A first Case Study of 3-Dimensional Turbulence with full Metrics in the Very Short Range Forecast Model LMK

LM-User Seminar, Langen, 07.03.2006

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LMK - (LM-Kürzestfrist)

Goal: NWP-system for very short range forecasts on the meso-γ scale

- better representation of deep moist convection
- fine scale topography

Development areas:

- Assimilation of radar data by Latent Heat Nudging (LHN)

→ lecture Klink, Stephan, Schraff

- Quality-controlled radar data (DXQ)
- LM improvements and adaptations
  - Numerical schemes
  - Physical parameterisations

→ lecture Förstner, Baldauf, Seifert

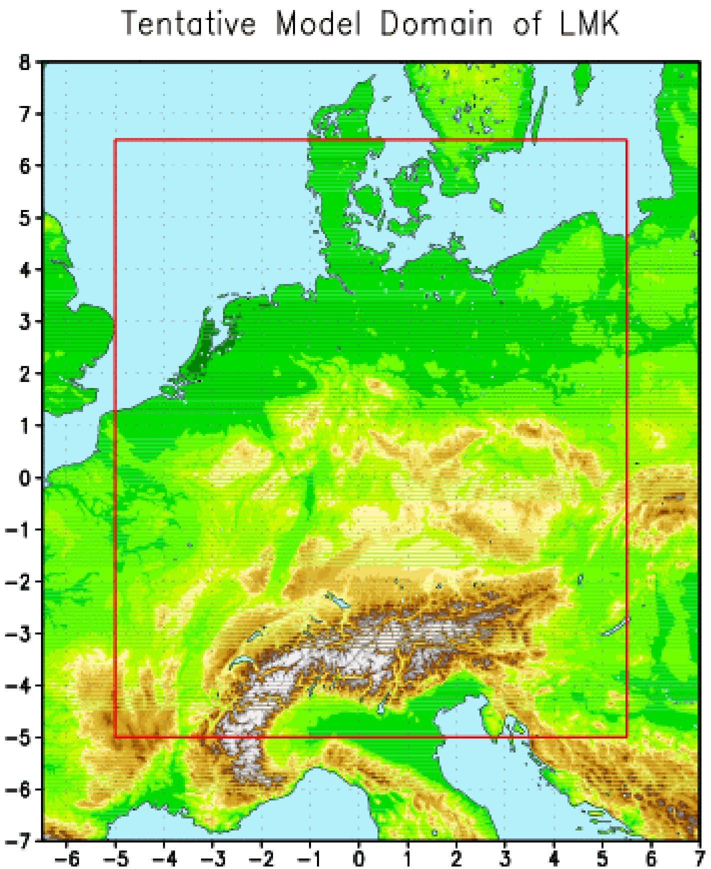
→ lecture Baldauf (Adv. Num. Sem.)

- Verification
  - traditional Synop, Temp-Verif.
  - by radar and satellite data

LMK-Configuration

- grid length: Δx = 2.8 km
  - direct simulation of the coarser parts of deep convection (!?)
  - interactions with fine scale topography
- timestep ΔT=30 sec.
- 421 x 461 x 50 grid points

  lowest layer in 10 m above ground
- center of the domain 10° E, 50° N
- boundary values from LM / LME (Δx = 7 km)



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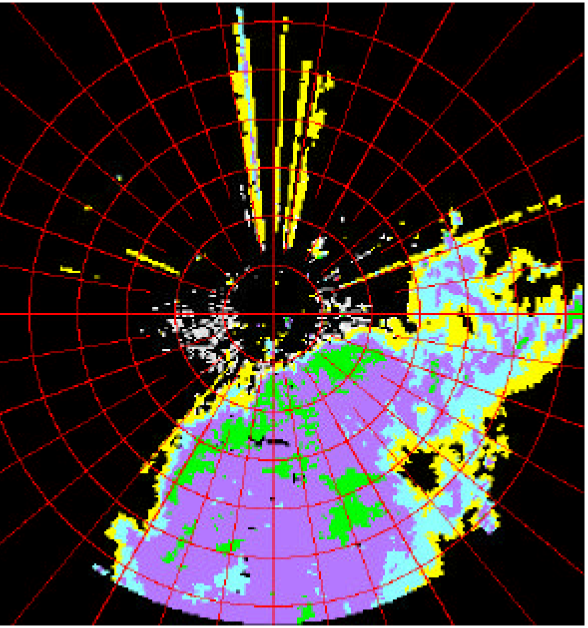
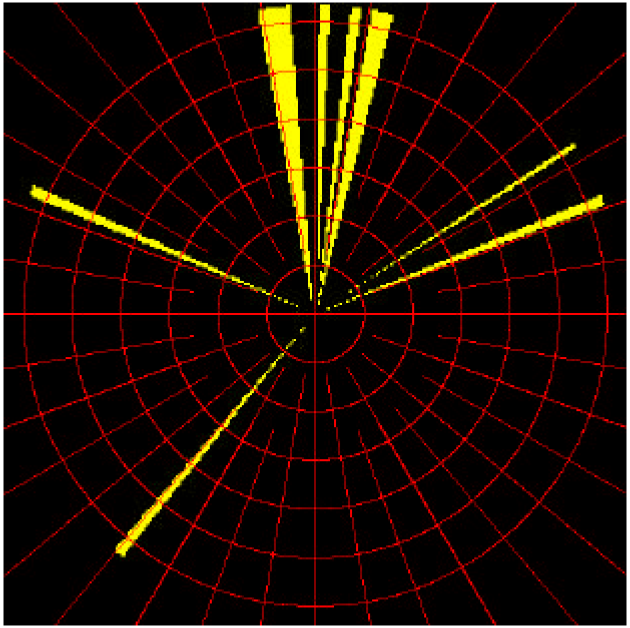
DXQ (example: spoke recognition algorithm)

