Status report of

WG2 - Numerics and Dynamics

COSMO General Meeting
07-10 Sept. 2015, Wroclaw, Poland

Michael Baldauf (DWD)

Outline

- Model development work in 2015
  - Redesign of 3D diffusion
  - Other work/Bug fixes in the RK dynamical core
- Higher Order Spatial Schemes for the COSMO Model
- Further plans
- PP CELO → see presentation by Z. Piotrowski
- New PP CDIC → see presentation on Thursday

Increase of numerical stability in the diffusion scheme for 3D turbulence

M. Baldauf (DWD)

scalar flux divergence:

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

terrain following coordinates

vertical

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*

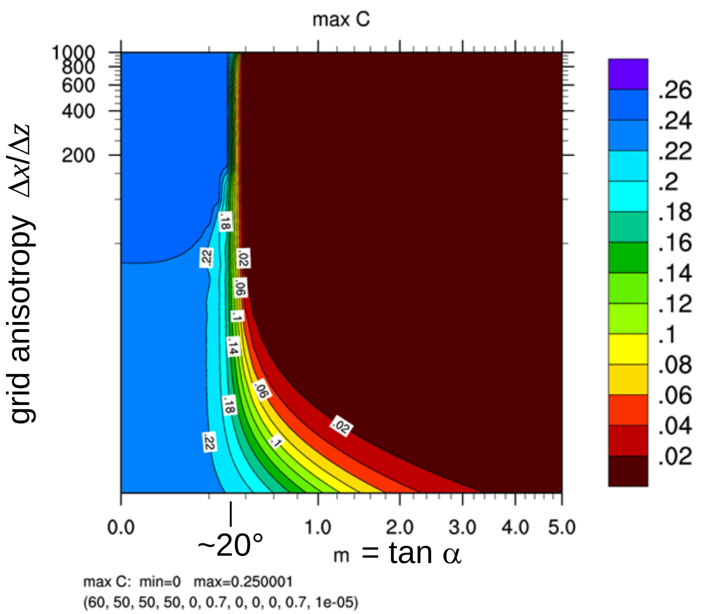
Baldauf (2005), COSMO-Newsl. Nr. 5

Increase of numerical stability in the diffusion scheme for 3D turbulence

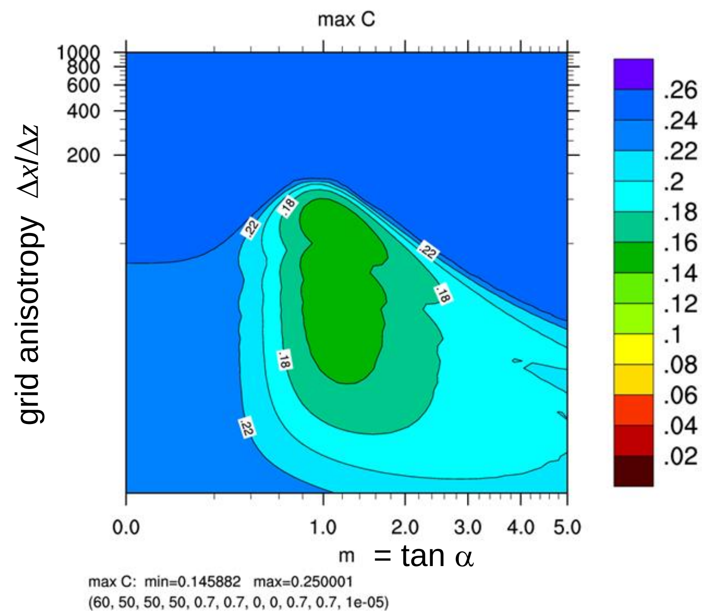
- The current implementation is not stable in steep terrain (found by *W. Langhans, O. Fuhrer, …*)
- Stability analysis indicates that 3D diffusion in terrain following coordinates may be stable in *arbitrary steep* terrain if
  - use as many terms as possible in the tridiagonal solver
  - some off-centering
- → new implementation of the 3D diffusion was necessary.
- Testing by idealised tests with known analytic solution successfully carried out both for scalar diffusion (*Baldauf, 2005*) and vector diffusion (new!)
- New implementation runs stable in real case simulations
- Available in COSMO 5.3
- Contribution to task 5.2.5 of the COSMO Science plan 2015-2020 (remark: 3D turbulence probably not necessary for $\Delta x > 1$ km)
- Thanks to *U. Schättler, G. Zängl, S. Brdar* for help and discussions!

Stability analysis of 3D vector diffusion in tilted terrain: max C_{diff} ~Δt

vertically implicit, only ‚pure' z-deriv,
off-centering=0.7 (=old COSMO)

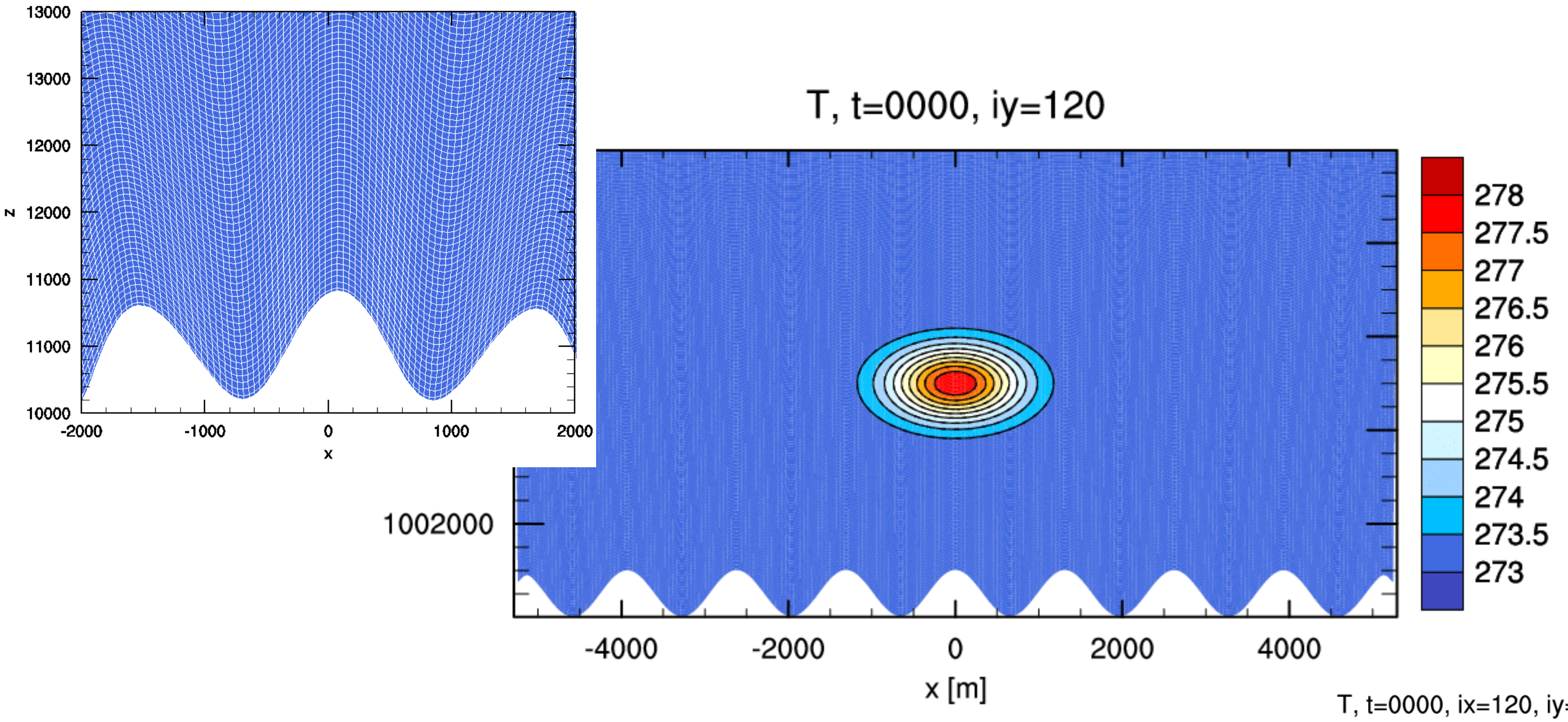


vertically implicit treatment of all possible terms,
off-centering=0.7 (COSMO 5.3)



