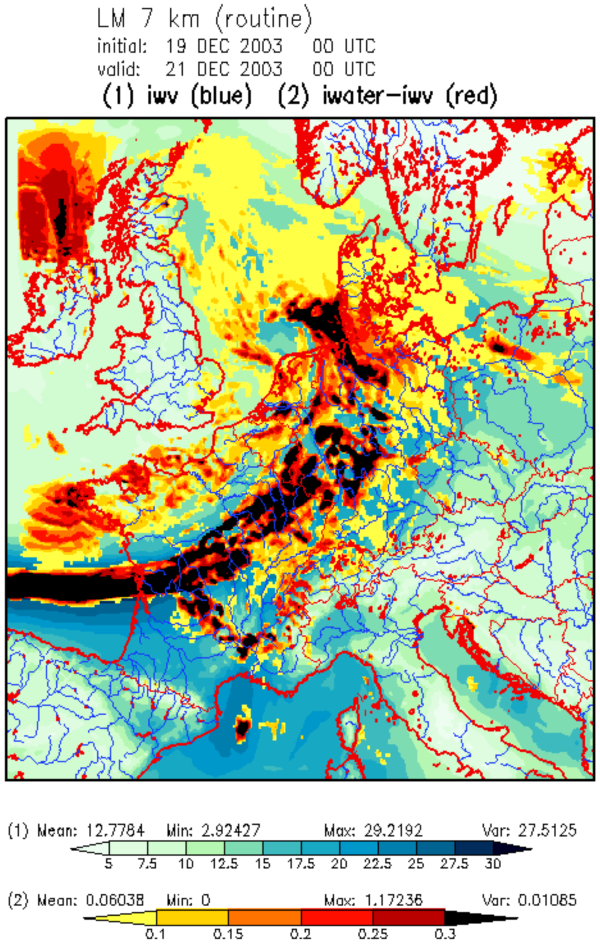
Goals:
- test of the new dynamic core

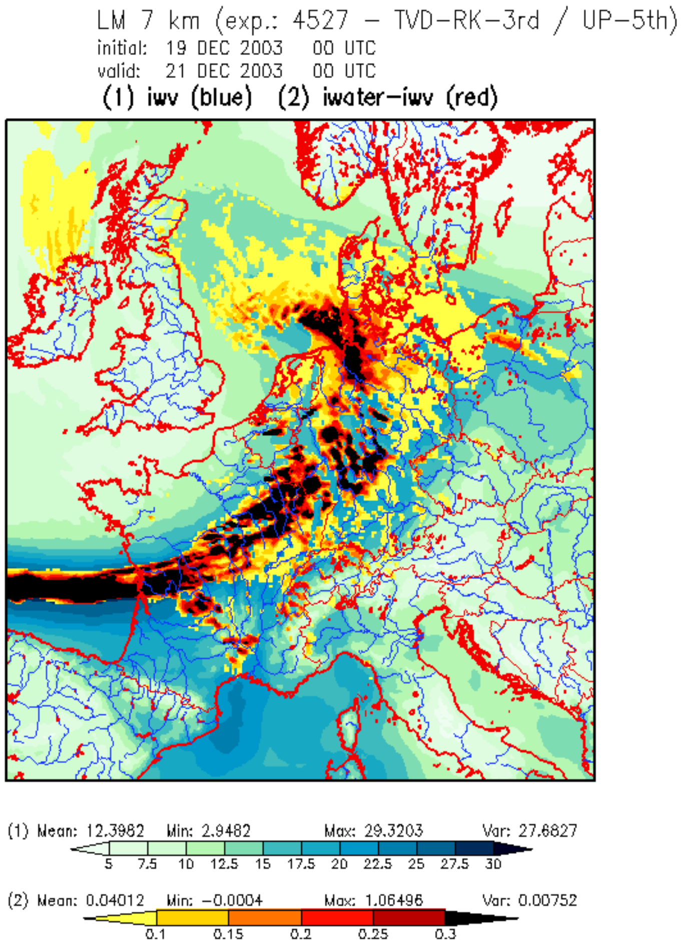
Testsuite 2: LM Routine <--> LM RK3-TVD (19. Dec 2003 +48h)