Berlin 21.06.2005 22:10 UTC

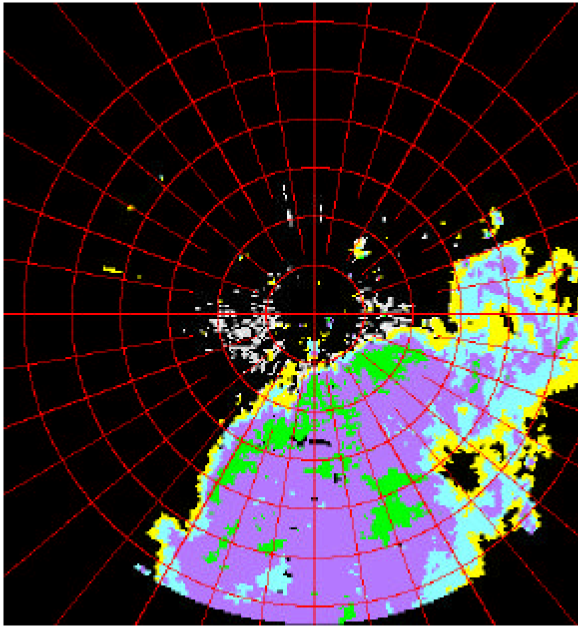
Original



'Pos. 3' of DXQ



nach Speichenerkennung



LHN

K. Helmert, B. Hassler

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  - Physical parameterisations
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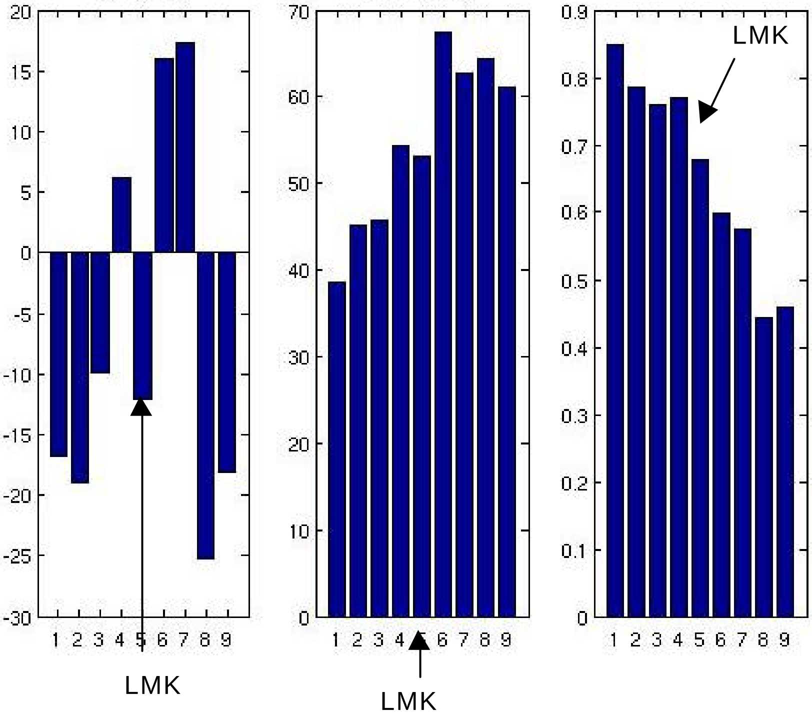
precipitation scores:

Bias (mm) RMSE (mm) Correl. coeff.



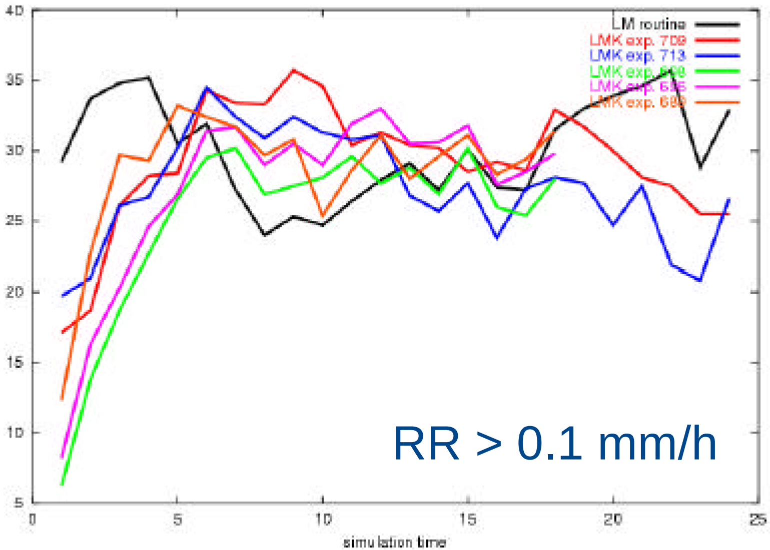
model intercomparison:
MAP IOP 2b
(„19./20.09.1999“)
heaviest RR during MAP
(300mm / 30 h)

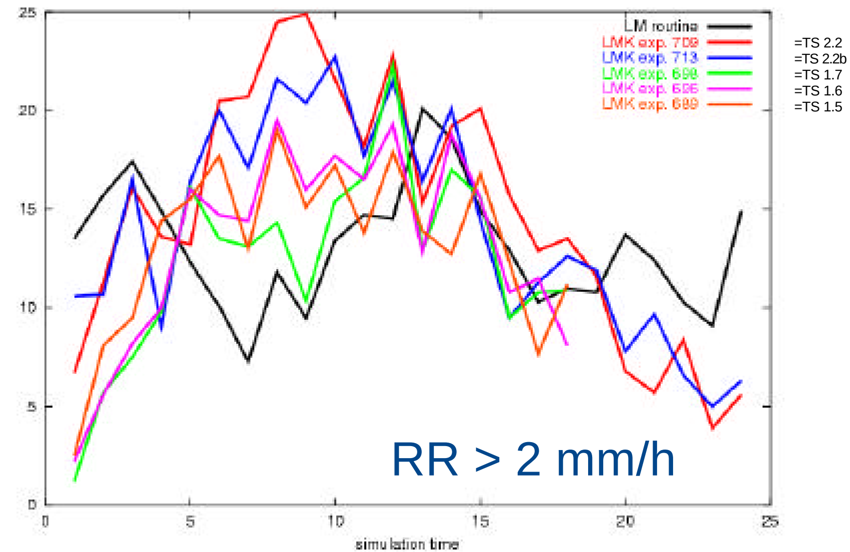
1: MM5
2: WRF
3: MOLOCH
4: Méso-NH
5: LMK
6: Aladin oper. 1999
7: Arpège oper. 1999
8: EZMW oper. 1999
9: EZMW oper. 2002 with MAP-reanalysis

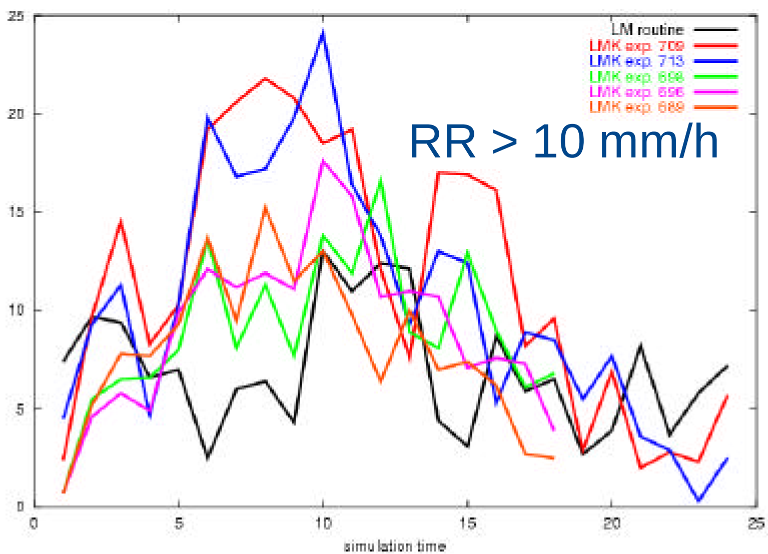
--> LMK performs not bad !:

- bias less than for the most other models
- correlation & RMSE better than for operational forecasts, worse than for (tuned?) science models.