similar stability properties for scalar diffusion

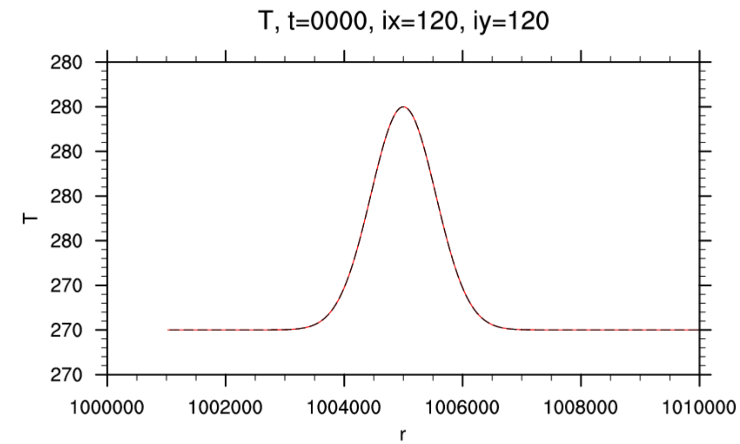
Scalar diffusion test



T,analy: min=273 max=277.997

T,simul: min=273 max=277.997

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrT



T,analy: min=273 max=277.997

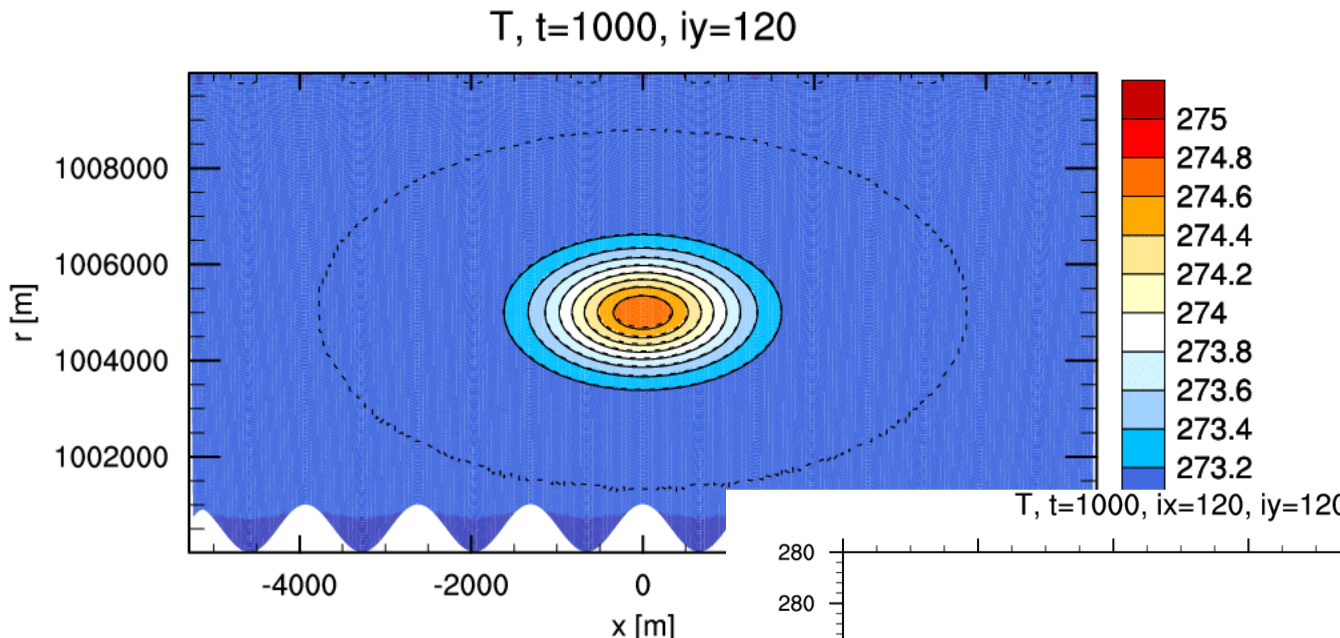
T,simul: min=273 max=277.997

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrT

analytic solution: solid lines

COSMO solution: colors + dashed lines

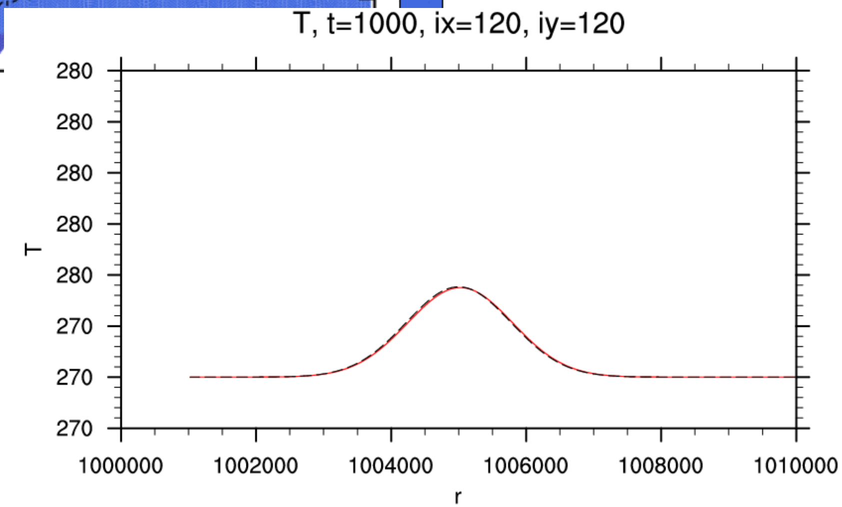
Scalar diffusion test



T,analy: min=273 max=274.767

T,simul: min=273 max=274.753

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrT



T,analy: min=273 max=274.767

T,simul: min=273 max=274.753

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrT

analytic solution: solid lines

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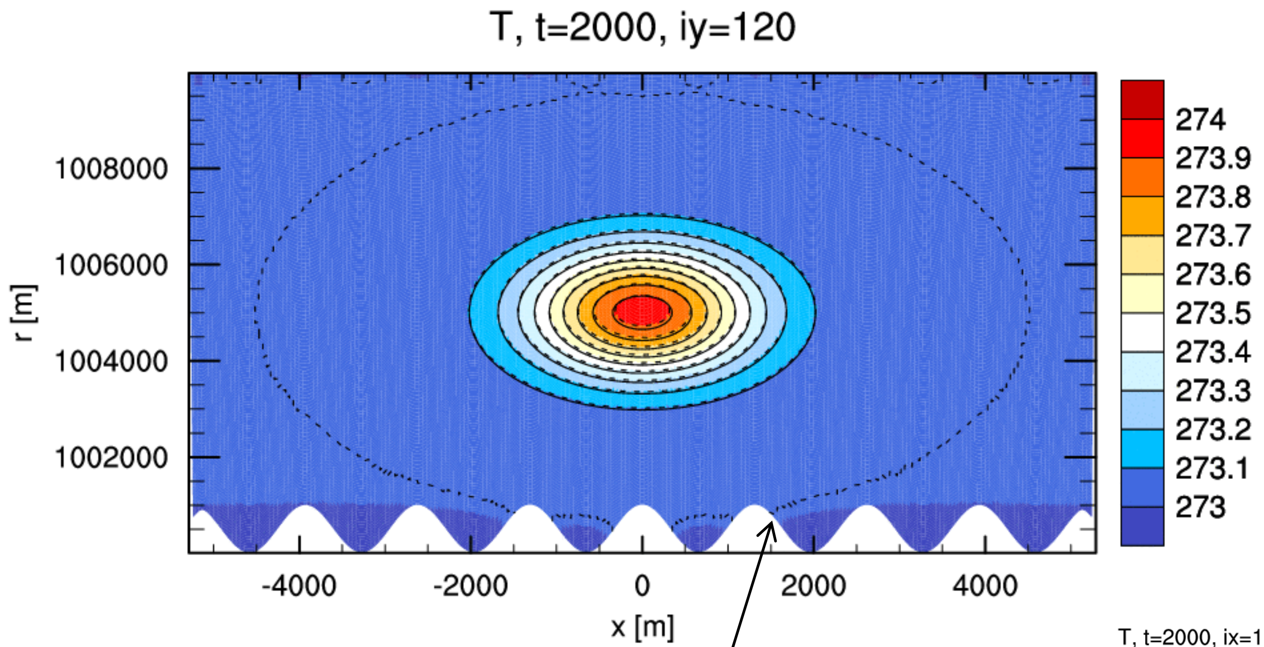
Scalar diffusion test

