Validation of the new 3D diffusion routines for COSMO 5.3

Michael Baldauf (DWD), 28 July 2015

This short document is a supplement to the presentation

M. Baldauf
Around the 3D diffusion: stability and testing
given at the WG2/CELO meeting during the COSMO User Seminar, 05 March 2015 in Offenbach.

The main purpose of this new development is to strongly increase the numerical stability of the (terrain-following) 3D diffusion in steep terrain. Additionally, due to some narrower stencils used, a slightly higher accuracy compared to the old version may be expected. Further information can be found in the above mentioned presentation.

The new development consists mainly in the completely rewritten subroutines
`explicit_horizontal_diffusion` and `implicit_vert_diffusion_uvwt_3D`
and updates of the subroutines `complete_tendencies_tke`, `complete_tendencies_trcr`
in `src_slow_tendencies_rk.f90`.

Section 1 validates the implementation by comparison with exact analytic solutions of the diffusion problem. Section 2 shows the good behaviour in a realistic test case.

All these tests have been performed with COSMO 5.2 together with the above mentioned new diffusion routines for COSMO 5.3.

1 Idealised test results of scalar and vector diffusion

The following pages show test results for scalar diffusion and vector diffusion in preparation of the new version COSMO 5.3.

Shown are the time steps n= 0, 500, 1000, and 2000 with a time step size of $\Delta t = 0.5$ sec. . The constant diffusion coefficient has been chosen as $K = 300$ m^2/s in both the scalar and the vector case. The grid consists of 240*240*200 grid points. The underlying orography is sinus-shaped in both λ- and ϕ-direction with a mountain height of 1 km and a maximum steepness of about 65°.

- left side: line plots along the z-axis through the center of the 'bubble'
  black dashed line: analytic solution
  red solid line: COSMO simulation
- right side: x-z-cross sections
  black solid lines: analytic solution
  colours + black dashed lines: COSMO simulation

A detailed description of the test and a stability analysis for the new discretization scheme is planned as a reviewed publication, too.

1.1 Test of the terrain-following metric terms

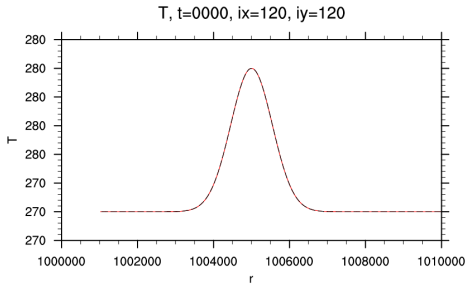
For this test a 'larger planet' with R=1000km has been chosen.

The results show a very good agreement between the analytic solution and the COSMO simulation in sections 1.1.2 and 1.1.4 (with `l3dturb_metr=.TRUE.`) even for steep mountains with orography gradients until about 65° for at least the first 2000 time steps (sec. 1.1.4). Furthermore, the simulation remains stable even for this steep orography.

This planet is large enough, i.e. the atmosphere with a thickness of 10km is shallow enough, that practically no deviation from the analytic solution steming from missing *spherical* metric terms and from the approximation $1/r = const.$ is recognizable.

In contrast, sections 1.1.1 and 1.1.3, which run with 3D diffusion but without the metric diffusion correction terms, demonstrate the need of these terms in hilly terrain.

1.1.1 Scalar diffusion, without terrain metric correction terms



T,analy: min=273 max=277.997
T,simul: min=273 max=277.997

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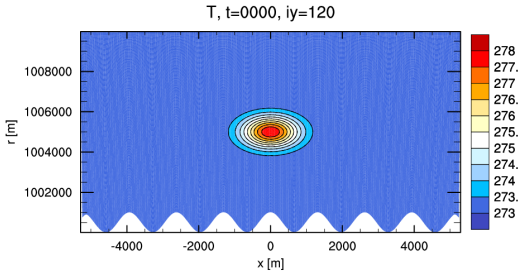