T. Reinhardt







TSS for precipitation

Juli 2004, 12 UTC runs

LMK: averaging to the 9 neighbouring grid points

C.-J. Lenz

Project LMK: time table

- **Summer 2003** Start of the project ‘LMK’
- **End 2003** First Testsuite with 2.8 km resolution
- **End 2004** First Testsuite with data assimilation
- **March 2006:** Prototype-Version of LMK-Systems with LHN ‘Summer 2005’ (Testsuiten 3.x).
- **March 2006:** DXQ-Komposit operational
- **Mai 2006:** Start of the pre-operational test phase
- **June 2006** installation of an ‘introduction group’
  coordination of evaluation tasks (FE 15, AG Evaluierung)
- **End 2006:** planned start of operational application

3D turbulence in LMK

LES-3D-turbulence model from LLM (Litfass-LM),
Herzog et al. (2003) COSMO Techn. rep. 4
implementation into LMK: J. Förstner

extension for orography -->

coordinate transformation

scalar flux divergence

$$\frac{\partial s}{\partial t} = -\nabla_j H^j = -\frac{\partial}{\partial x^j} H^j - \Gamma^j_{jk} H^k$$

vectorial flux divergence

$$\frac{\partial v^i}{\partial t} = -\frac{1}{\rho} \nabla_j T^{ij} = -\frac{1}{\rho} \left(\frac{\partial}{\partial x^j} T^{ij} + \Gamma^i_{jk} T^{kj} + \Gamma^j_{jk} T^{ik} \right)$$

-> a problem in LM-documentation exists

Metric terms of 3D-turbulence

LES-3D-turbulence model from 'Litfass-LM'
Herzog et al. (2003) COSMO Techn. rep. 4

scalar flux divergence:

terrain following coordinates — vertical

$$\frac{\partial s}{\partial t} = -\frac{1}{r\cos\phi}\frac{\partial H^{*1}}{\partial \lambda} - \frac{J_\lambda}{\sqrt{G}}\frac{1}{r\cos\phi}\frac{\partial H^{*1}}{\partial \zeta} - \frac{1}{r}\frac{\partial H^{*2}}{\partial \phi} - \frac{J_\phi}{\sqrt{G}}\frac{1}{r}\frac{\partial H^{*2}}{\partial \zeta} + \frac{1}{\sqrt{G}}\frac{\partial H^{*3}}{\partial \zeta}$$
$$-\frac{2}{r}H^{*3} + \frac{\tan\phi}{r}H^{*2}.$$

horizontal (cartesian)

earth curvature

scalar fluxes:

$$H^{*1} = -\rho K_s \frac{1}{r\cos\phi}\left(\frac{\partial s}{\partial \lambda} + \frac{J_\lambda}{\sqrt{G}}\frac{\partial s}{\partial \zeta}\right),$$
$$H^{*2} = -\rho K_s \frac{1}{r}\left(\frac{\partial s}{\partial \phi} + \frac{J_\phi}{\sqrt{G}}\frac{\partial s}{\partial \zeta}\right),$$
$$H^{*3} = +\rho K_s \frac{1}{\sqrt{G}}\frac{\partial s}{\partial \zeta},$$

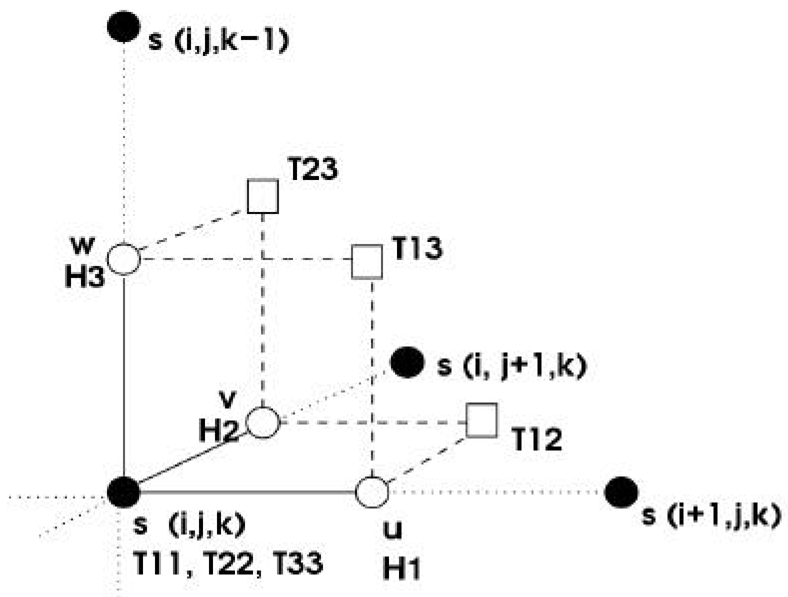
analogous:
‚vectorial' diffusion of *u*, *v*, *w*

Baldauf (2005), COSMO-Newsl. Nr. 5

Implementation, Numerics

- all metric terms are handled explicitly ->
  implemented in Subr. `explicit_horizontal_diffusion`
- new PHYCTL-namelist-parameter `l3dturb_metr`
- available with LM 3.18

Positions of turbulent fluxes in staggered grid:



Test of diffusion routines:
3-dim. isotropic gaussian tracer distribution

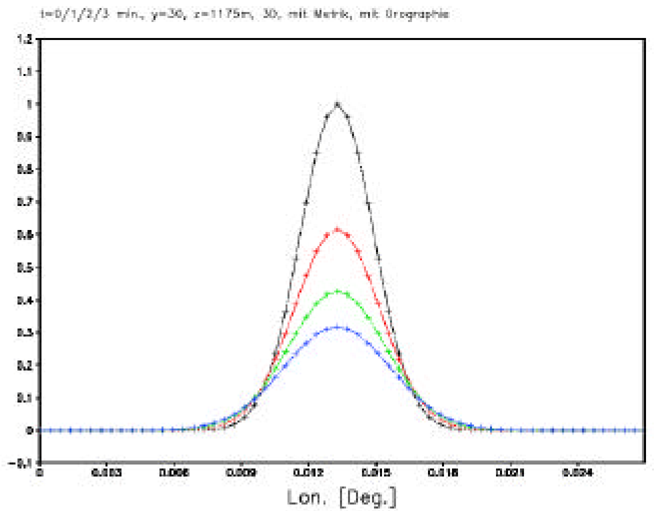
3D diffusion equation:

$$\frac{\partial \phi}{\partial t} = K \Delta \phi$$

analytic Gaussian solution for K=const.:

$$\phi(r,t) = \frac{\Phi_0}{\sqrt{4\pi K (t+t_0)^3}} \exp\left(-\frac{r^2}{4K(t+t_0)}\right),$$