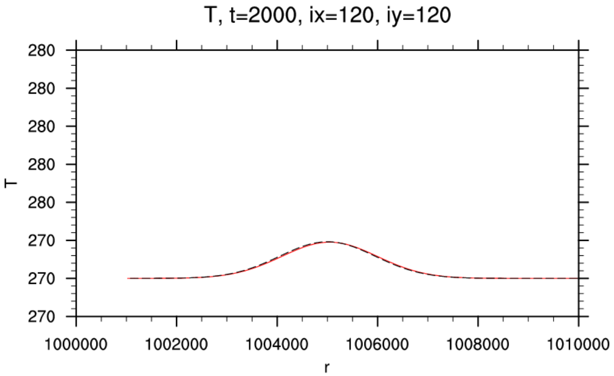


T,analy: min=273 max=273.962
T,simul: min=273 max=273.952

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_ImetrT

max slope ~ 2.3 ~ 67°

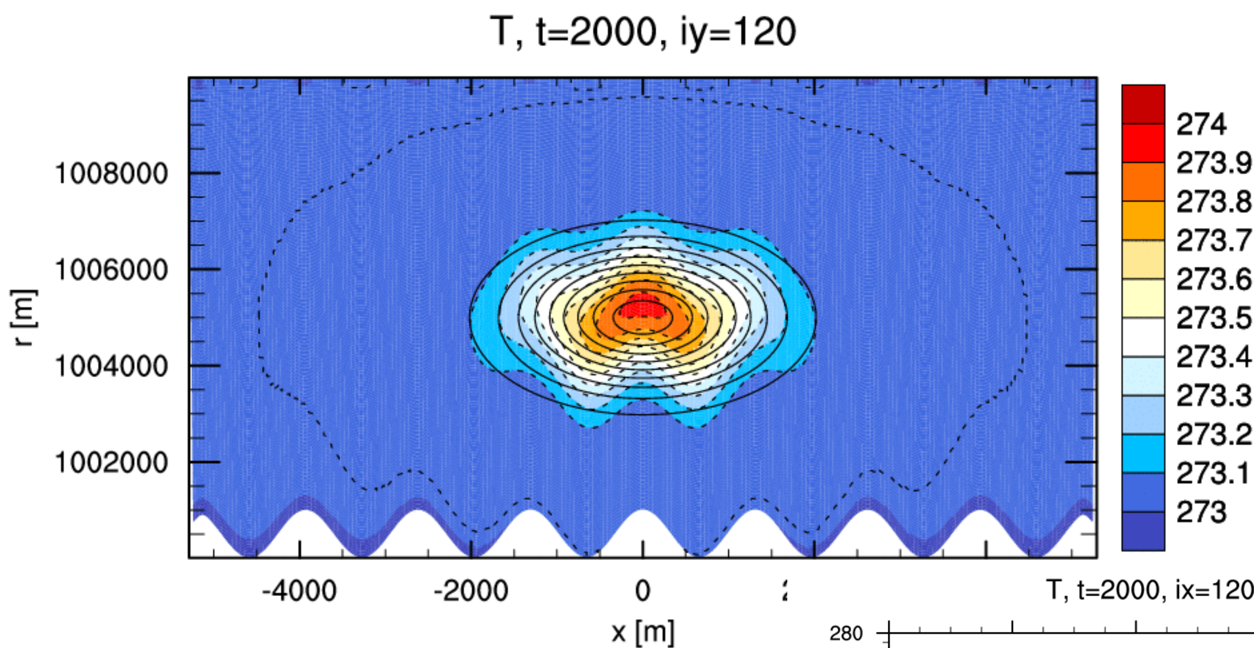
the run with only one vertical implicit term
(=old COSMO version) became unstable!



T,analy: min=273 max=273.962
T,simul: min=273 max=273.952

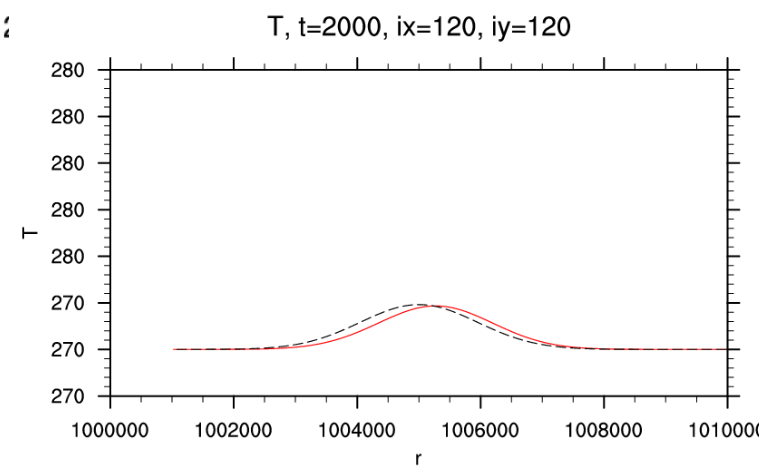
5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_ImetrT

Scalar diffusion test



T,analy: min=273 max=273.962
T,simul: min=273 max=273.934

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrT



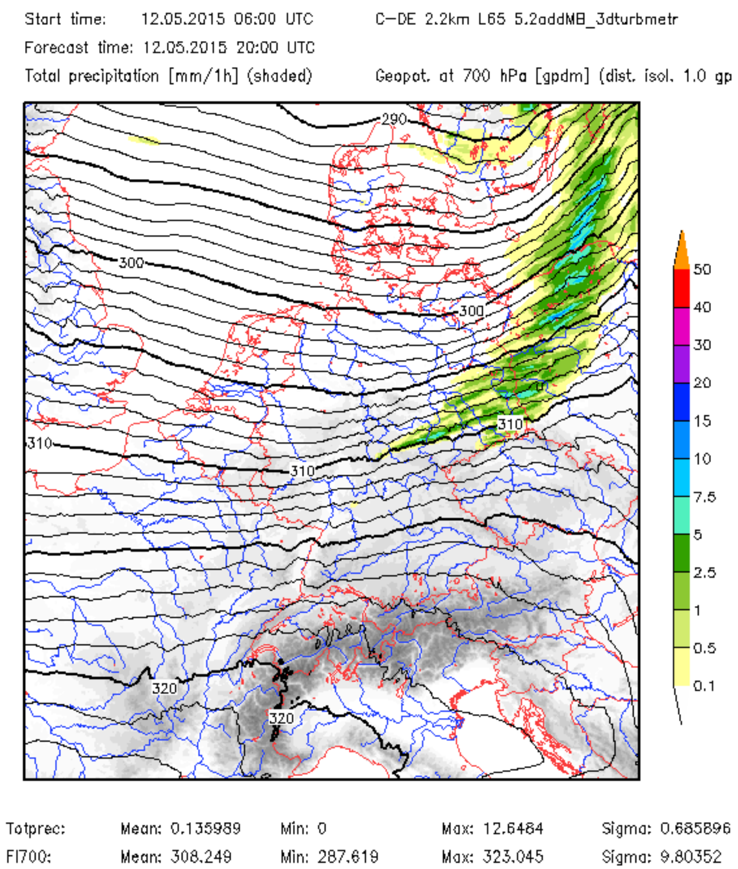
T,analy: min=273 max=273.962
T,simul: min=273 max=273.934