Testsuite 2: LM Routine <--> LM RK3-TVD (19. Dec 2003 +48h)

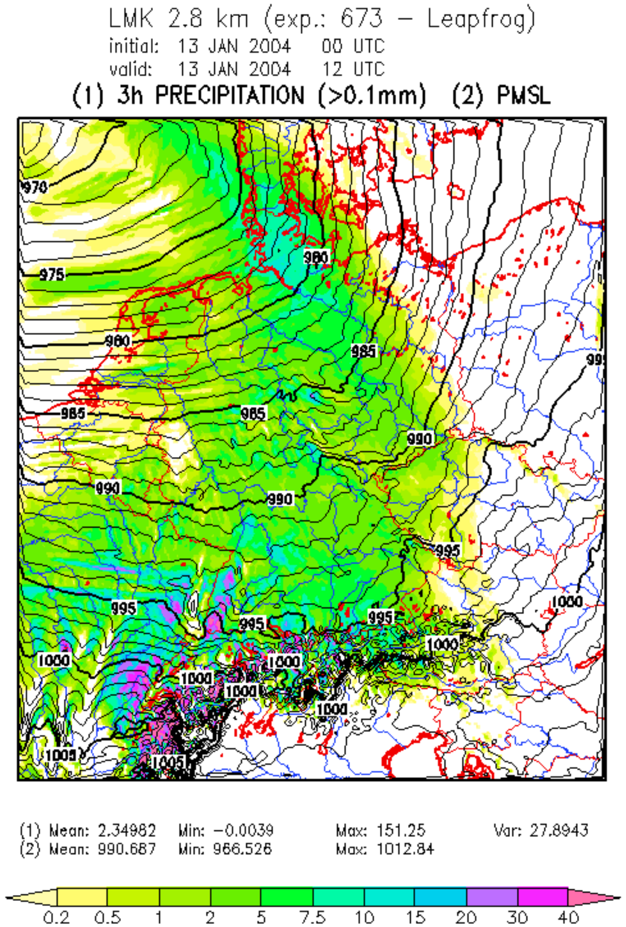


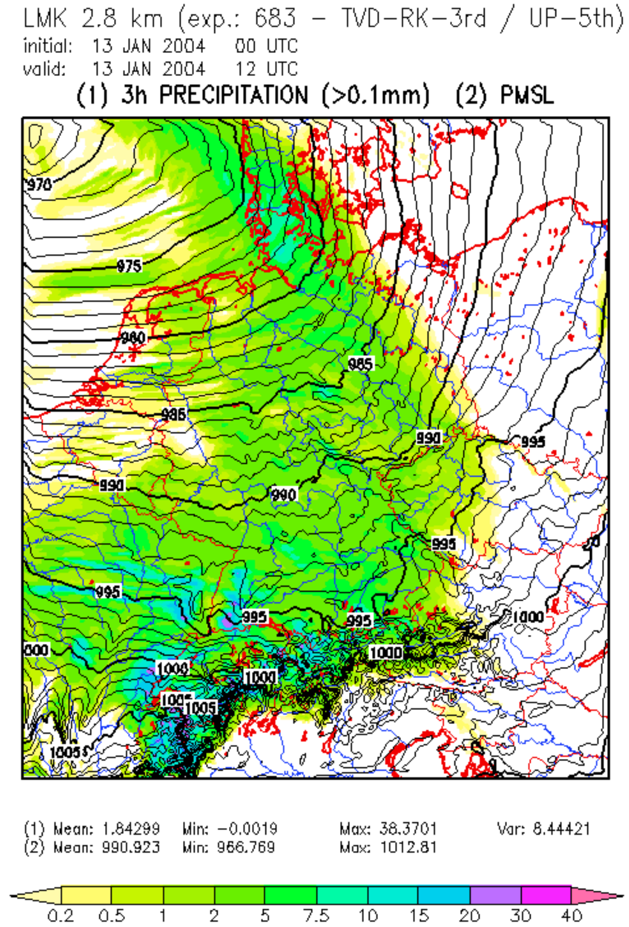


Testsuite 3

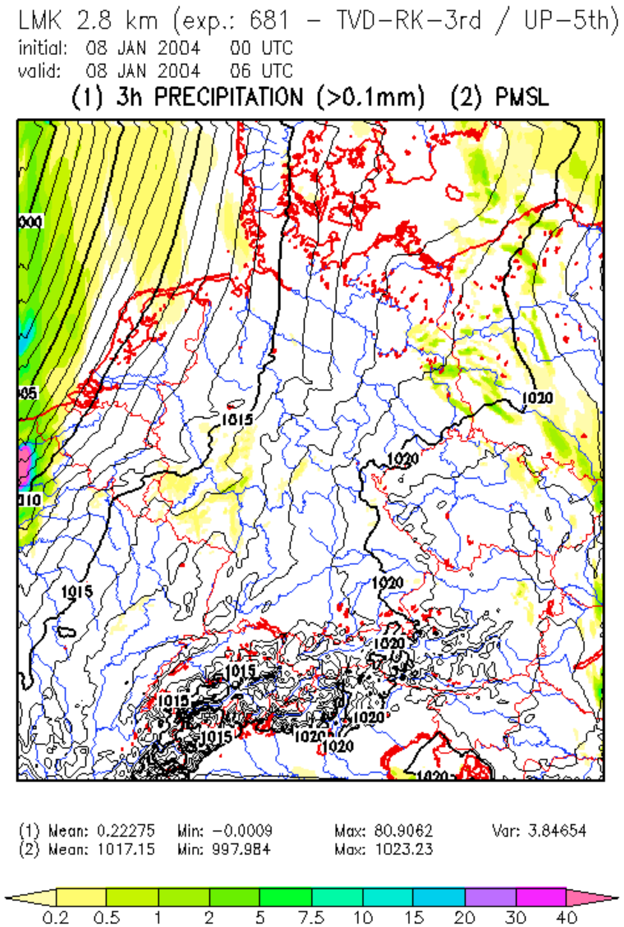
- LMK-Domain, dx=2.8 km, 50 layers
- RK3-TVD time integration, 5th-order advection, dt=30 sec
- new metrics
- with prognostic precipitation (w/o. LBC for rain + snow)
- with prognostic TKE turbulence
- synthetic satellite images
- no data assimilation
- period: Jan. 2004

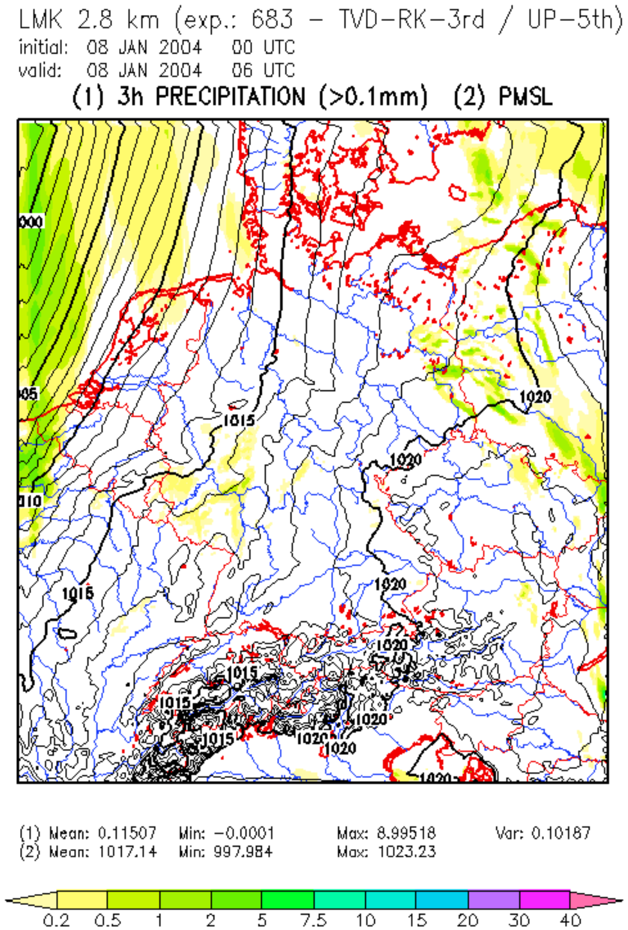
Testsuite 3: Prognostic precipitation + RK3-TVD





Testsuite 3: Lateral Boundary conditions for rain and snow

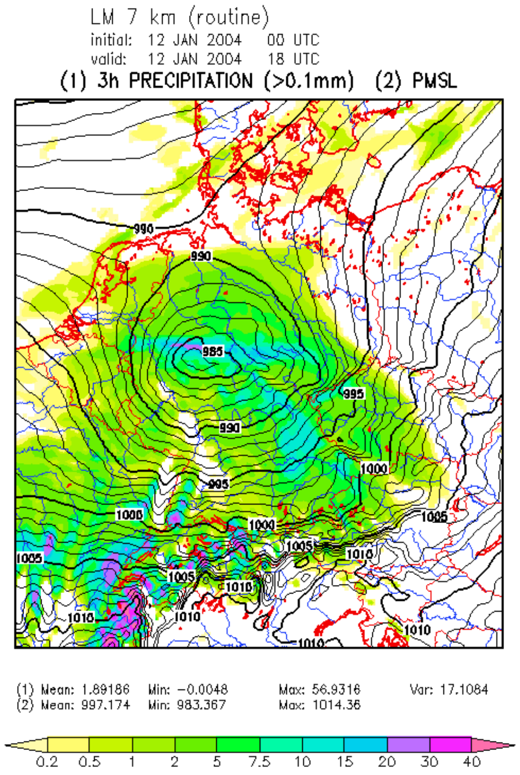


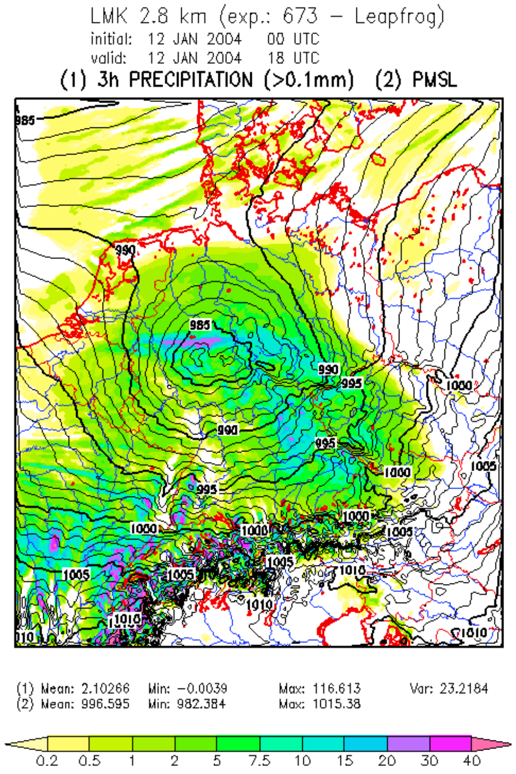


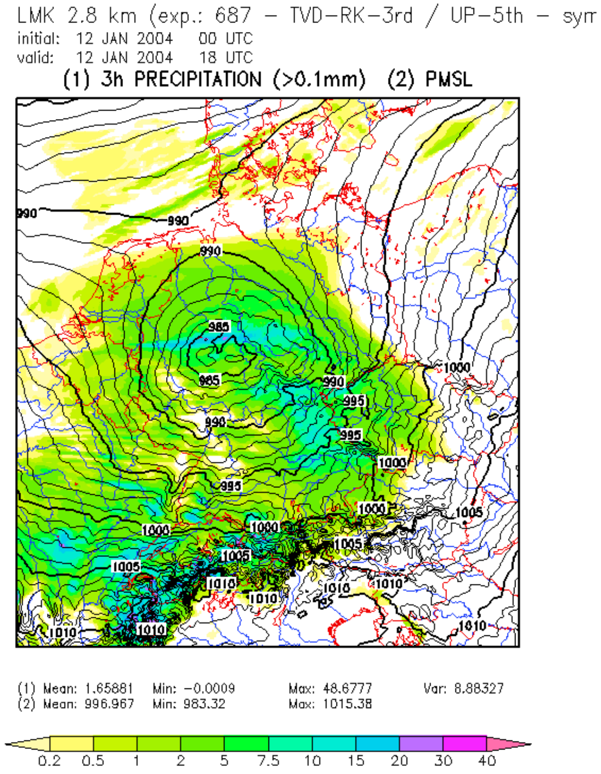
Testsuite 4

- LMK Domain, dx=2.8 km, 50 layers
- RK3-TVD time integration, 5th-order advection, dt=30 sec
- new metrics
- with prognostic precipitation
- with prognostic TKE-turbulence (1-dim. scheme)
- synthetic satellite images
- ‘symmetric thermodynamics’
- smooth boundary relaxation zone
- period: Jan. 2004

Testsuite 4: Symmetric thermodynamics and smooth boundaries







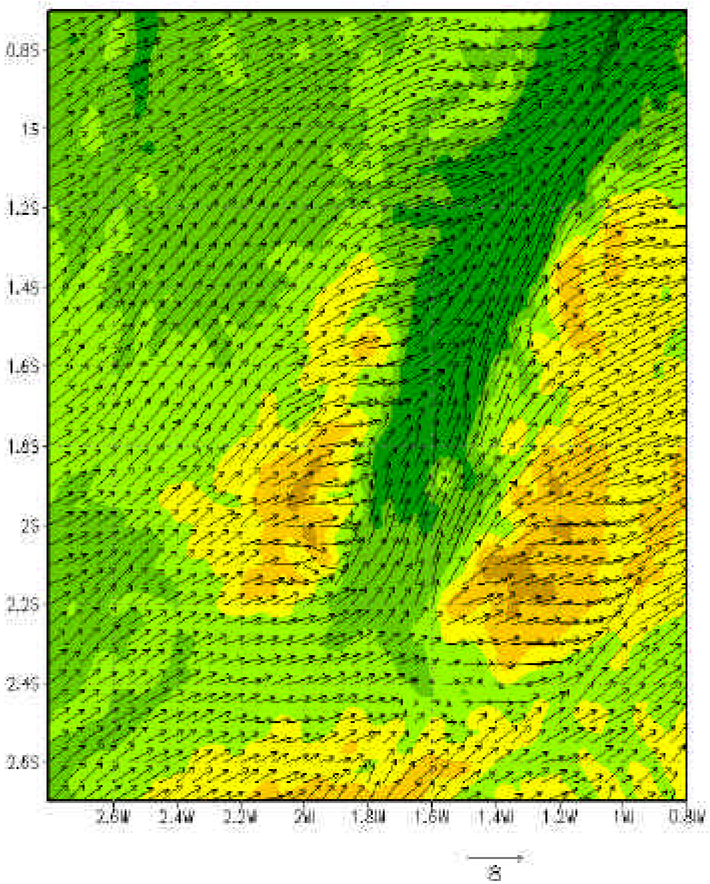
Testsuite 5

- LMK Domain, dx=2.8 km, 50 layers
- RK3-TVD time integration, 5th-order advection, dt=30 sec
- new metrics
- with prognostic precipitation
- with prognostic TKE-turbulence (1-dim. scheme)
- synthetic satellite images
- 'non-symmetric thermodynamics'
- period: May-July 2004

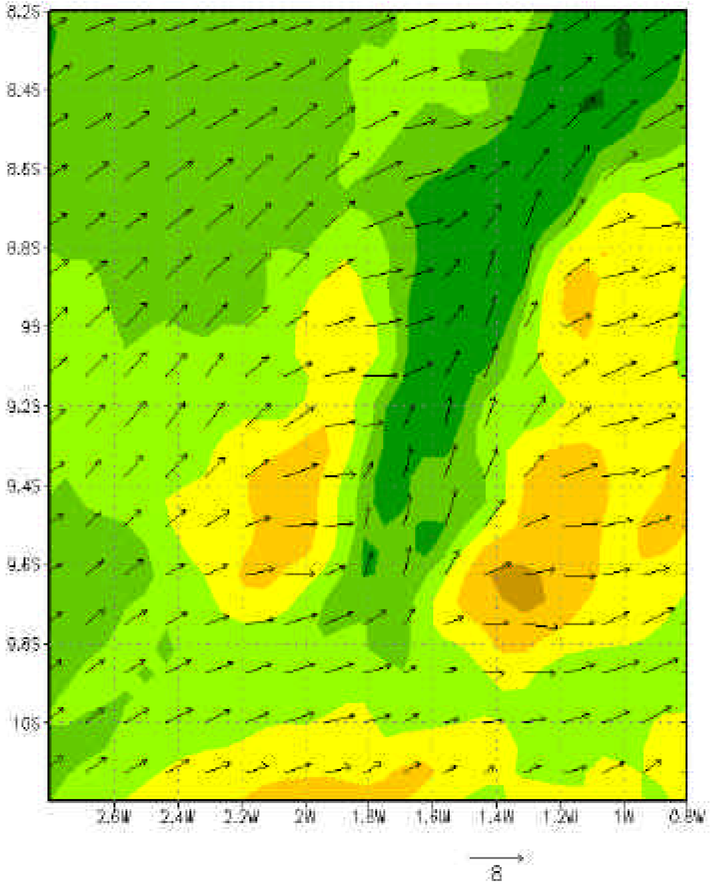
Testsuite 5: channeling in rhine valley (7.5.2004, 06 UTC)

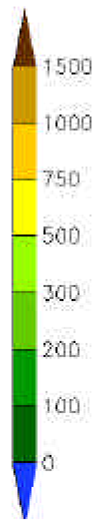
(every 2. wind vector in 10 m above ground)

LMK, dx=2.8 km, RK3+upstream 5. order



LM, dx=7 km, Leapfrog





Further planned tests:

- **Idealized test cases**
  - Linear mountain flow (hydrostatic / non-hydrostatic case)
  - cold bubble (Straka et al., 1993)
  - warm bubble in shear flow (Weisman, Klemp, 1982)

- **test cases especially for turbulence**
  - roughness jump
  - tilted plane
  - checkerboard heating

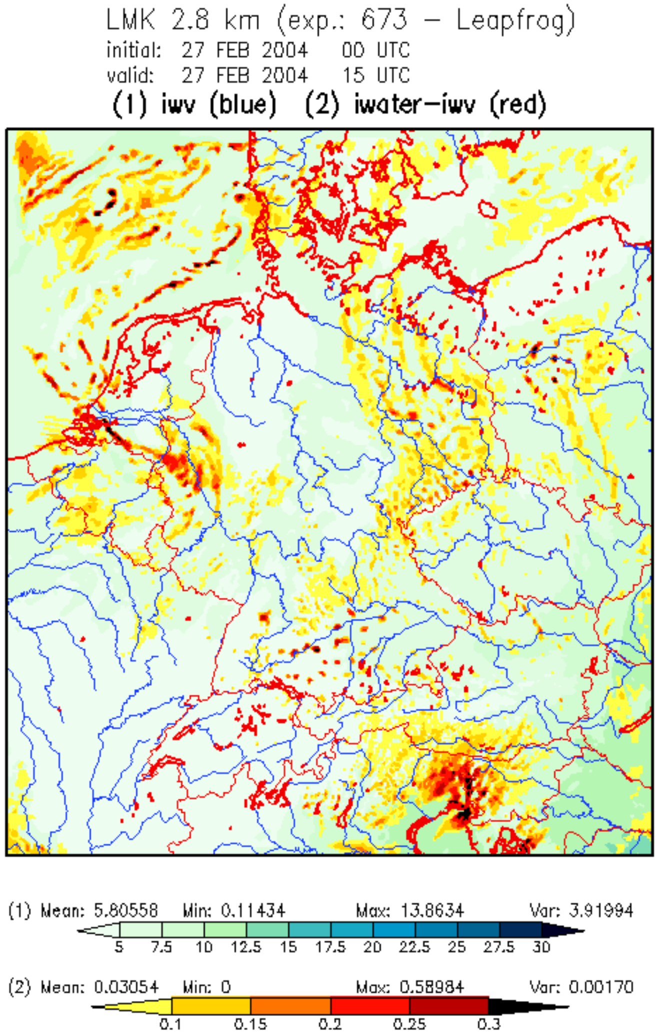
- **test cases especially for cloud physics scheme**
  - IMPROVE-2