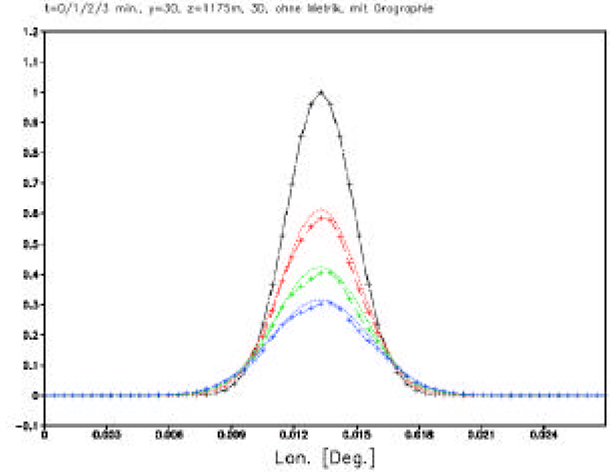
$$r := \sqrt{x^2+y^2+z^2}$$

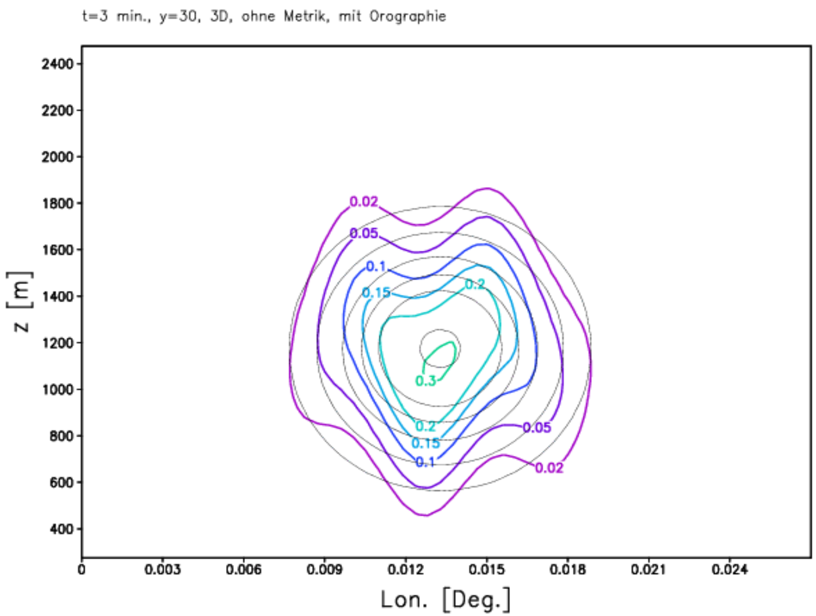


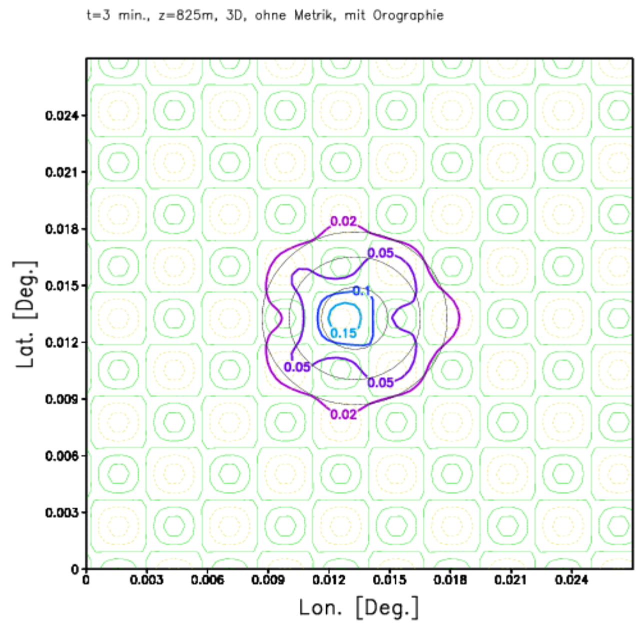
Case 3: 3D-diffusion, without metric terms, with orography