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrT

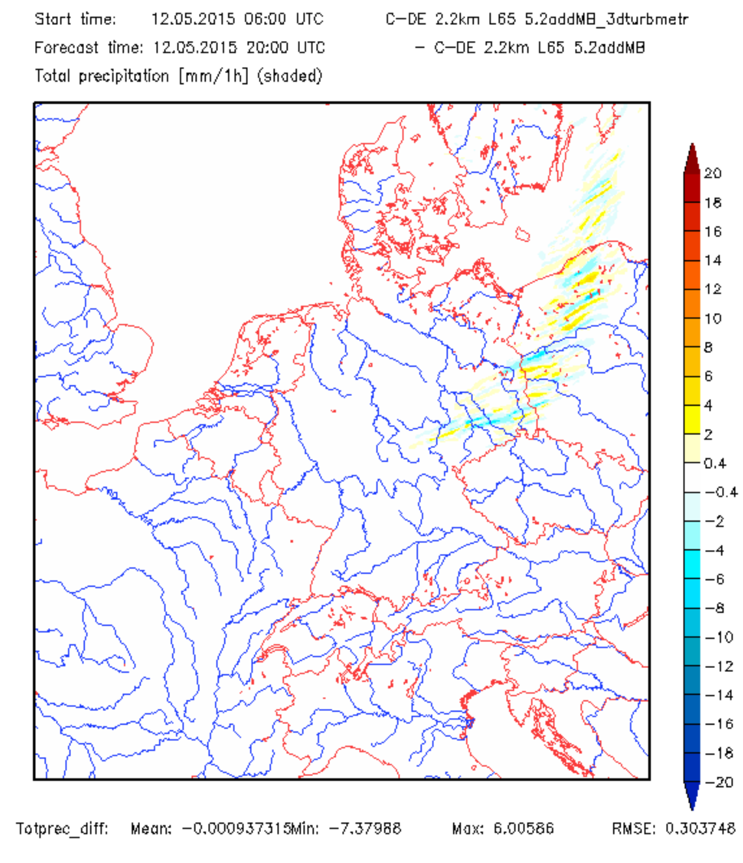
for comparison:
3D diffusion without metric terms