T,analy: min=273 max=277.997
T,simul: min=273 max=277.997

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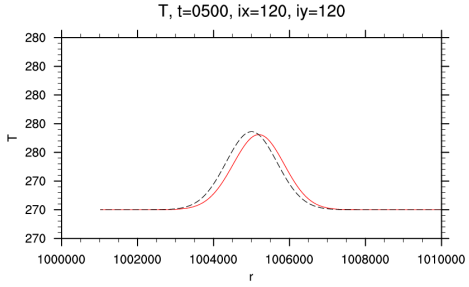
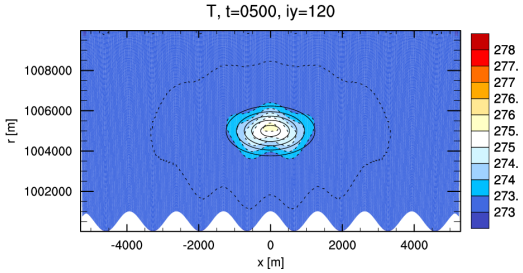


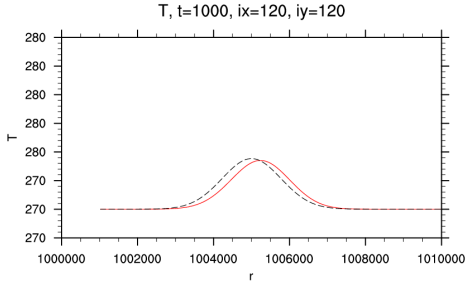
T,analy: min=273 max=275.721
T,simul: min=273 max=275.618

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrT



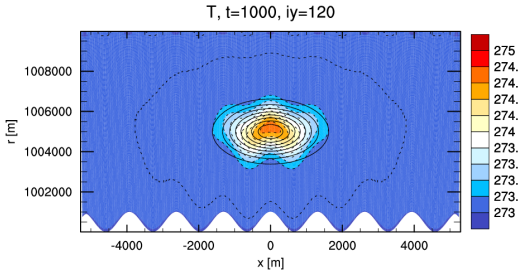
T,analy: min=273 max=275.721
T,simul: min=273 max=275.618

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrT



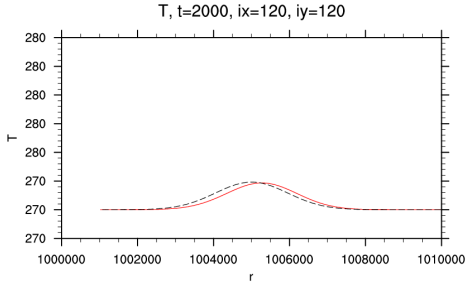
T,analy: min=273 max=274.767
T,simul: min=273 max=274.703

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrT



T,analy: min=273 max=274.767
T,simul: min=273 max=274.703

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrT



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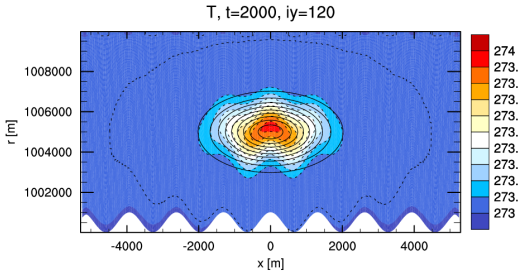

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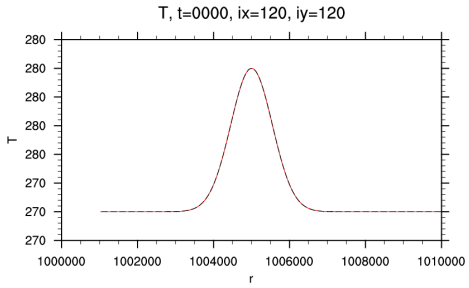
1.1.2 Scalar diffusion, with terrain metric correction terms