nearly isotropic grid

goal: show false diffusion in the presence of orography



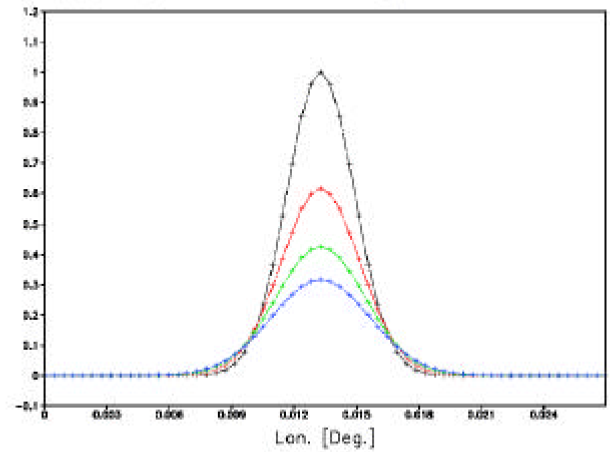


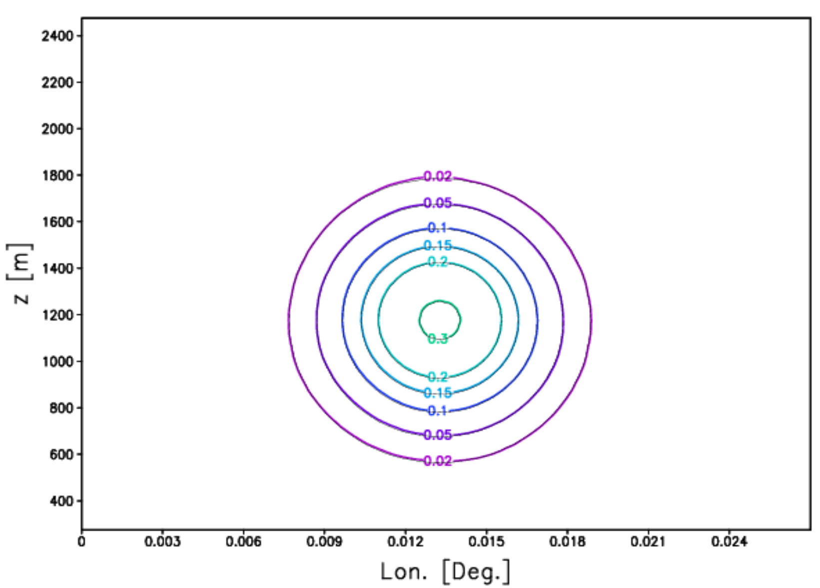


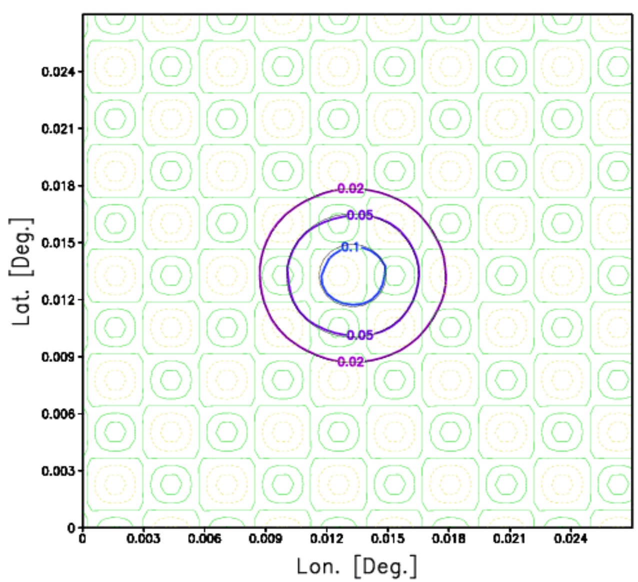
Case 4: 3D-diffusion, with metric terms,
with orography

nearly isotropic grid

goal: show correct implementation of the new metric terms







Are horizontal turbulent fluxes important for LMK 2.8 km?

sensitivity study: LMK (2.8 km resolution) ‚12.08.2004, 12 UTC-run‘

- LM 3.16 (with extensions)
- 3-dim turbulence: `l3dturb= F / T`
- complete metrics: `l3dturb_metr= F / T`
- prognostic TKE (without advection) `itype_turb=3`
- `imode_turb=1`
- `ninctura=1`
- `itype_tran=2`, `imode_tran=1`

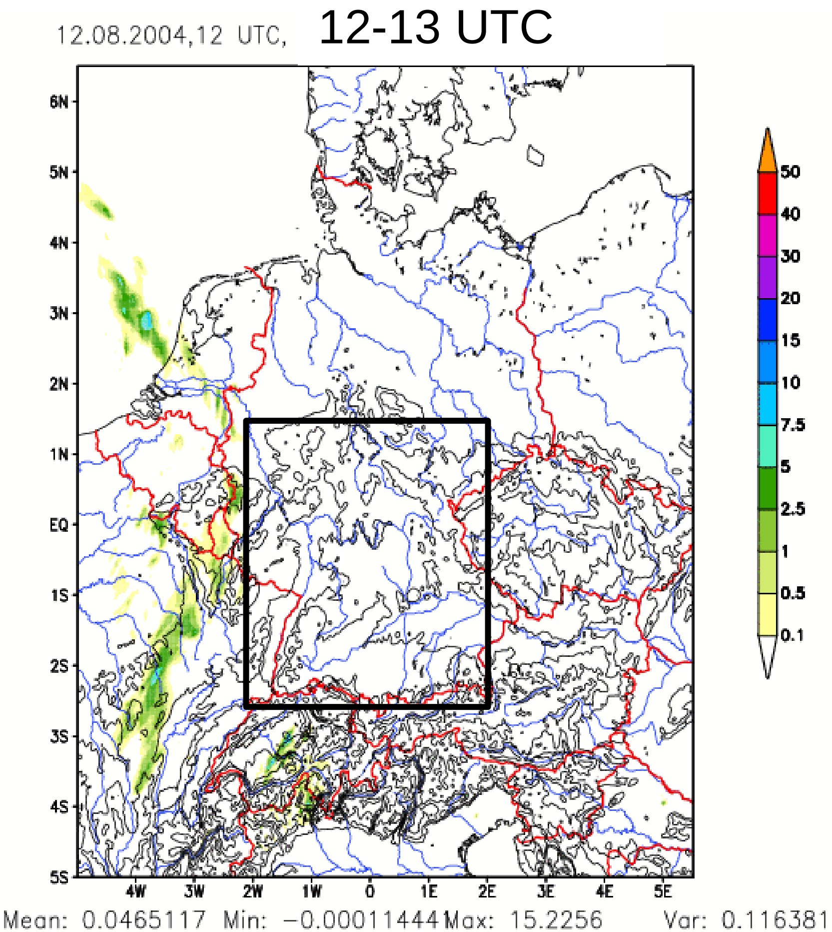
- Runge-Kutta RK3-TVD, 5. order upwind, implicit vertical adv. 2. order

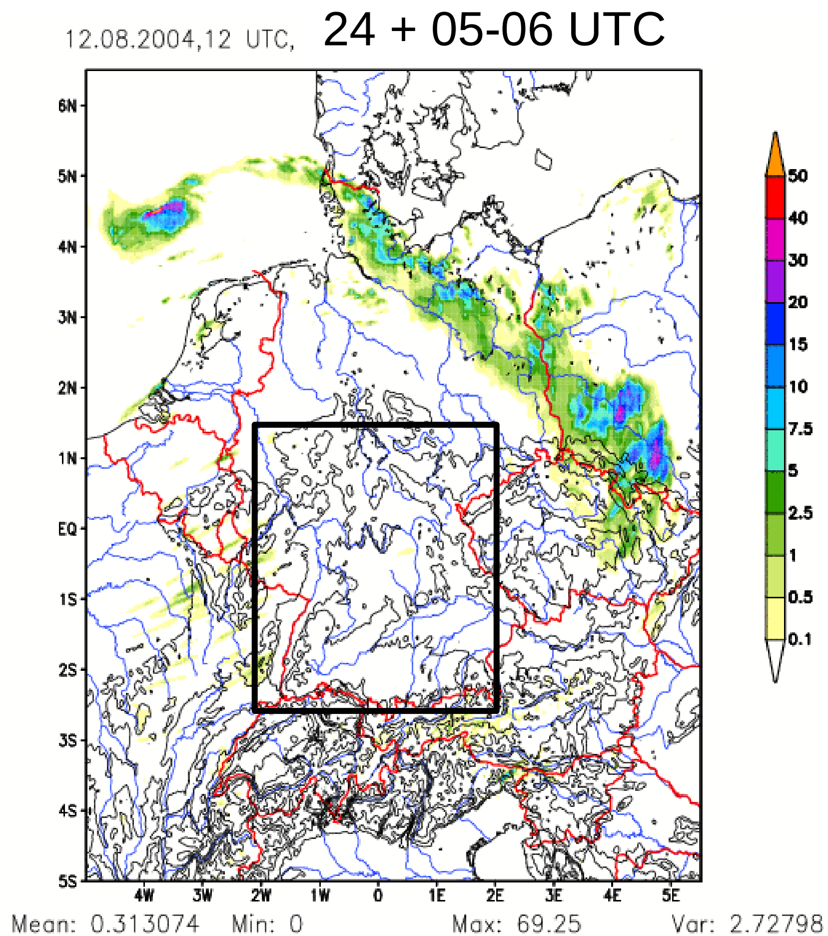
special features (not contained in LM 3.16):