Real case: ‚12 May 2015, 06 UTC run', COSMO-D2, 1h precipitation sum

with 3D diffusion

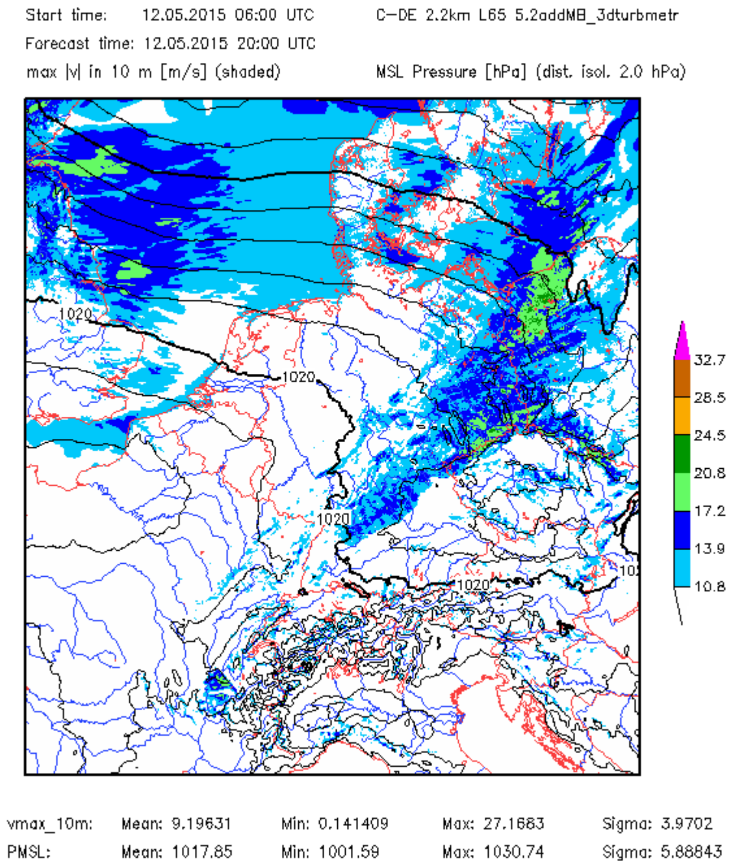


difference to 1D diffusion

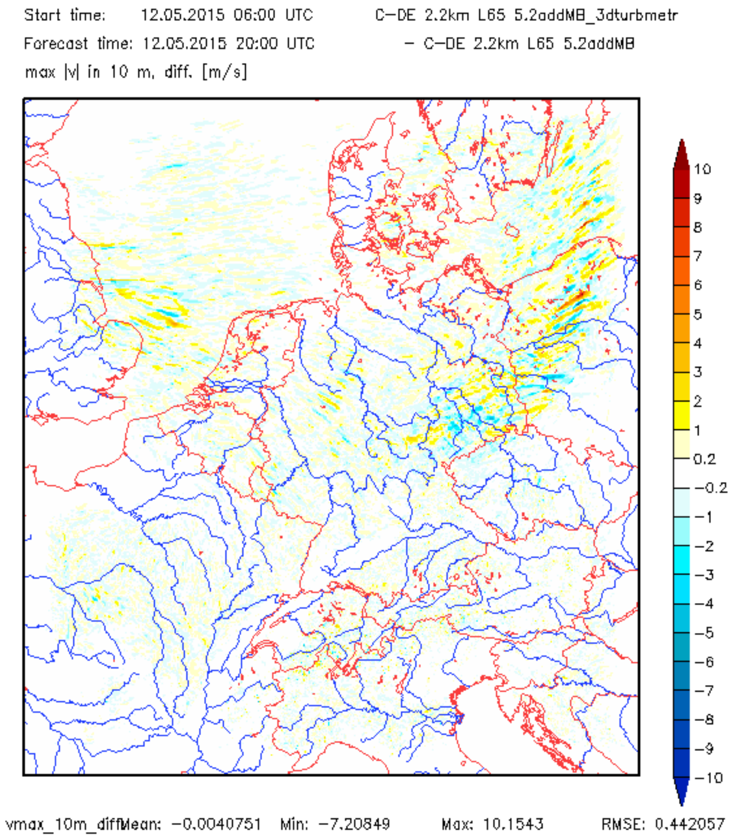


Real case: ‚12 May 2015, 06 UTC run‘, COSMO-D2, gusts

with 3D diffusion



difference to 1D diffusion

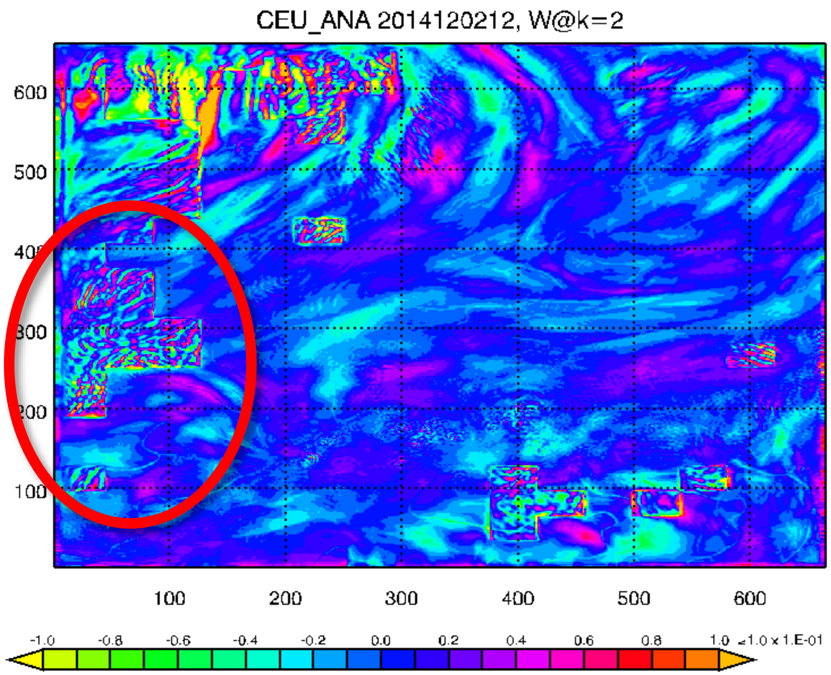


Bug in computation of kflat on distributed domains

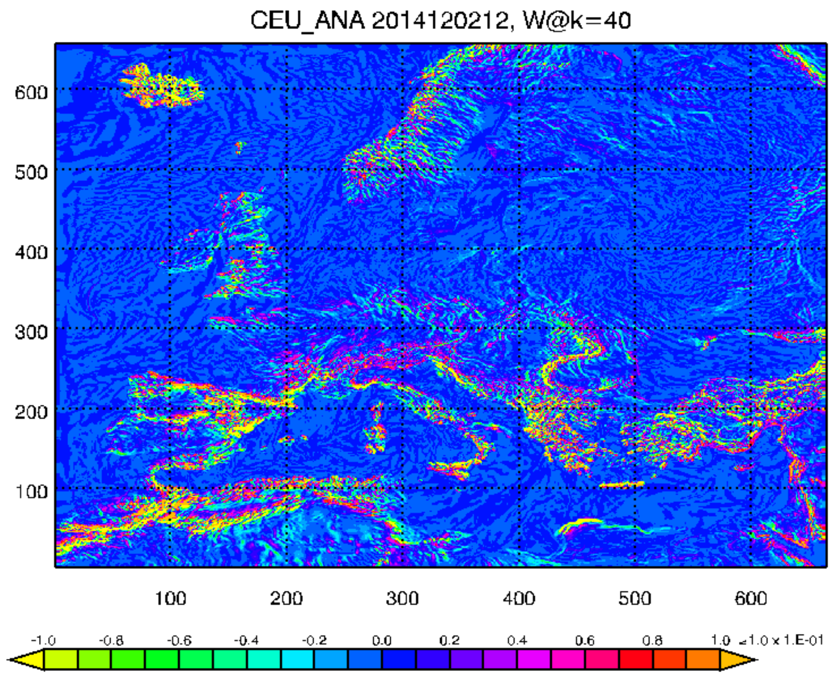
Uli Blahak (DWD)

w in upper damping layer, ‚02.12.2014‘:

k = 2 (within damping layer)



k = ke (bottom)



Bug concerning computation of „kflat“ for grib2 input data, which turns off the damping layer over flat surfaces!
Explanation next slide!

Reason and bug fix

- **Problem exists for grib2 input data:**
  - Because for grib2, kflat can no longer be determined from the meta data in the grib file, it is computed in the initialization stage of COSMO. This computation was done on each processor domain separately. However, this only works, if the spread of hsurf > 10 m. If this is not the case, kflat was set to 1 (e.g., if hsurf = 0.0 everywhere).
  - In COSMO, kflat was used in a loop boundary in the computation of the Rayleigh damping coefficients, but if kflat = 1, no coefficients are computed and remain at their initial value of 0.0 ⇨ **no damping!**

- **Solution:**
  - Eliminated kflat from the computation of the damping coefficients
  - Exchange kflat after computation and take the min over all domains.
  - Set kflat = ke_tot-1, if the domain is completely flat, because kflat is used as loop boundary in other parts of the code to save computing time.

- **The problem was discovered only shortly before the release of COSMO 5.1. Therefore the fix is not part of 5.1, but will come with 5.3.**

Reformulated divergence damping coeff. in new fast waves solver (II)

M. Baldauf (DWD), Guy deMorsier (MeteoCH)

Problem: model crash in COSMO-1 at ‚04.11.2014' at MeteoCH

Solution:
again a correction of the slope dependent reduction of the divergence damping coefficient (*Baldauf, 2013*) in a staggered grid.

1) COSMO 4.26: do a spatial averaging of the damping coefficient
2) COSMO 5.1: no averaging of the coefficient; coefficient is determined by the maximum steepness of the left and right slope at the scalar position
3) new for COSMO 5.3: as for 5.1, but take the average of the left and right slope.
   Cures all of the previous problems, too.

… further work done in/for WG2

- New **explicit sedimentation scheme** for the 2-moment cloud microphysics scheme, mitigating problems with rainrate spikes for longer time steps,
  Motivation: explicit sedimentation locally unstable for higher Courant numbers,
  semi-implicit scheme is (currently) not efficient enough,
  available in COSMO 5.3 (*U. Blahak, DWD*) → see talk 'status cloud microphysics'
- Bug fix in the ‚**targeted diffusion to avoid cold pools**' (*A. Arteaga, MeteoCH*)
  → roughly this halves the strength of the diffusion
  (retuning of diffusion coefficient necessary?)
- '**targeted diffusion …** ' now also avoids ‚hot pools' (*O. Fuhrer, MeteoCH*)
  → COSMO 5.1.1

Higher Order Spatial Schemes for the COSMO Model

A. Will, J. Ogaja (BTU Cottbus)

New discretization of the advection operator:

$$AdvS4 := \quad (\mathbf{v_h} \cdot \nabla_h u)_{i+\frac{1}{2},j} := \frac{9}{8}\overline{\overline{u}^{O4,\lambda}\delta_{\lambda} u}^{\lambda} - \frac{1}{8}\overline{\overline{u}^{O4,\lambda}\delta_{3\lambda} u}^{3\lambda} + \frac{9}{8}\overline{\overline{v}^{O4,\lambda}\delta_{\phi} u}^{\phi} - \frac{1}{8}\overline{\overline{v}^{O4,\lambda}\delta_{3\phi} u}^{3\phi}$$

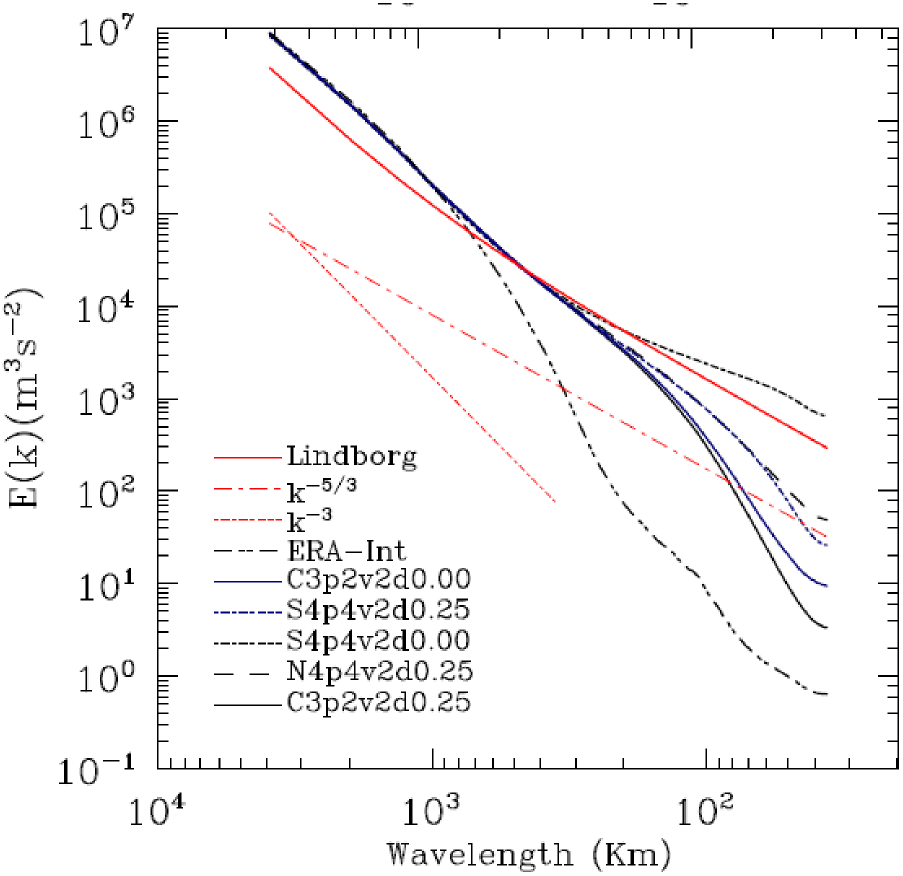
kinetic energy conserving discretization (Morinishi et al. (1998))