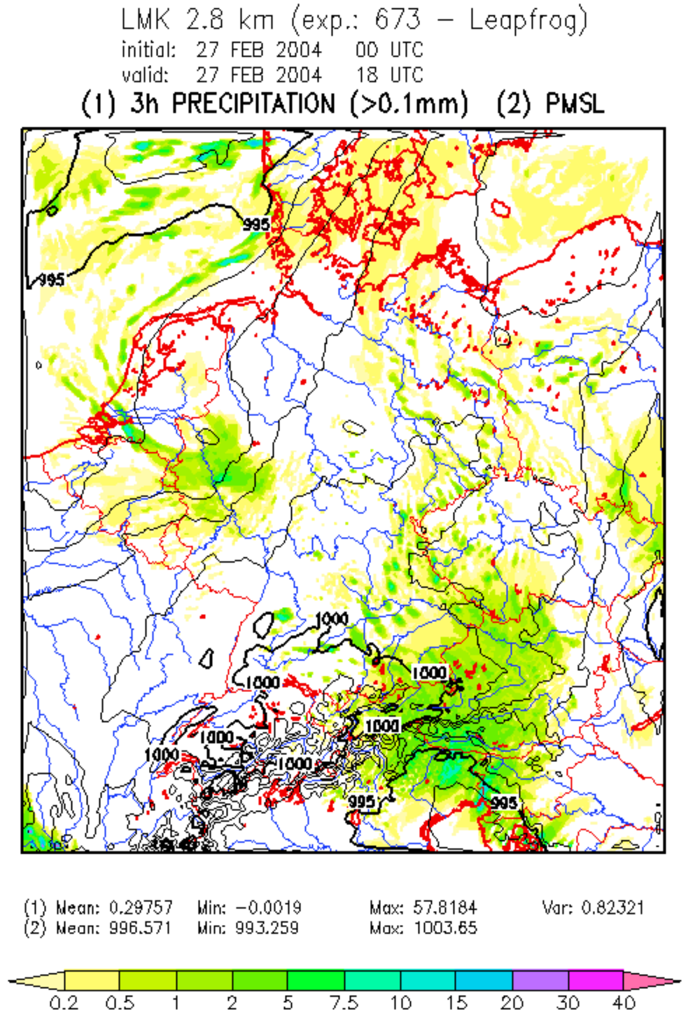
Project LMK: Milestones

- End 2003:
  First test-suite with LM at high resolution is running.
- Autumn 2004:
  Prototype version of the LMK-System with data assimilation but without LHN running.
- Summer 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 .

Final Remarks and Outlook

- Preliminary test of LM at 2.8km grid-spacing (operational set-up, convection switched off) from Dec 2003 - Feb 2004
  - stable and robust
  - deficiencies from explicit convection -> shallow convection needed
  - sometimes convective structures verify subjectively, sometimes not
  - pressure discontinuity at lateral boundaries is solved now
  - spin-up of about 1 h (also at lateral boundaries)
- Re-run of the testsuite for the same starting from Jan 2004 using
  - RK3-TVD time-split integration with 5th order horizontal advection (no horizontal diffusion required)
  - full budget equations for rain and snow (prognostic precipitation)
  - SLEVE (smooth level vertical) coordinate
- Upgrade with new physics / dynamics and data assimilation
- Deterministic and probabilistic products
- Many open questions concerning skill and predictability


LMK 2.8 km (exp.: 673 – Leapfrog)
initial: 27 FEB 2004 00 UTC
valid: 27 FEB 2004 15 UTC
(1) iwv (blue) (2) iwater–iwv (red)
(1) Mean: 5.80558 Min: 0.11434 Max: 13.8634 Var: 3.91994
5 7.5 10 12.5 15 17.5 20 22.5 25 27.5 30
(2) Mean: 0.03054 Min: 0 Max: 0.58984 Var: 0.00170
0.1 0.15 0.2 0.25 0.3


LMK 2.8 km (exp.: 673 – Leapfrog)
initial: 27 FEB 2004 00 UTC
valid: 27 FEB 2004 18 UTC
(1) 3h PRECIPITATION (>0.1mm) (2) PMSL
(1) Mean: 0.29757 Min: –0.0019 Max: 57.8184 Var: 0.82321
(2) Mean: 996.571 Min: 993.259 Max: 1003.65
0.2 0.5 1 2 5 7.5 10 15 20 30 40