- Semi-Lagrange-adv., tricubic interpol. with ‚multiplicative filling‘ for q_v, q_c, q_i, q_r, q_s, q_g
- (‚old‘ physics-dynamics-coupling (`ldiabh_lh=F`))

Baldauf (2005) COSMO-Newsl. Nr. 6

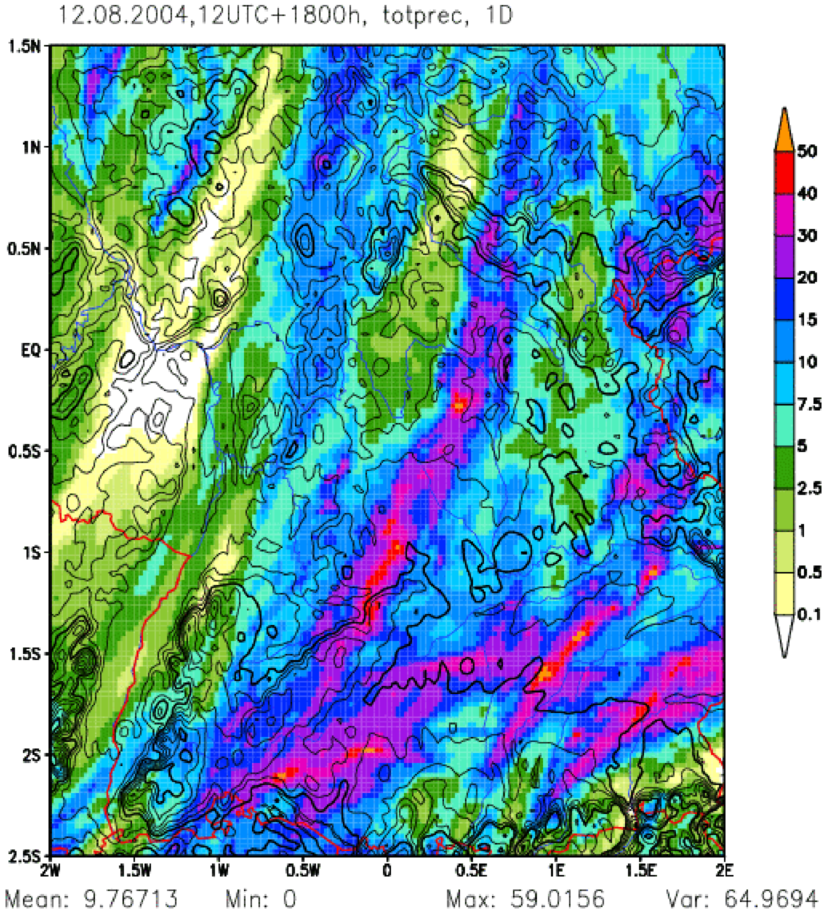
Real case study: LMK (2.8 km resolution) ‚12.08.2004, 12 UTC-run‘