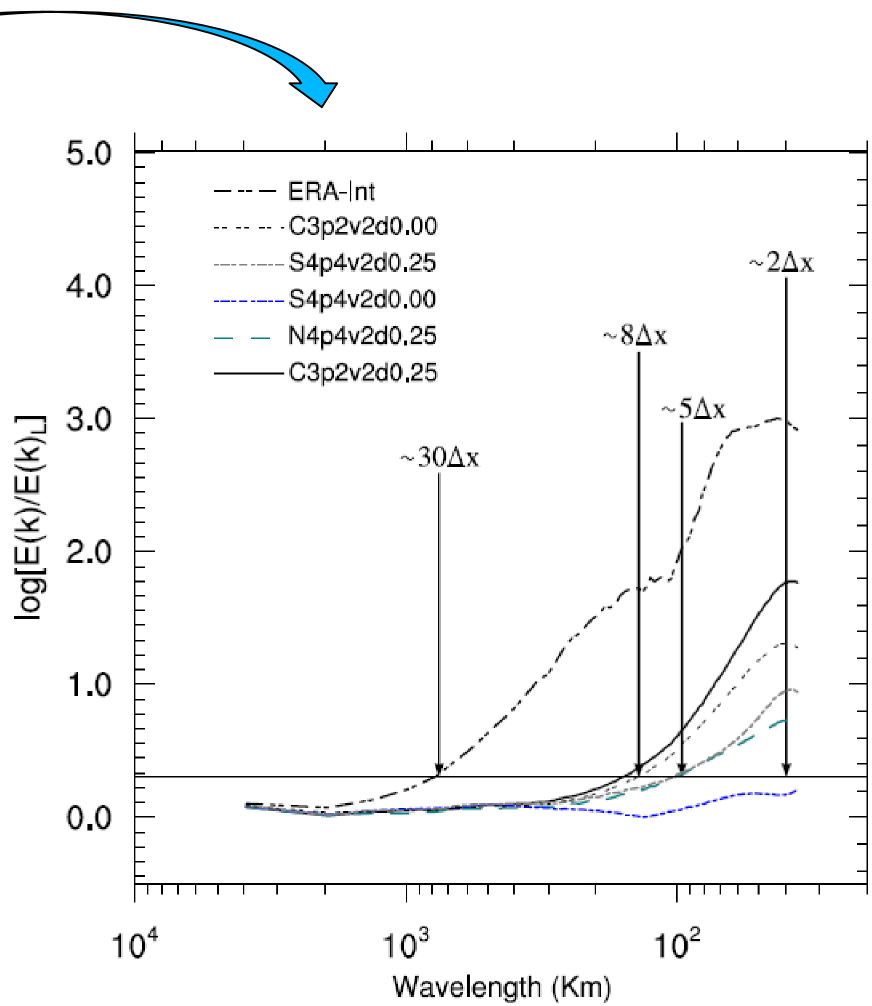
Additionally one can use 4th order discretizations of horizontal derivatives in the fast waves solver.

4. Real case climate simulation: Stability

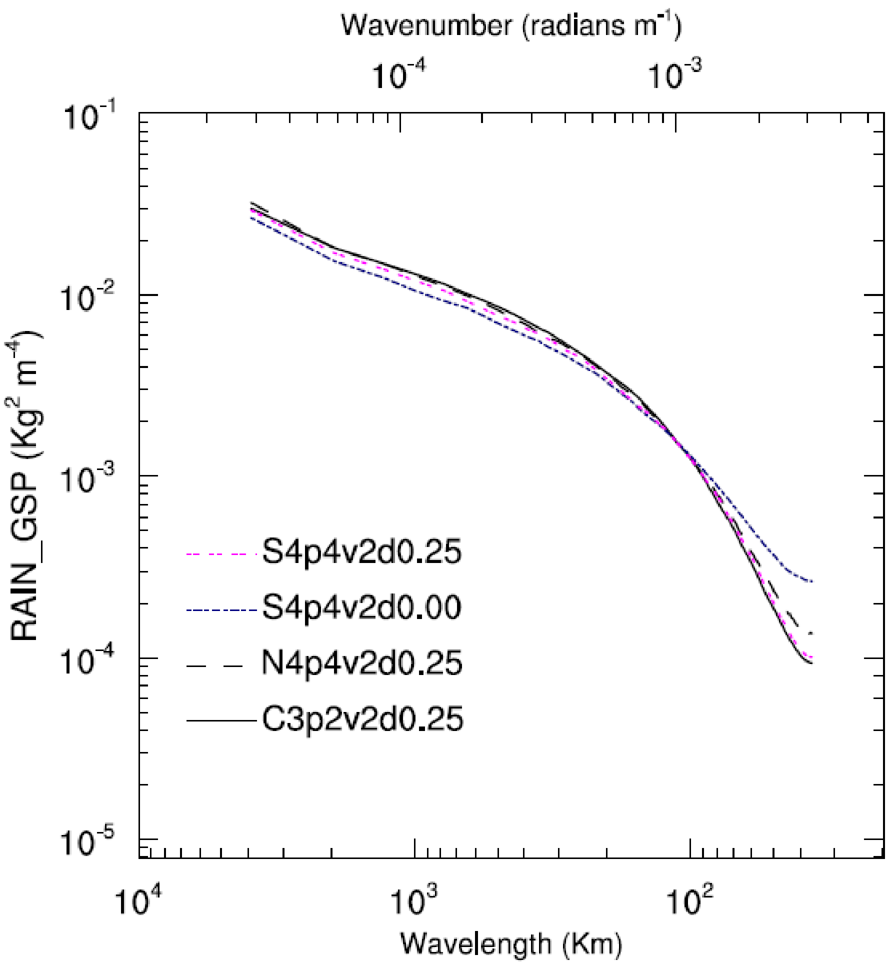
Schemes:	Implicit diffusion	KE conservation	Explicit diffusion coefficient	Model run time at $\Delta t = 150s$
$C3p2v2d0.00$:	Yes	No	0.00	Beyond 3 months‡
$C3p2v2d0.25$:	Yes	No	0.25	Beyond 20 years
$N4p4v2d0.25$:	No	No	0.25	Beyond 3 months§
$S4p4v2d0.00$:	No	Yes(for, $\nabla \cdot \mathbf{v_h} = 0$)	0.00	Beyond 20 years
$S4p4v2d0.25$:	No	No	0.25	Beyond 20 years
$S4p2v2d0.00$:	No	No¶	0.00	up to 1st month