T,analy: min=273 max=277.997
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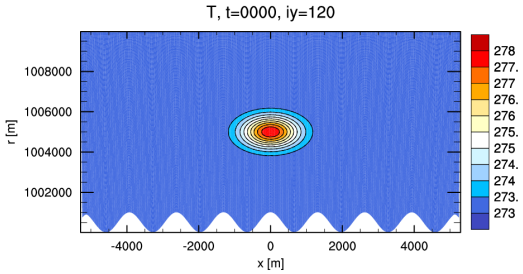
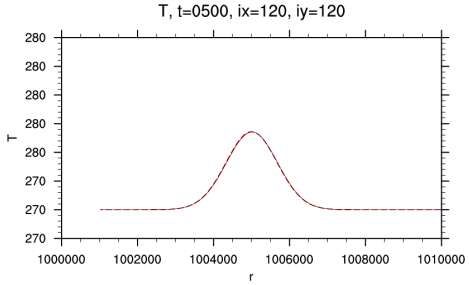


T,analy: min=273 max=277.997
T,simul: min=273 max=277.997

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTI0.75_lmetrT



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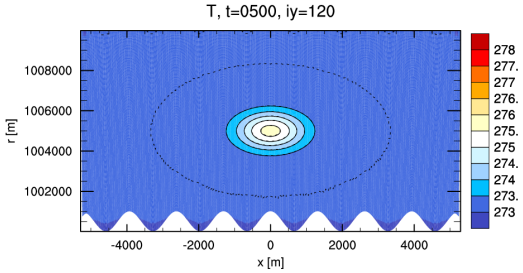

T,analy: min=273 max=275.721
T,simul: min=273 max=275.706

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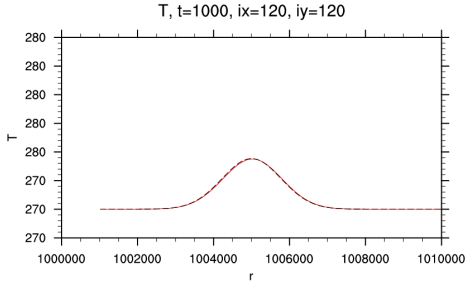

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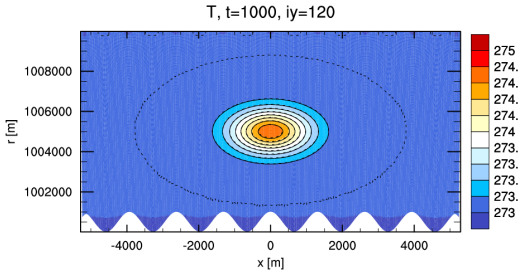
5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTI0.75_lmetrT



T,analy: min=273 max=274.767
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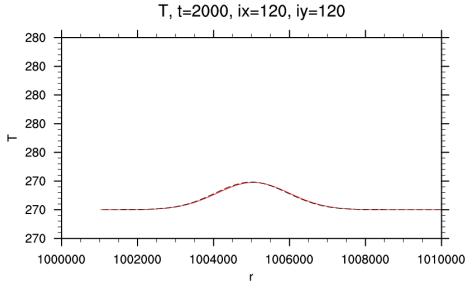
5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTI0.75_lmetrT



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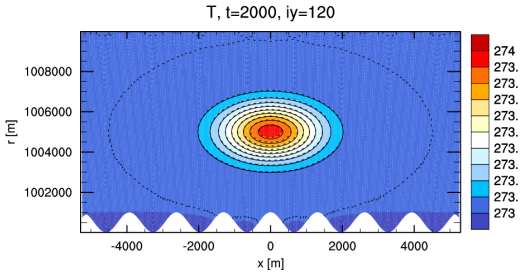
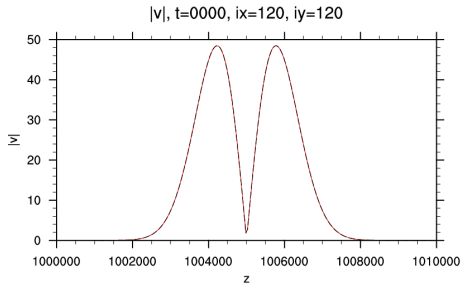


T,analy: min=273 max=273.962
T,simul: min=273 max=273.952

5.1r39_50_s_R1000km_h1000m_3dneu_3dturbT_3dmetrTI0.75_lmetrT

1.1.3 Vector diffusion, without terrain metric correction terms



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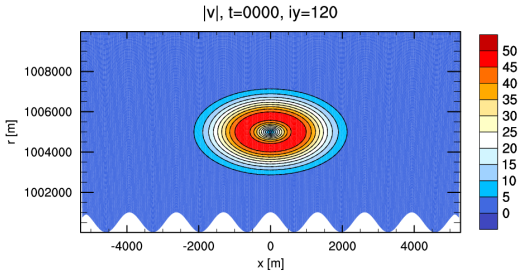

v,analy: min=0 max=48.5371
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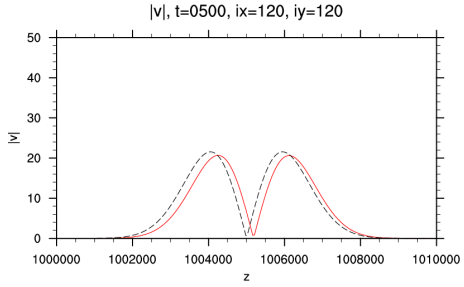
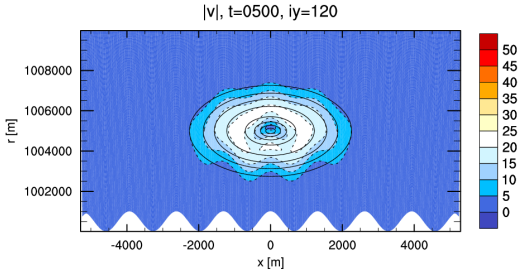


v,analy: min=0.000197735 max=21.549
v,simul: min=5.91226e-05 max=20.6684

5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrF



v,analy: min=0 max=21.5729
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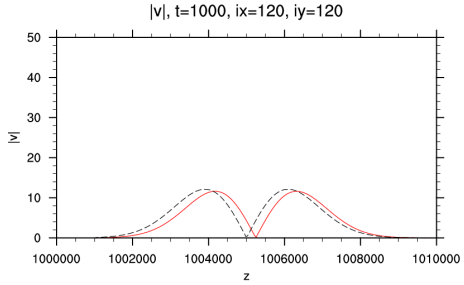
5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrFi0.75_lmetrF



v,analy: min=0.0029977 max=12.1255
v,simul: min=0.000704336 max=11.6262

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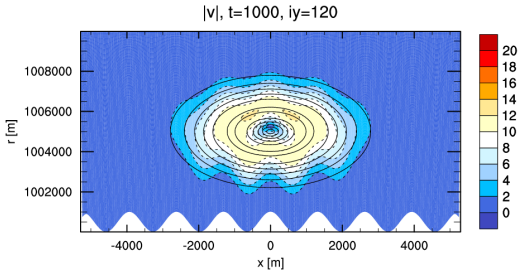

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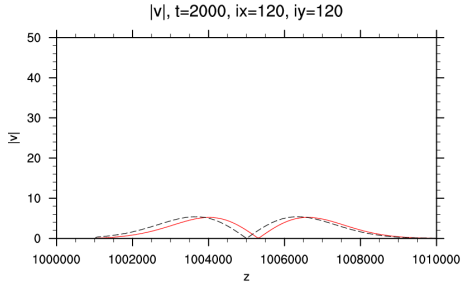

v,analy: min=0.0338866 max=5.38961
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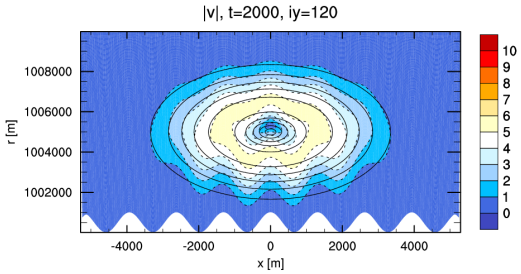

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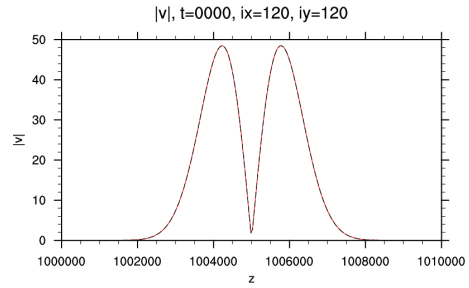
1.1.4 Vector diffusion, with terrain metric correction terms



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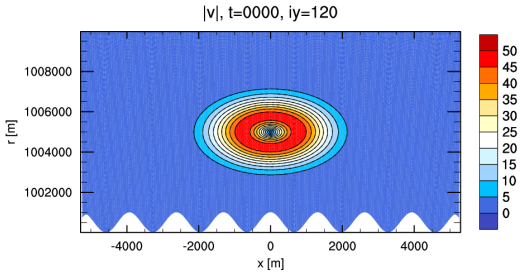
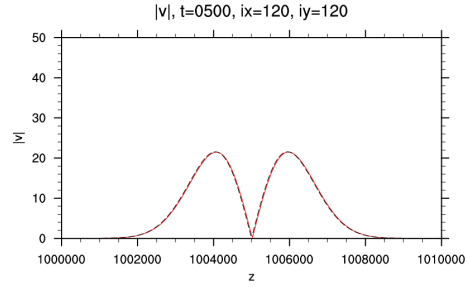


v,analy: min=0 max=48.5371
v,simul: min=0 max=48.5371

5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF



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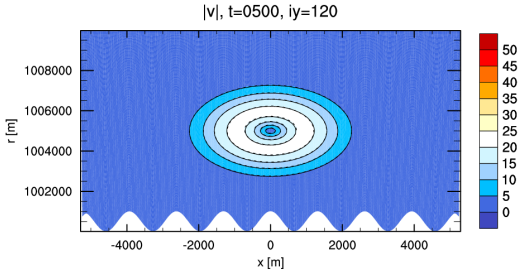

v,analy: min=0 max=21.5729
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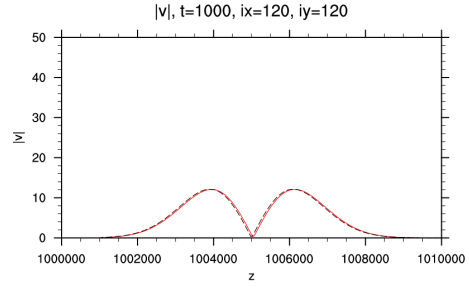
5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF



v,analy: min=0.0029977 max=12.1255
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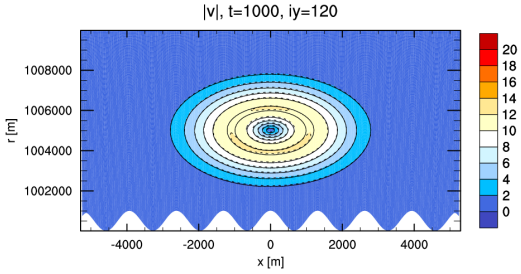
5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF



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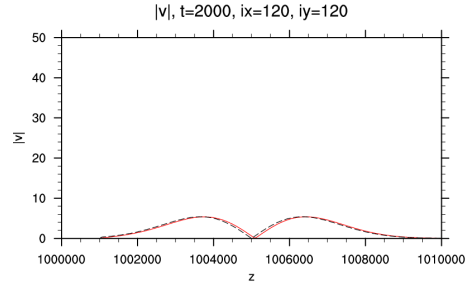

v,analy: min=0.0338866 max=5.38961
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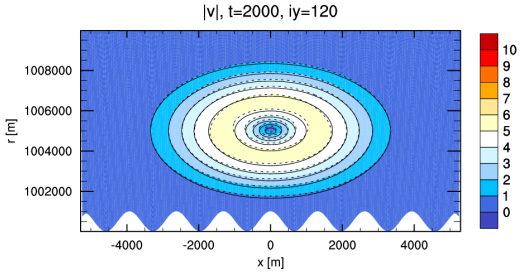

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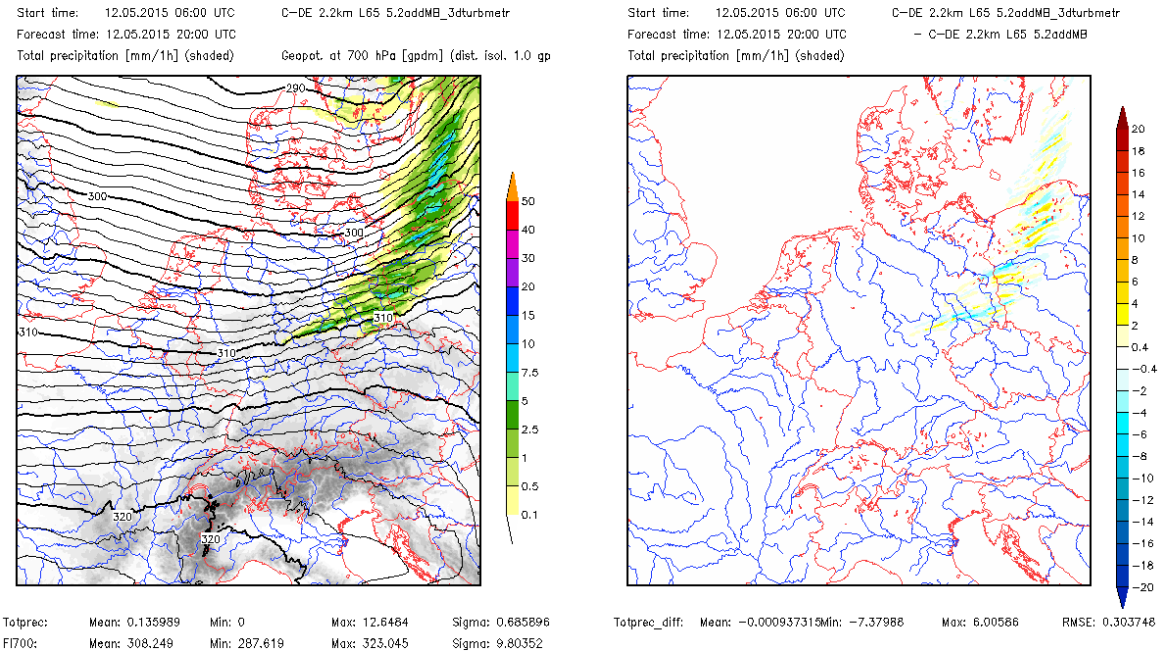
5.1r39_50_v_R1000km_h1000m_3dneu_3dturbT_3dmetrTi0.75_lmetrF

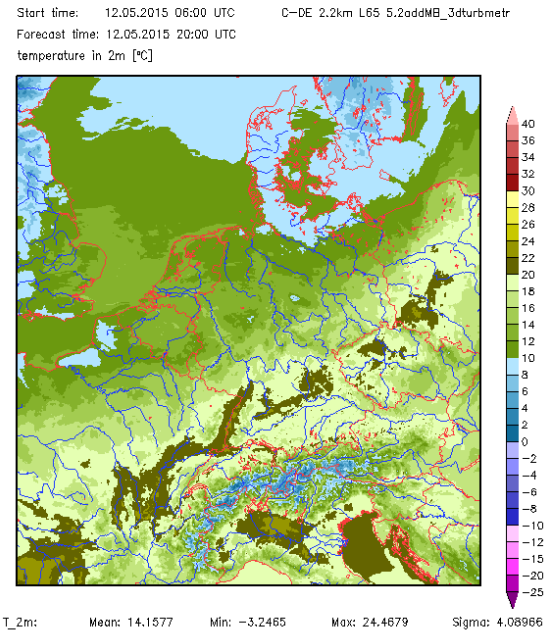
2 Real case study

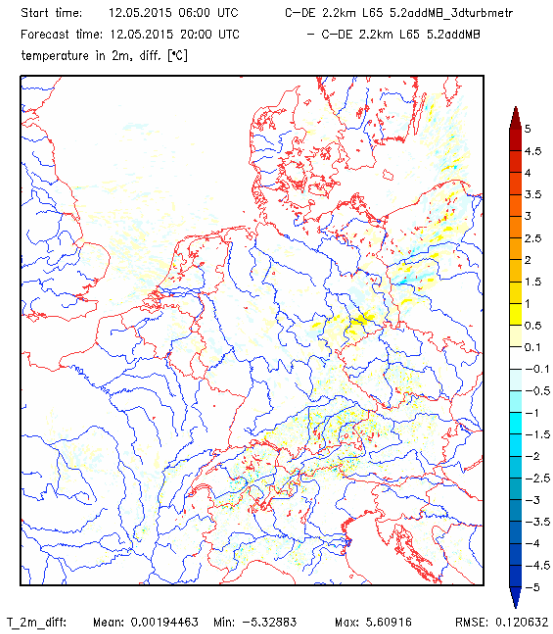
As a real case test of the new 3D diffusion routines, a COSMO model run with a horizontal resolution of 2.2 km, 65 vertical levels until 22 km height and a time step of 20 sec. was used. It covers an area over middle Europe and in particular contains the whole Alpine region.

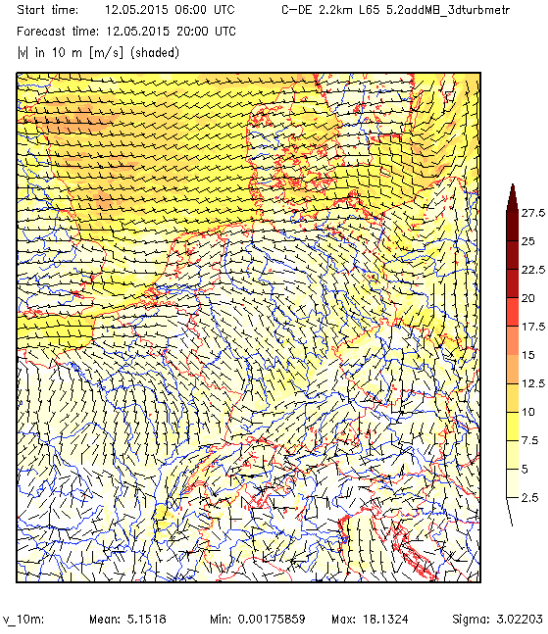
The day chosen was the 12 May 2015, 06 UTC run. At this day the operational COSMO 2.8 km version at DWD missed some convective events which produced heavy rain and intensive gusts.

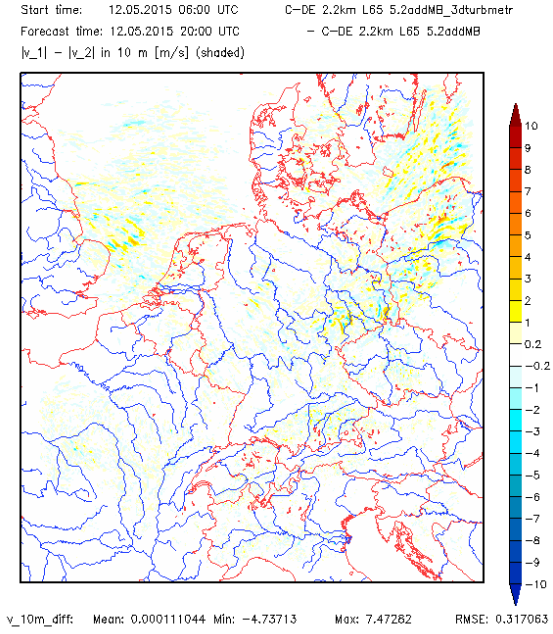
In the following plots the variables total precipitation (1h precipitation sum), 2m temperature, 10m wind velocity, and 10 maximum winds are shown for a simulation for all the 3D diffusion terms (on the left). On the right side differences against the same simulation, but without any 3D diffusion (and appropriate metric terms) is shown. Forecast time is 20 UTC, i.e. 14 h after model start. At this time differences between the simulation with and without 3D diffusion are highest. Nevertheless the differences are in general quite small. Larger differences seem mainly to be induced by a spatial shift in the structures. In any case, the differences do not indicate any strange behaviour in the 3D diffusion.

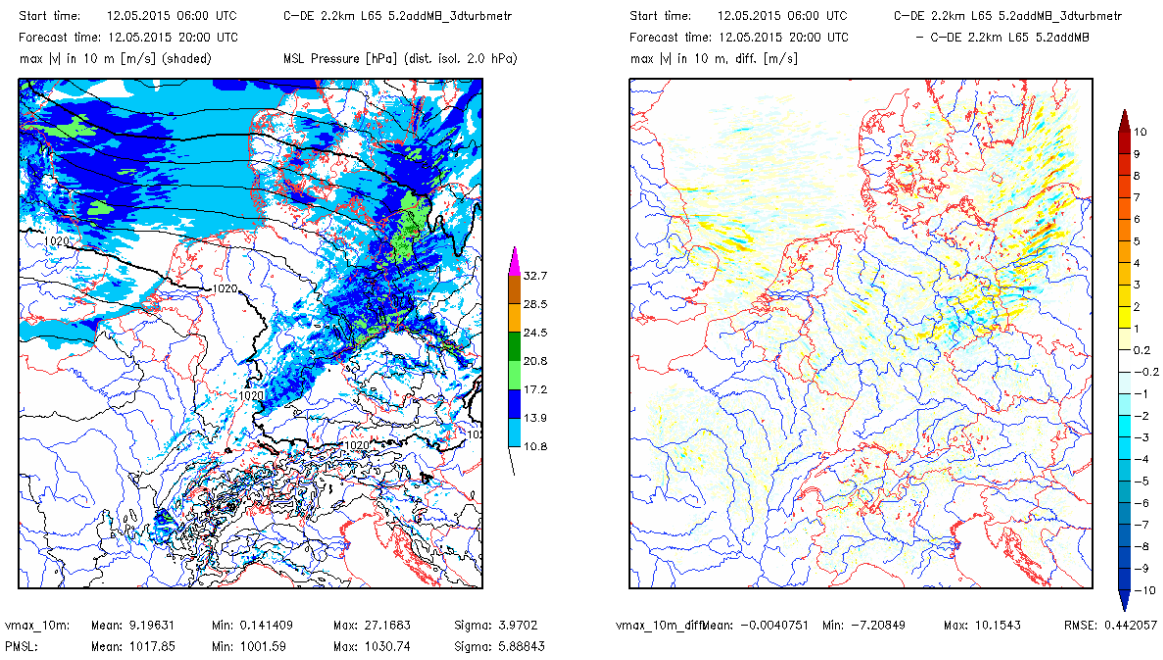



Start time: 12.05.2015 06:00 UTC C-DE 2.2km L65 5.2addMB_3dturbmetr
Forecast time: 12.05.2015 20:00 UTC
temperature in 2m [°C]
40
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
−15
−20
−25
T_2m: Mean: 14.1577 Min: −3.2465 Max: 24.4679 Sigma: 4.08966


Start time: 12.05.2015 06:00 UTC C-DE 2.2km L65 5.2addMB_3dturbmetr
Forecast time: 12.05.2015 20:00 UTC − C-DE 2.2km L65 5.2addMB
temperature in 2m, diff. [°C]
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0.1
−0.1
−0.5
−1
−1.5
−2
−2.5
−3
−3.5
−4
−4.5
−5
T_2m_diff: Mean: 0.00194463 Min: −5.32883 Max: 5.60916 RMSE: 0.120632


Start time: 12.05.2015 06:00 UTC C-DE 2.2km L65 5.2addMB_3dturbmetr
Forecast time: 12.05.2015 20:00 UTC
|v| in 10 m [m/s] (shaded)
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
v_10m: Mean: 5.1518 Min: 0.00175859 Max: 18.1324 Sigma: 3.02203


Start time: 12.05.2015 06:00 UTC C-DE 2.2km L65 5.2addMB_3dturbmetr
Forecast time: 12.05.2015 20:00 UTC − C-DE 2.2km L65 5.2addMB
|v_1| − |v_2| in 10 m [m/s] (shaded)
10
9
8
7
6
5
4
3
2
1
0.2
−0.2
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
v_10m_diff: Mean: 0.000111044 Min: −4.73713 Max: 7.47282 RMSE: 0.317063



The relatively small change due to 3D diffusion can also be seen in time series of the maximum horizontal wind velocity (left figure, red: with 3D diffusion, green: only 1D diffusion). Only the maximum vertical wind velocity shows some differences (right figure) (remark: the total simulation time was 24h, the time axis indeed shows these 24h instead of only 12h as erronously indicated).