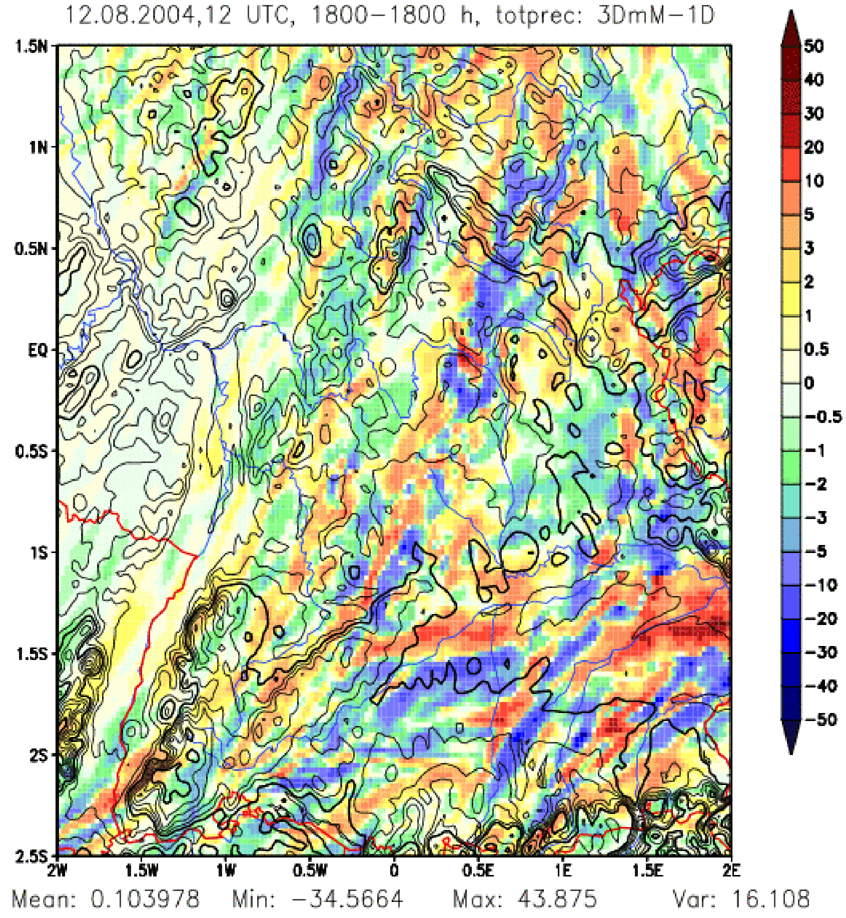


Real case study: LMK (2.8 km resolution) ‚12.08.2004, 12 UTC-run‘

total precip. in 18 h



‚3D-turb., with metric‘ - ‚1D‘



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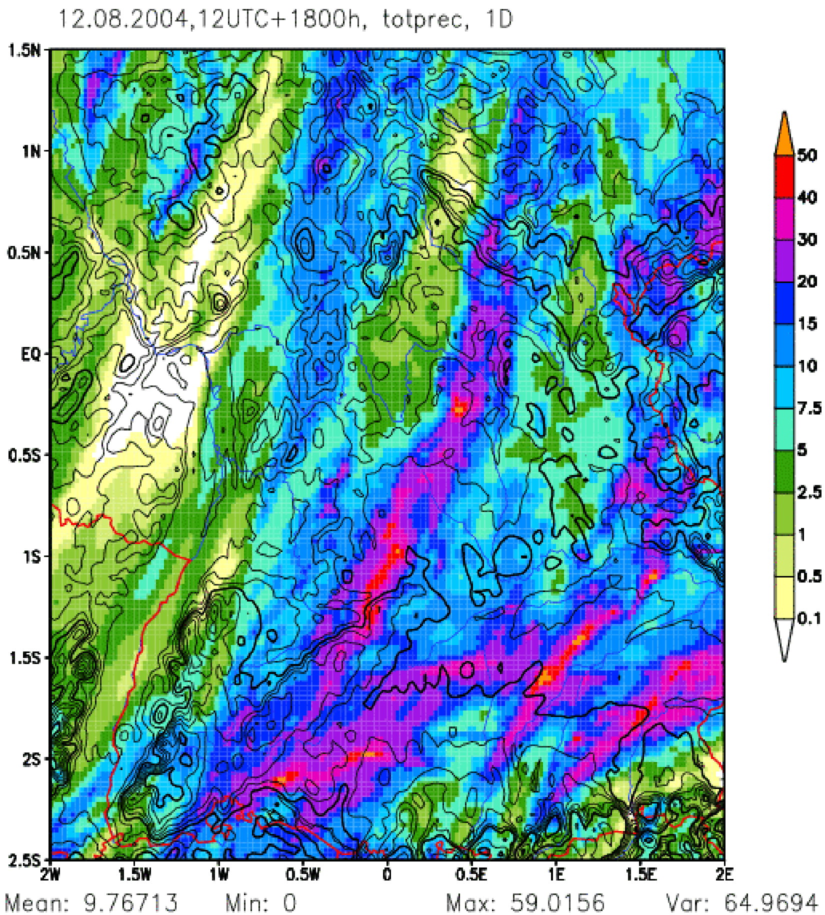
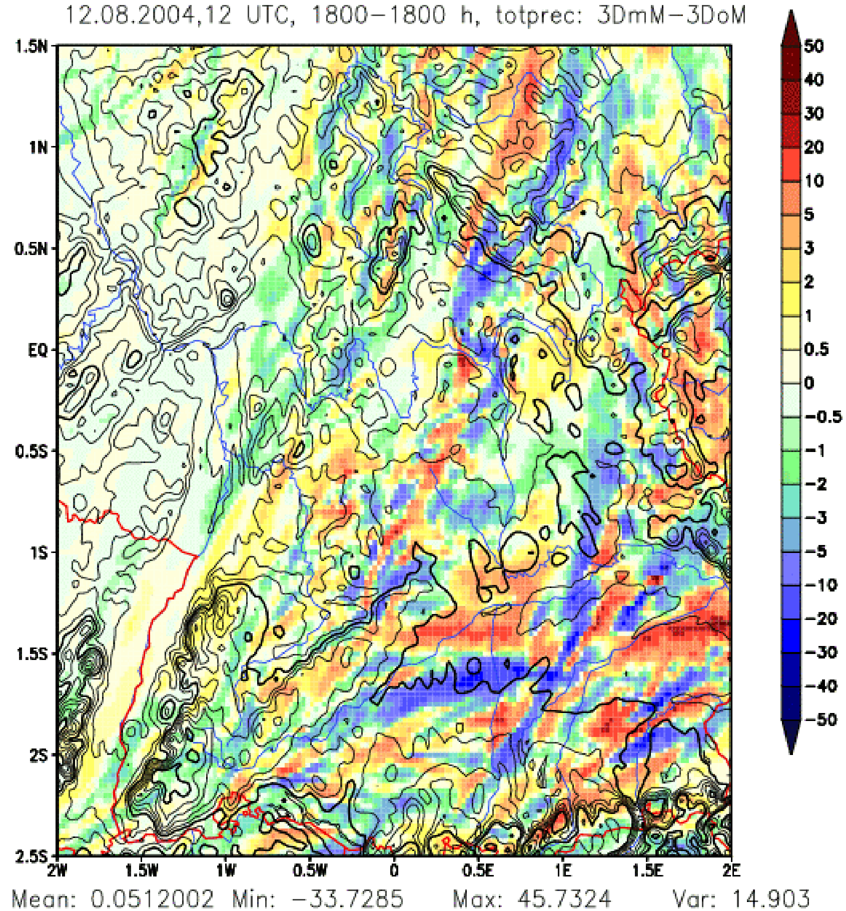
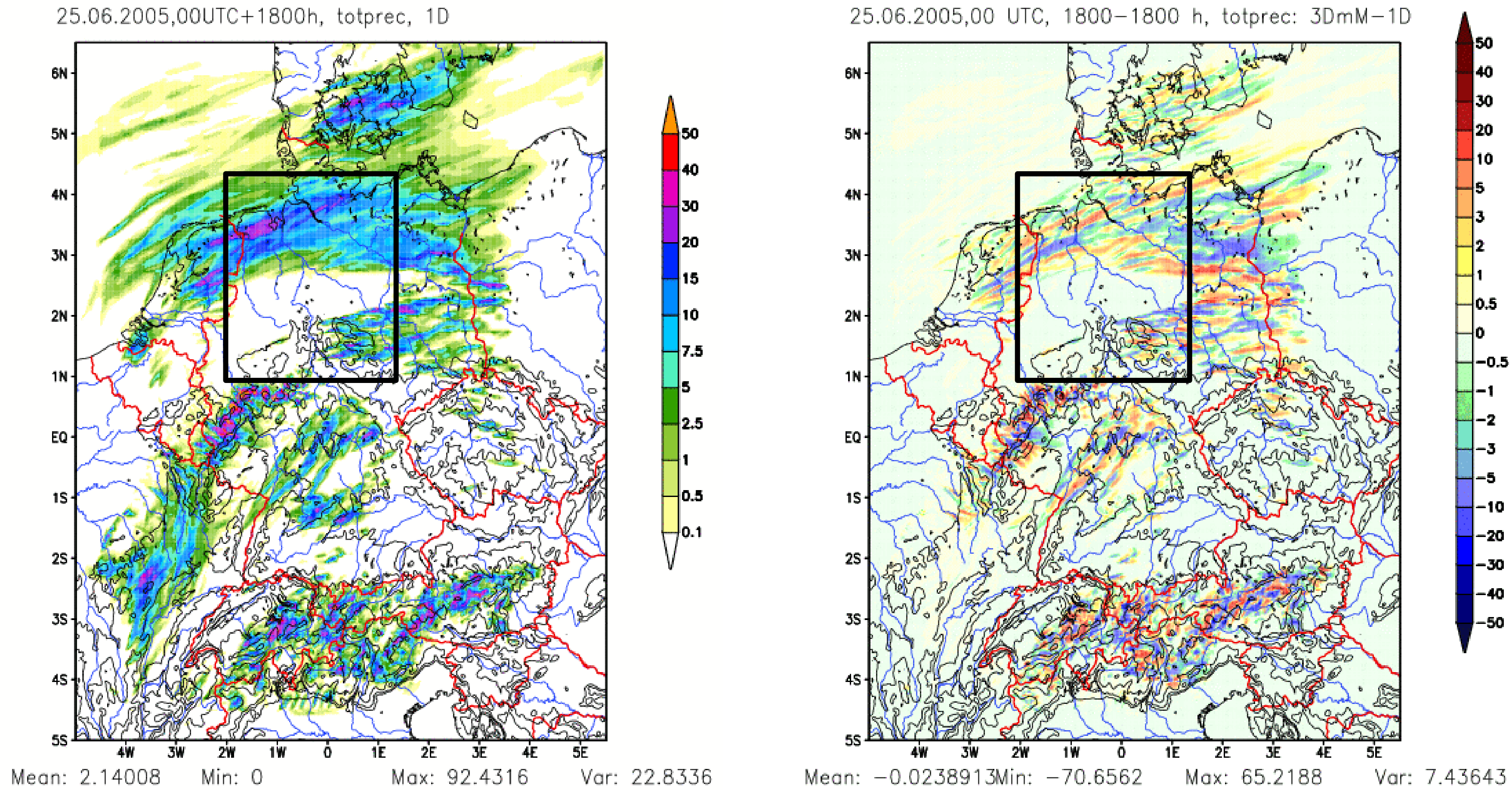


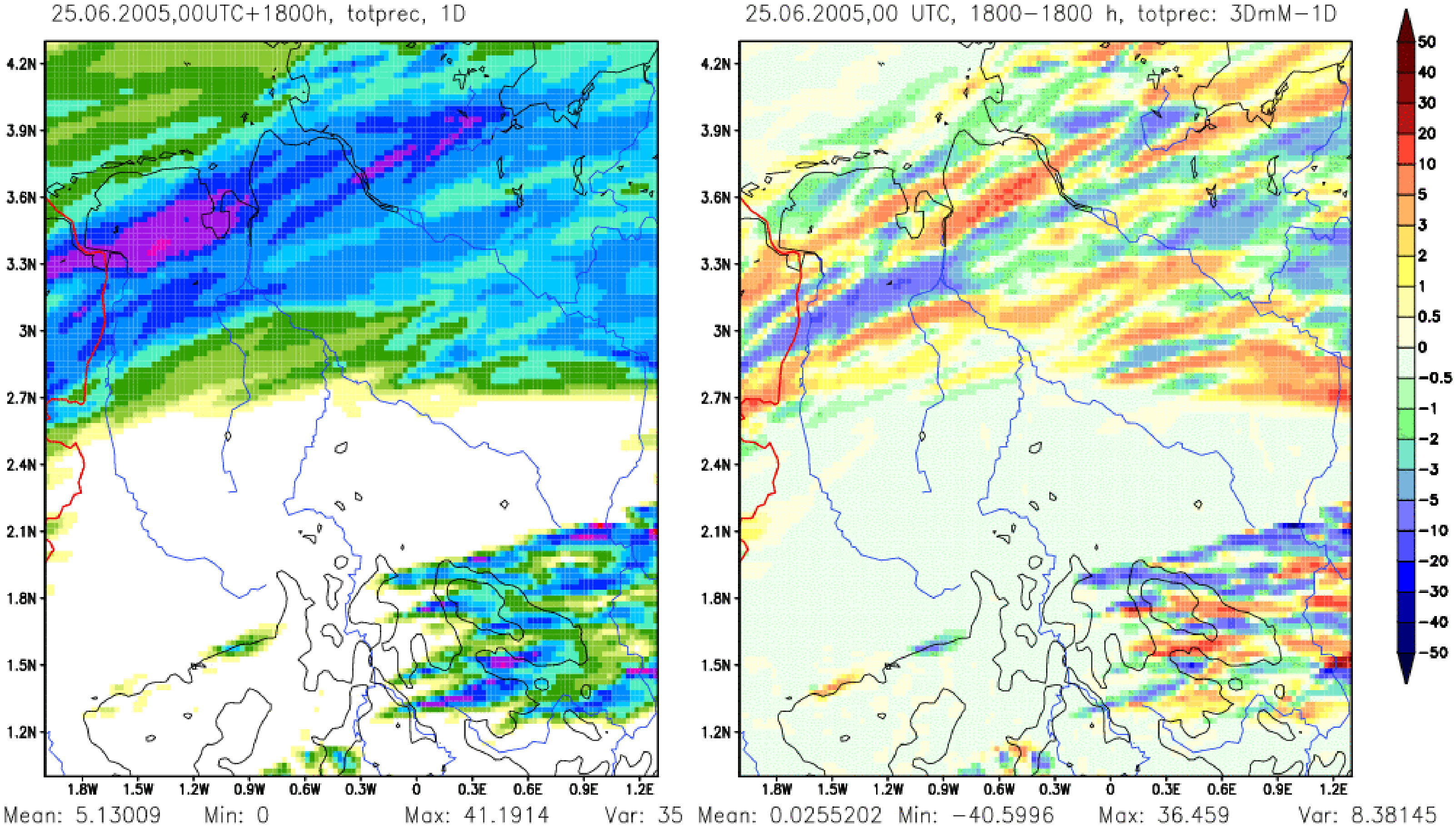
3D-turb.: ‚with‘ - ‚without‘ metric



Real case study: LMK (2.8 km resolution), 25.06.2005, 00 UTC-run‘



Real case study: LMK (2.8 km resolution), 25.06.2005, 00 UTC-run‘



Summary

Idealized tests ->

- metric terms for *scalar* variables are correctly implemented

Real case, sensitivity studies ->

- explicit treatment of metric terms is stable
- impact of 3D-turbulence on precipitation:
  - no significant change in area average of total precipitation
  - changes in the spatial distribution, differences up to ~40 mm/18h due to spatial shifts (up to 20...30 km)
  - small relevance in non-convective situations (<-- smaller diffusion coeff.)
- impact of metric terms on precipitation:
  - play a comparable role to the cartesian horizontal terms
- computing time for Subr. `explicit_horizontal_diffusion`
  - without metric: about 5% of total time
  - with metric: about 8.5% of total time (slight reduction possible)

Outlook

- Idealized tests also for ‚vectorial' diffusion (*u,v,w*)
- What is an adequate horizontal diffusion coefficient?
  - Used here: isotropic diffusion coefficient
    $$K_{hor} = K_{vert}$$
    (e.g. Klemp, Wilhelmson (1978) for cloud resolving sim. (Δx=1 km))
  - instead of LES ansatz:
    $$K_{hor} = 0.1 \cdot \frac{\sqrt{\Delta x^2 + \Delta y^2}}{\Delta z} \cdot K_{vert}$$
    dependence on u'u', w'w', ...?
- TKE advection (has to be implemented)
- Are the differences induced by 3D-turbulence relevant compared to the stochastic behaviour of convective cells?
- Verification needed
  → decision about the importance of 3D-turbulence and the metric terms on the 2.8km resolution

Idealised 3D-diffusion tests:

- $\Delta x = \Delta y = \Delta z = 50$ m, $\Delta t = 3$ sec.
- number of grid points: $60 \times 60 \times 60$
- area: 3 km $\times$ 3 km $\times$3 km
- constant diffusion coefficient K=100 m^2/s
- sinusoidal orography, h=0...250 m