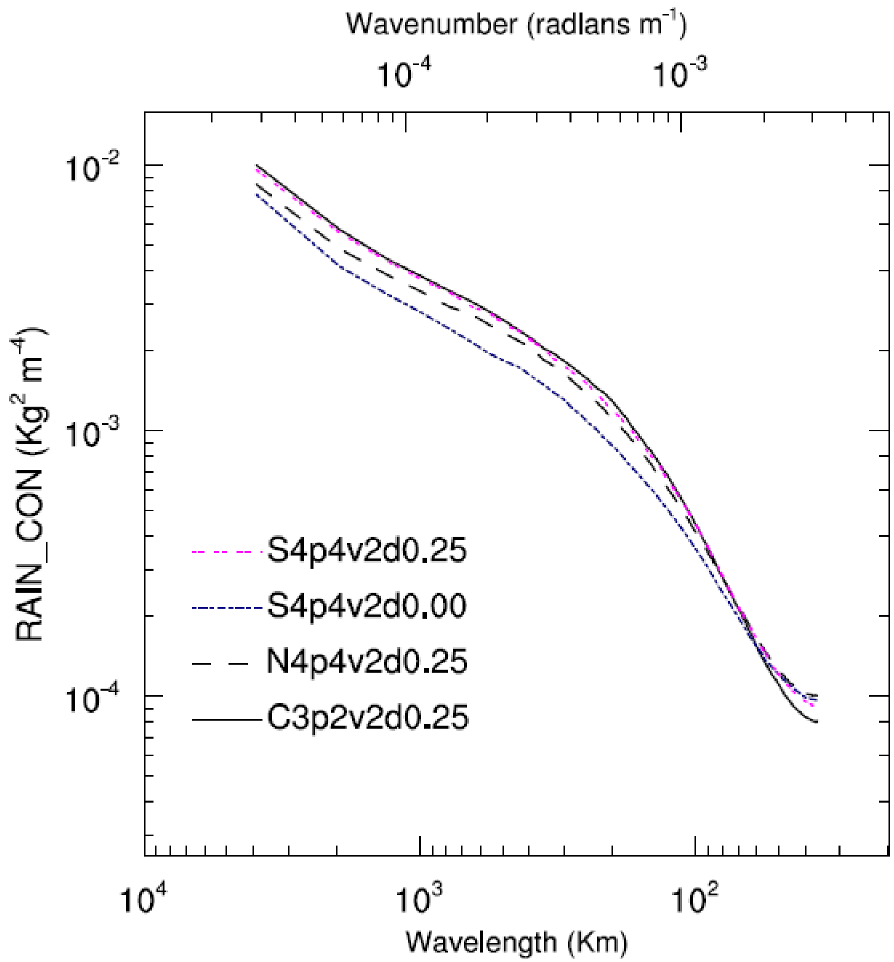
5. Effective model resolution:
A: Real case zonal kinetic energy spectra



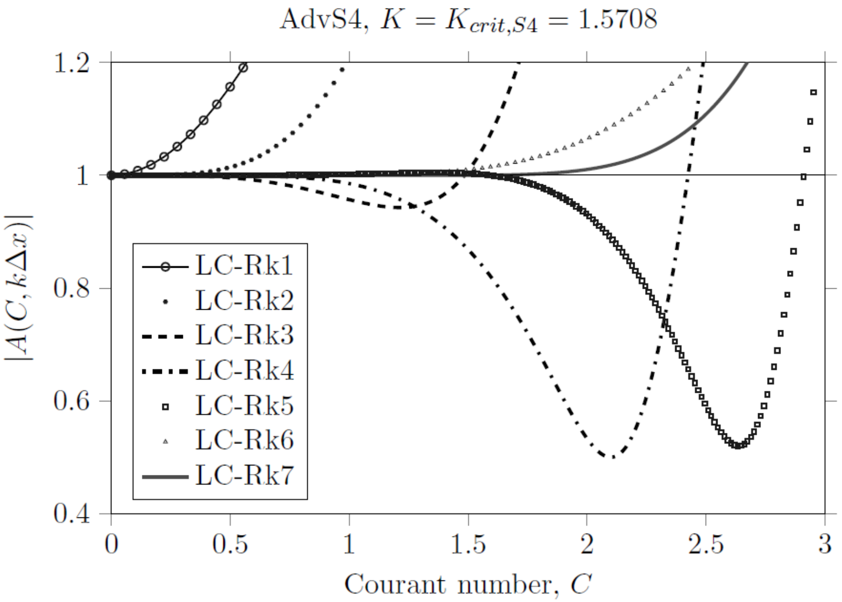


4. Real case climate simulation: Spectra of July precipitation





2. Linear advection equation: amplific. factor |A(C,K_crit)|



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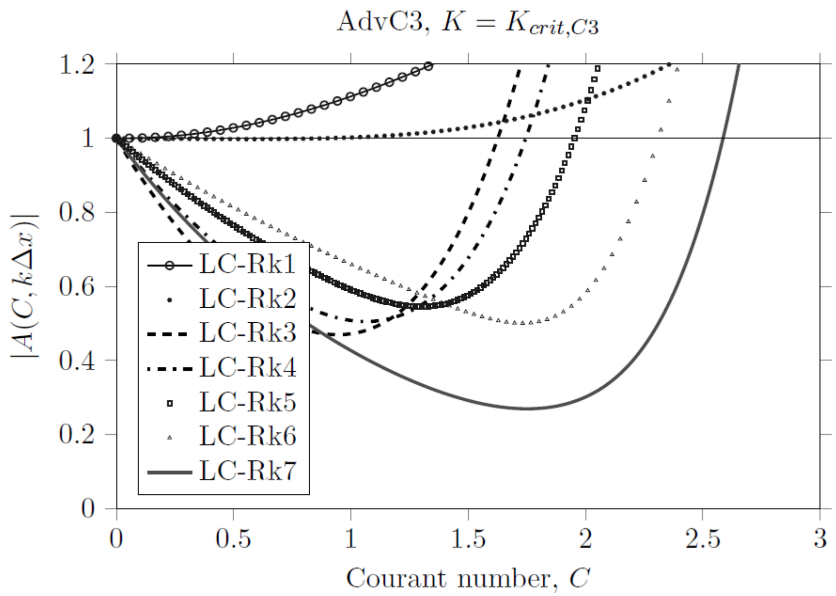


2. Linear advection equation: Critical Courant number

Schemes	$AdvC2$	$AdvS2$	$AdvC3$	$AdvC4$	$AdvS4$	$AdvC5$	$AdvC6$	$AdvS6$
$LC-RK1$	0	0	0	0	0	0	0	0
$LC-RK2$	0	0	0.87358	0	0	0	0	0
$LC-RK3$	1.73205	1.73205	1.62589	1.26222	1.48614	1.43498	1.09210	1.39494
$LC-RK4$	2.82843	2.82843	1.74526	2.06120	2.42437	1.73197	1.78339	2.27793
$LC-RK5$	0	0	1.95350	0	0	1.64375	0	0
$LC-RK6$	0	0	2.31039	0	0	1.86707	0	0
$LC-RK7$	1.76442	1.76442	2.58599	1.28581	1.51200	2.26079	1.11251	1.41600

analysis analogous to *Baldauf (2008) JCP*

,

:

6. Implementation

6.2 New namelist parameters

l_higher_order_ss	logical	If .TRUE., 4th order interpolation is used for all schemes but advection
ladv_symmetric	logical	If .TRUE., symmetric formulation of advection is used.

6.3 Implementation and testing procedure

1. COSMO_5.0: Implementation finished
   Compilation of COSMO_5.0 on mistral (DKRZ) successfull.
   Reference simulations using 4.24_hos on mistral planned to start on 10.9.2015
   Test simulations (using COSMO_5.0_hos) on mistral planned to start on 17.9. 2015
2. COSMO_5.3: Implementation planned to start 20.9. 2015
   Test simulations on mistral planned to start end of September 2015.

Further plans and next steps

Adaptive time step

A. Smalla, T. Reinhard (DWD)

Todo:

- existing work must be migrated from COSMO 4.26 to 5.1
- MPI-parallelisation still needed
- Treatment of parameterisations with different time steps (e.g. convection)

Due to the work load invested for the change from GME to ICON at MetBW,
→ implementation of the adaptive time step into the next COSMO 5.4 version is less probable.

Kaas (2008)-conserving extension of the Semi-Lagrangian Advection

Guy deMorsier (MeteoCH)

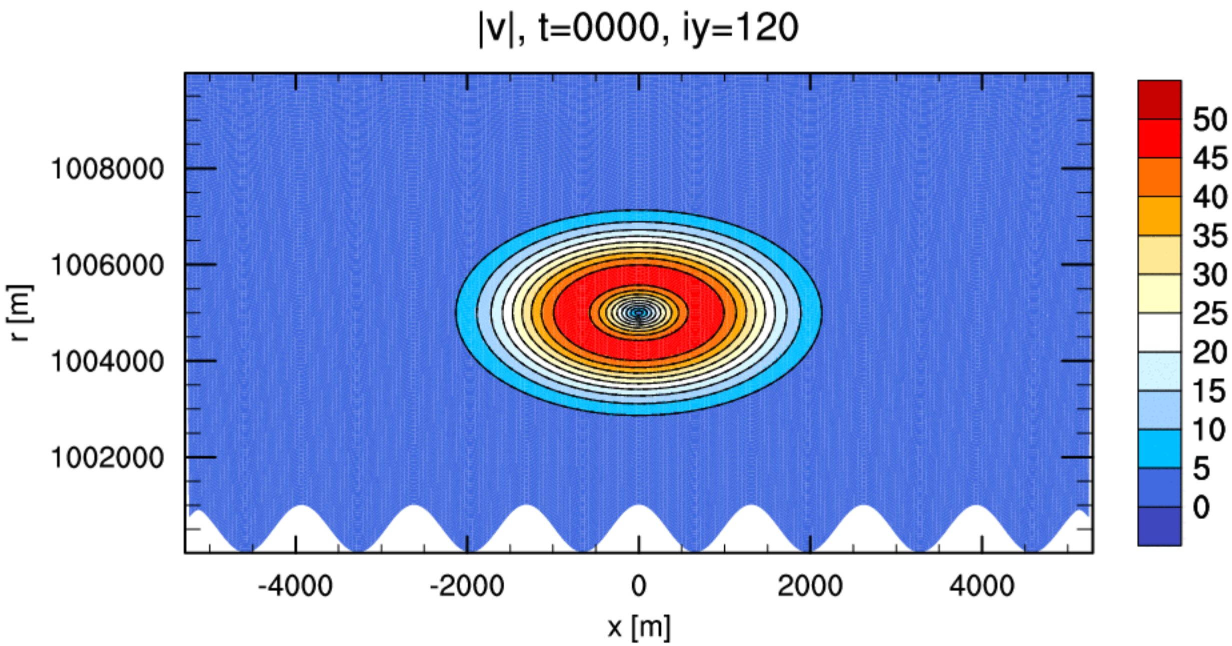
(Work initiated at EMPA (ETH) has now moved to MeteoCH)

WG2 publications in 2015

CONSORTIUM FOR SMALL SCALE MODELING
COSMO

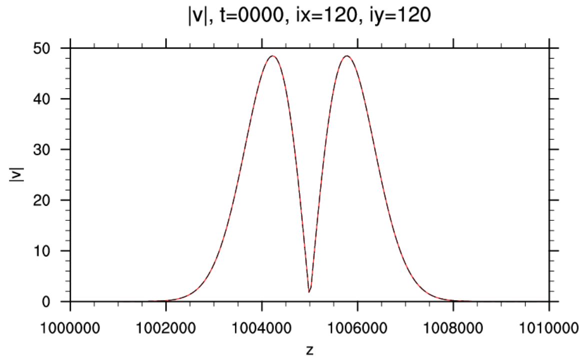
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Vector diffusion test



v,analy: min=0 max=48.5371
v,simul: min=0 max=48.5371

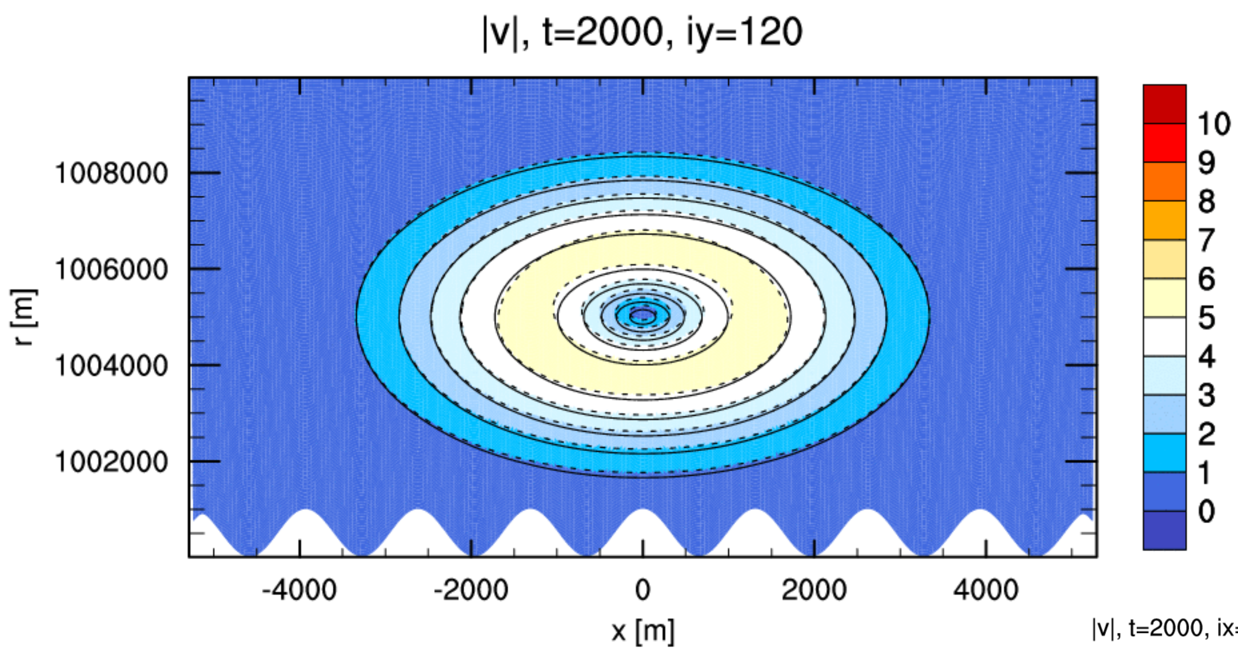
5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF



v,analy: min=5.64219e-07 max=48.4769
v,simul: min=5.64219e-07 max=48.4769

5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF

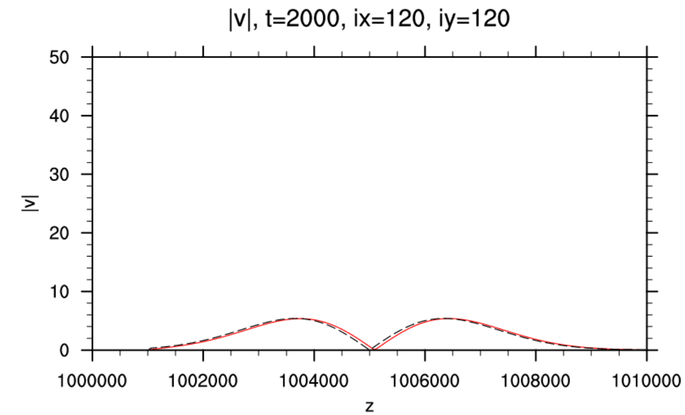
Vector diffusion test



v,analy: min=0 max=5.3929

v,simul: min=0 max=5.41991

5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF



v,analy: min=0.0338866 max=5.38961

v,simul: min=0.00462753 max=5.3754

5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF