Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Status report of

WG 2 – Numerical aspects

COSMO GM, DWD, Offenbach
5-8 Sept. 2016

Michael Baldauf (DWD)

with contributions from
Guy deMorsier (MCH), Andreas Will, Jack Ogaja (Univ. Cottbus)

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

M. Baldauf (DWD)

Problem: bug identified: missing metric factor

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

→ has cured all known model crashes occuring in the past, for which the divergence damping was responsible…
… and cures the following new model crashes occuring with COSMO 5.3, too:

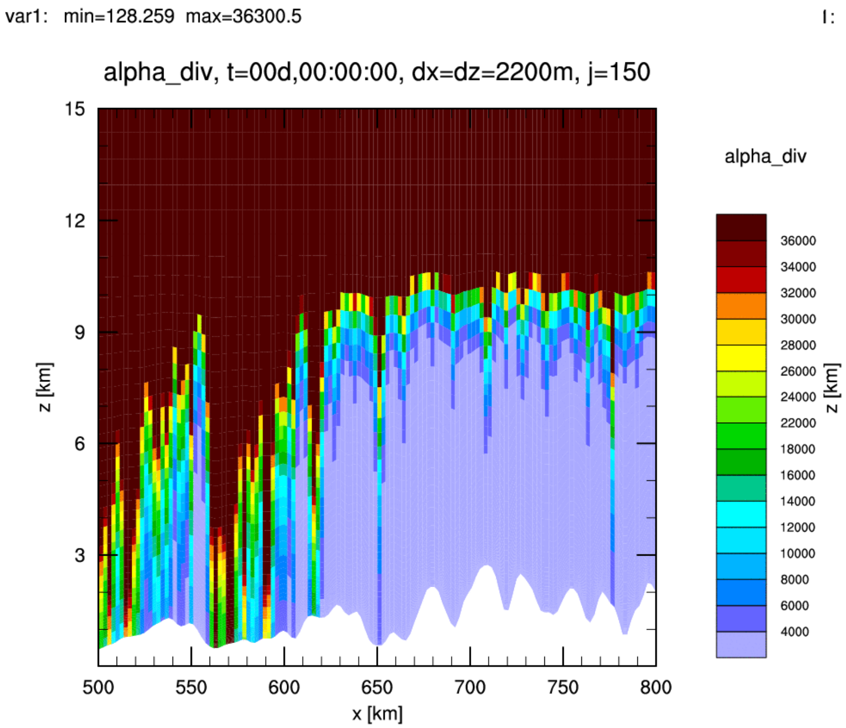
- COSMO-DE ‚20.02.16, 12 UTC, 21.02.16, 00 and 12 UTC' (Exp. by Klaus Stephan)
- COSMO-IT (10km) at ‚09.01.2016' (reported by Lucio Torrisi)
- KENDA NUMEX-Exp. 929w COSMO-DE at '17.09.2015, around 13 UTC (reported by Christoph Schraff, Hendrik Reich)

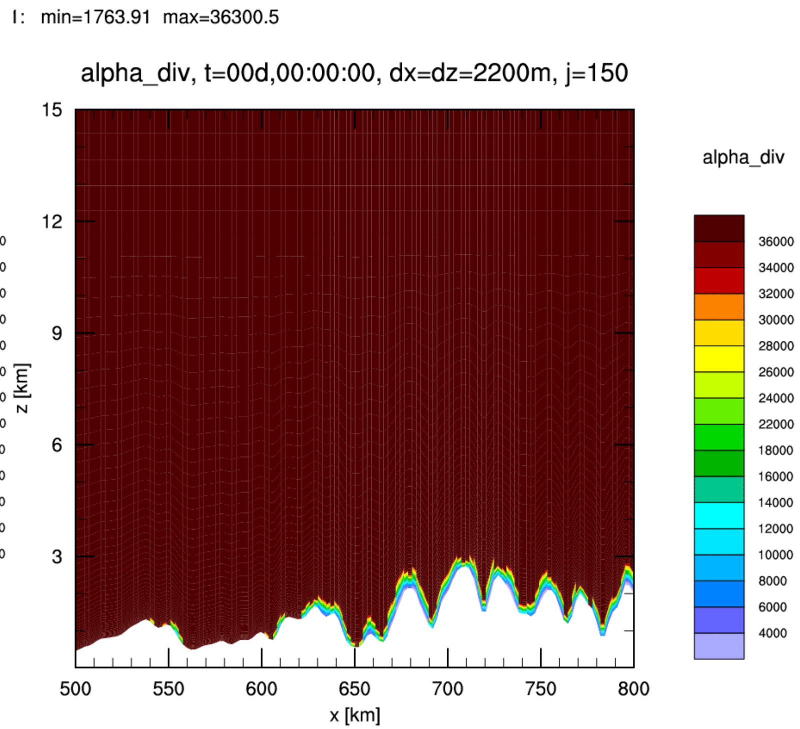
→ in operations at DWD since 02 June 2016

Bug identified: missing metric correction term
and now … `divdamp_slope = 1` is possible!

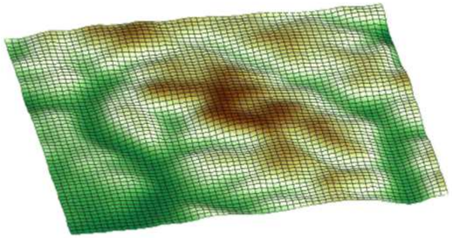
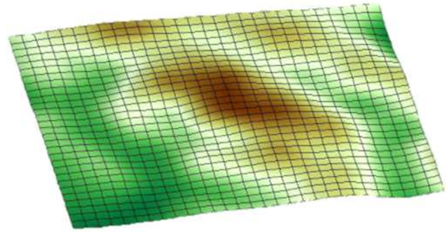
Divergence damping coefficient α_{div} over steep terrain (example: Alpine region)

COSMO 5.3 | New (5.4)





COSMO-1
Keywords

G. deMorsier (MeteoCH)

- **Convection-resolving** deterministic forecasts
- Initial conditions (ICs) from Nudging (later LETKF)
- **L**ateral **B**oundary **C**onditions from IFS-HRES **not** COSMO-7
- **More vertical levels** (80, COSMO-2 has 60; **SLEVE-type**)
- **Larger domain** (about 25% but same lead-time as COSMO-2)
- ❑ **No** parameterised **shallow convection** (results of Turb-i-Sim)
- **No** **S**ub-grid **S**cale **O**rographic **drag** (assumed to be resolved)
- **Different** wind gusts parameterisation (10 to 20% reduction)
- ❑ **External parameters** (higher resolution and better quality!)
- **FLake** (soon)

Summary

- **COSMO-1 is operational since 31.03.2016**
- Successful Co-design of Software, Hardware and Workflow which can **solve a 40x larger problem** with COSMO-E & LETKF
- Finalist for Swiss ICT Award 2016
- Seasonal verification benchmarks mostly attained: COSMO-1 is at least as good as COSMO-2 and will hence replace COSMO-2 which will be switched off by the end of Sep 2016.

Outlook

- Further development of **Data Assimilation at 1.1km**
- **Improvements** through better choices for namelist parameters (see CALMO Priority Project)
- Latest soil and/or turbulence parametrization

Higher order discretization

A. Will, J. Ogaja (BTU Cottbus)

Status

- Large improvement in efficiency done!
  In the comparison advS4-P4 / advUP5-P2:
  advection ~10%, fast waves ~3% more expensive.
  → without artificial diffusion, the costs are roughly the same!
- Dissertation J. Ogaja is available.
- Summerly precipitation dry bias is still not solved.
- Model crash COSMO-DE (‚20.06.2013')

Plans:

- Deliver the revised source code COSMO 5.00 hos2 for preparing it for the (next?) official COSMO version.
- Deliver final reports on the results obtained for the COSMO-EU and COSMO-DE configuration.

Further plans

Adaptive time step

A. Smalla, T. Reinhard (DWD)

Todo:

- existing work must be migrated from COSMO 4.26 to current version
- 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 5.5 version is less probable.

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

G. deMorsier (MeteoCH)

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

Improved Bott-scheme

W. Schneider (Bonn)

promises to give up the Strang splitting

CONSORTIUM FOR SMALL SCALE MODELING COSMO

Deutscher Wetterdienst
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PP CDIC – Status report

COSMO GM, DWD, Offenbach
5-8 Sept. 2016

Michael Baldauf (DWD)

with contributions from
Günther Zängl, Florian Prill, Daniel Reinert (DWD),
Rodica Dumitrache, Amalia Iriza (NMA),
Marina Shatunova (RHM), Guy deMorsier (MCH)

Task 1. Good performance on a standard set of idealized test cases

1.	Advection test with nonlinear dynamics (Schär et al. (2002))	NN	?!
2.	Atmosphere at rest (Zängl et. al (2004) MetZ)	Barbu/Dumitrache/Iriza	🛠
3.	Cold bubble (Straka et al. (1993)) (unstationary density flow)	Barbu/Dumitrache/Iriza	🛠
4.	Mountain flow tests (stationary, orographic flows)		
4.1	Schaer et al. (2002), section 5b	Baldauf	🛠
4.2	Bonaventura (2000) JCP	"	!
4.3	3D-case (dry) Schmidli (?)	"	!
5.	Linear Gravity waves (Baldauf, Brdar (2013))	Baldauf	🛠
6.	Warm bubble (Robert (1993), Giraldo (2008))	Wojcik	!
7.	Moist, warm bubble: Weisman, Klemp (1982) MWR	Wojcik	🛠
8.	Advection tests for tracer schemes (solid body rotation, …)	Will (without FTE)	!

Overall assessment:

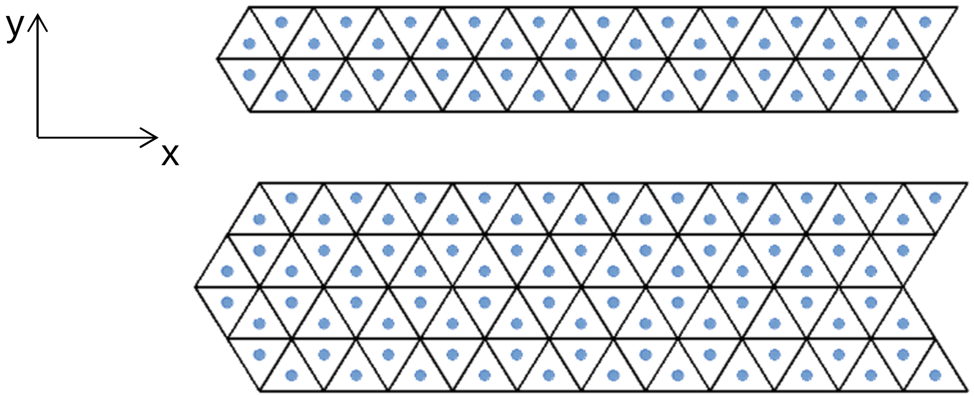
- volunteers for almost all tests have been found
- test cases are a bit behind schedule ← to get familiar with ICON is more difficult compared to COSMO mainly due to the unstructured grid (both code complexity and use of external grid files)

- All the tests use flat domains
- most of them are 2D slice (x-z) model tests
- and some of those use (double) periodic BCs → torus grid

Problems in ICON fixed:

- Interpolation to regular latlon-grid for output for a ‚torus-grid' (extension of subroutine `gc2cc`, `cc2gc`, thanks to *Florian Prill*)
- Choice of a usable torus-grid (*L. Linardakis, MPI-M*) for 2D slice (x-z-) simulations:

used now:



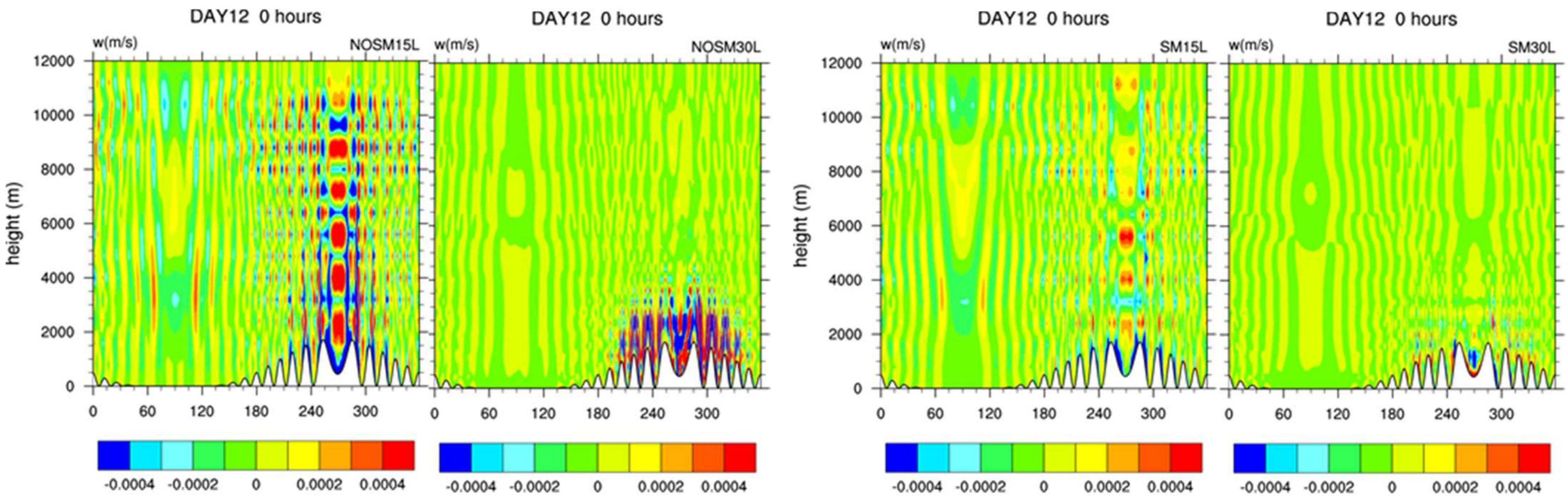
Test case 2: atmosphere at rest

R. Dumitrache, A. Iriza (NMA)

global model ICON with dx ~80 km, mountains at equator.
w after 12 days for 15 or 30 vertical levels (equidistant) and with or without Smagorinski-diffusion

Test properties:

- dry Euler equations
- test of well-balancing
- reference solution trivial

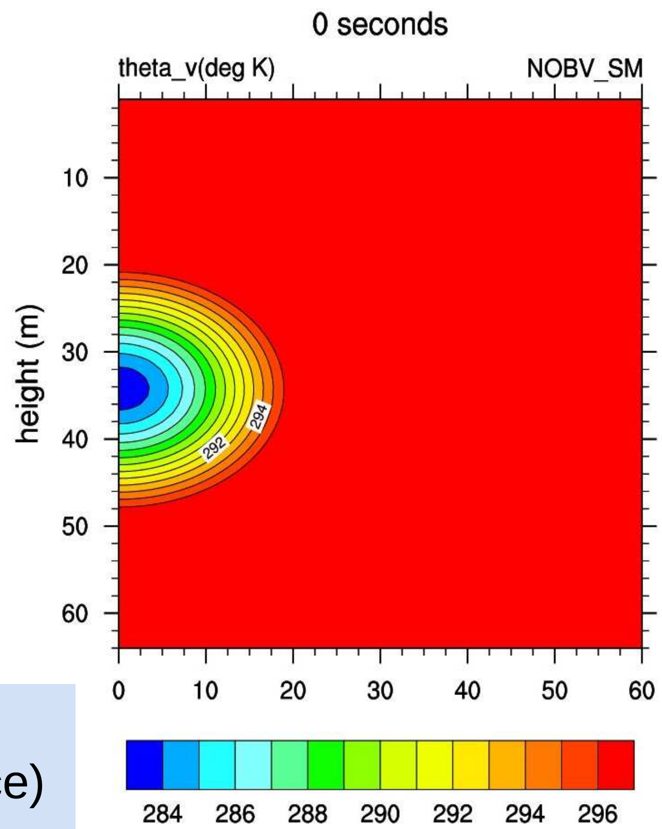


Test case 3: cold bubble

R. Dumitrache, A. Iriza (NMA)

Testsetup by *Straka et al (1993)*

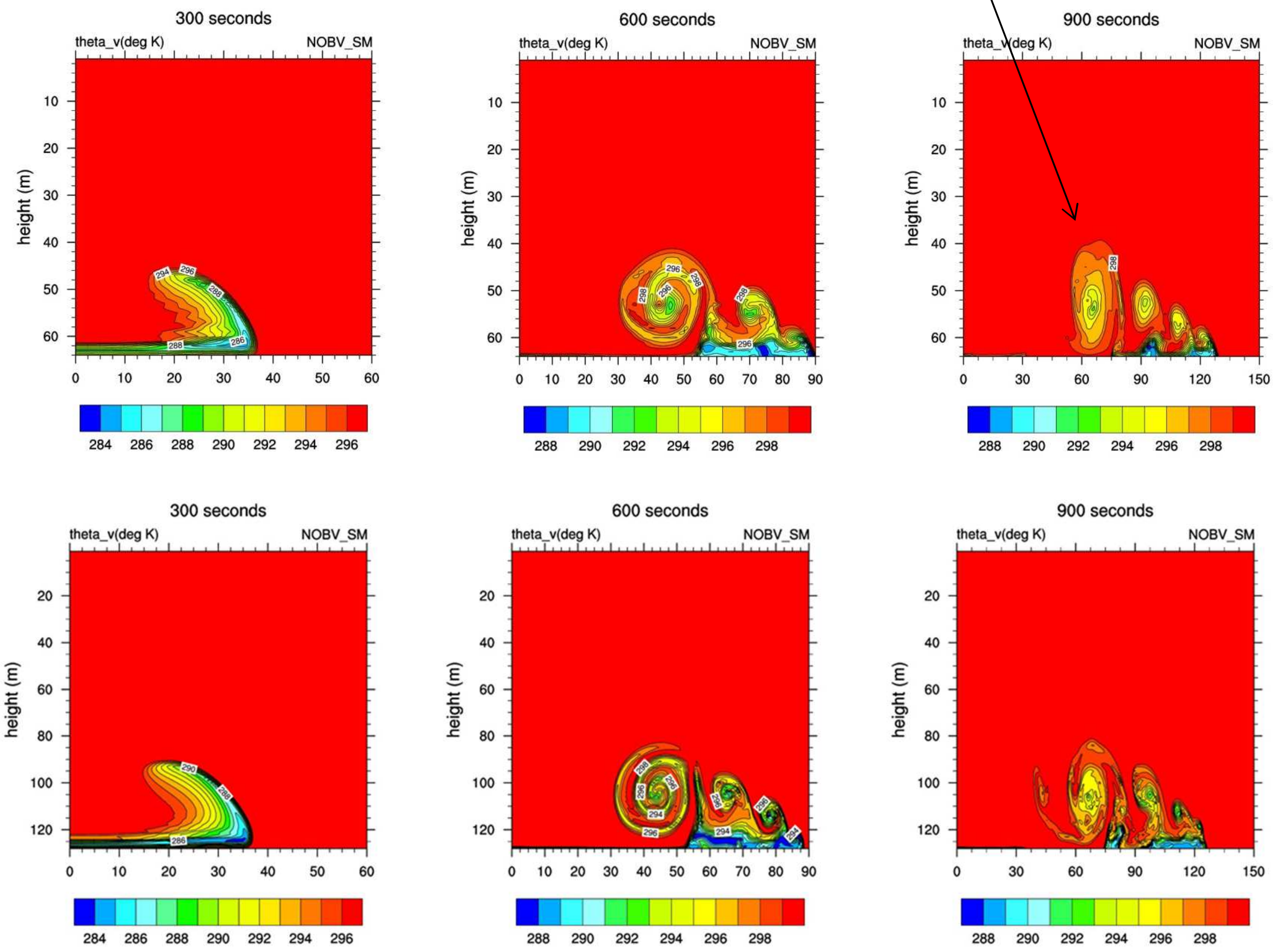
(virtual) potential temperature (in K)
at the beginning of the run
(similar for all experiments)



Test properties:

- test of dry Euler equations (without Coriolis force)
- unstationary
- strongly nonlinear
- comparison with reference solution from paper

physical 3D diffusion is still missing!



dx=100m
dt=0.5

dx=50m
dt=0.25

Test case 4.1: linear flow over mountains

M. Baldauf (DWD)

setup: *Schär et al. (2002)*

Orography: $$h(x) = h_0 \cdot e^{-x^2/b^2} \cdot \cos^2 \pi \frac{x}{\lambda}$$

h_0=25m, b=5km, λ=4km
u_0=10m/s, N=0.01 1/s, $T(z=0)$=288K

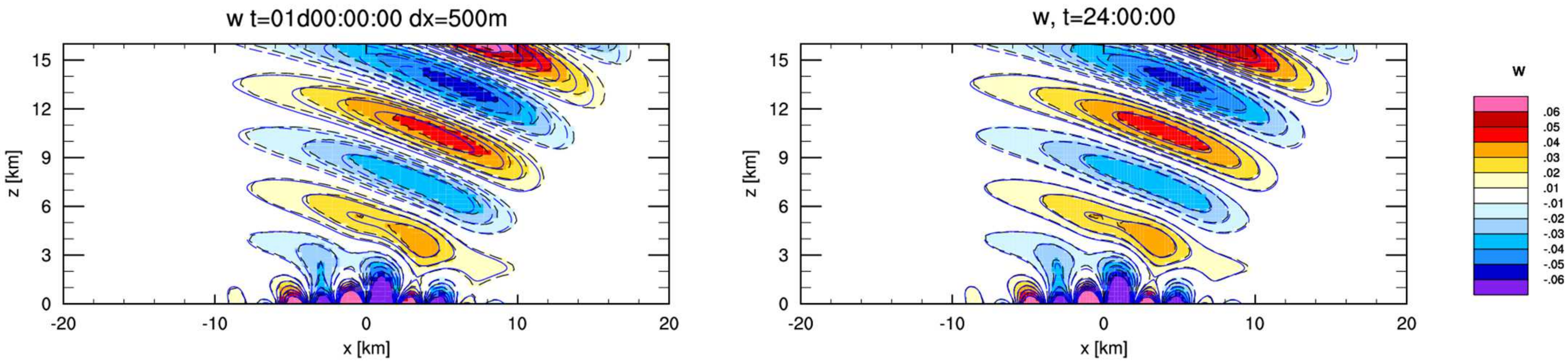
analytic linear solution: *Baldauf, 2008, COSMO-NL*
(uses almost no further simplifications, e.g. it is a fully compressible solution)

Test properties:

- test dry Euler equations without Coriolis terms
- stationary
- with orography → test also metric terms
- small amplitude → linear → comparison with analytic solution possible

COSMO ICON

dx=500m

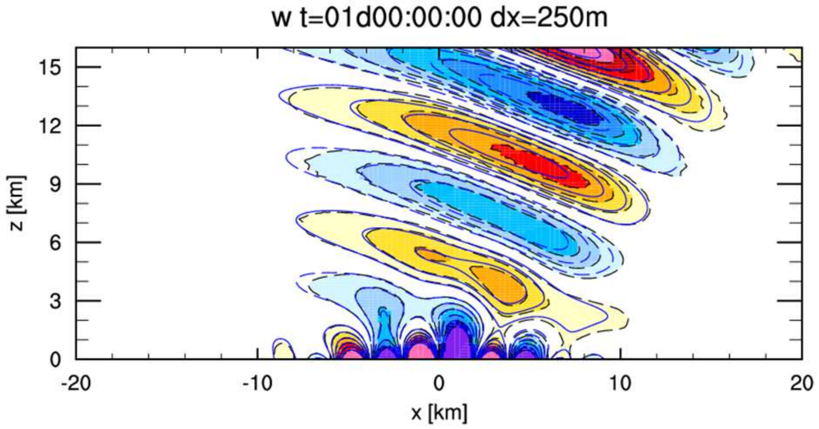


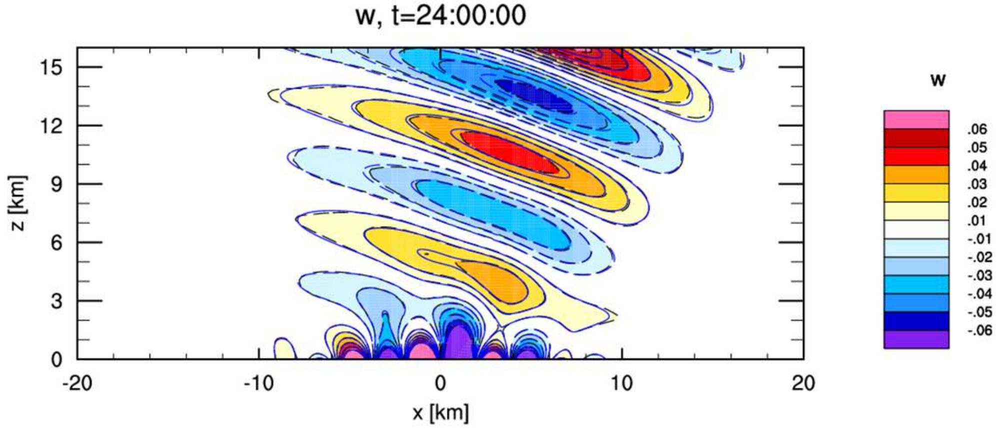
colors and black dotted lines: COSMO or ICON
blue lines: analytic solution

COSMO

ICON

dx=250m





colors and black dotted lines: COSMO or ICON
blue lines: analytic solution

Summary for linear flow over mountains (Schär et al.) test

- In this low mountain test both models COSMO and ICON behave quite similar; with slight advantages for ICON.
- The overall agreement with the analytic solution is very good
  → metric terms are correctly implemented

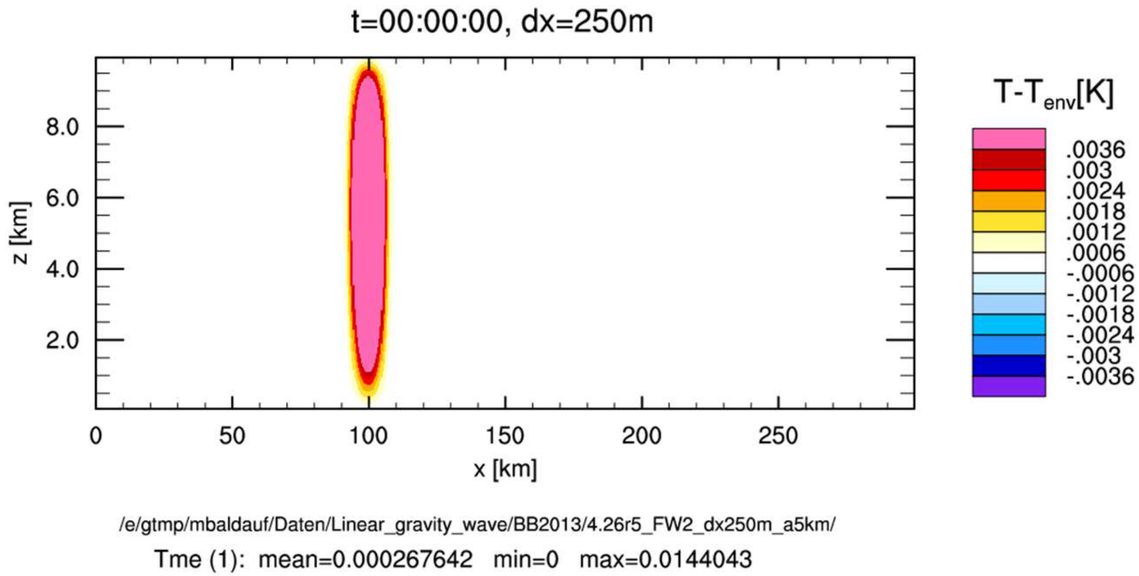
Next steps

- agreement with analytic solution in the 3D case (test case 4.3)
- comparison of stability limits for very high/steep mountains

Test case 5: Linear gravity waves

M. Baldauf (DWD)

test defined in *Baldauf, Brdar (2013) QJRMS*
(similar to *Skamarock, Klemp (1994) MWR)*



Test properties:
- test dry Euler equations
- unstationary
  → inspect time integr.
- no orography
- small amplitude
  → linear → comparison with analytic solution

Initialization similar to
Skamarock, Klemp (1994)

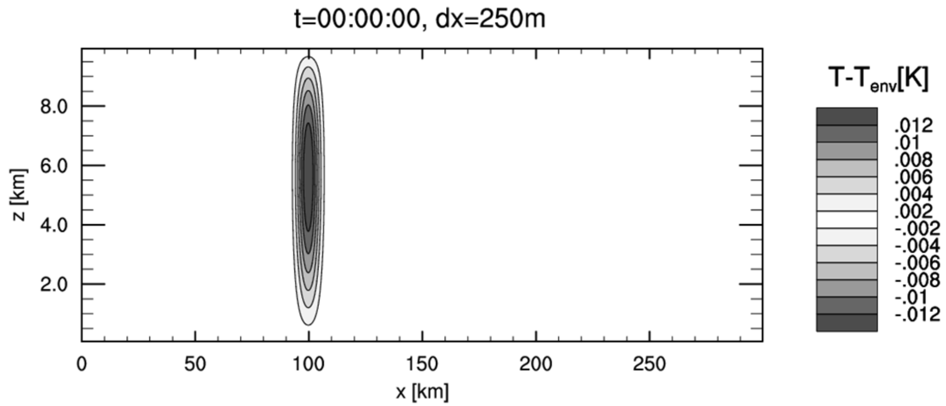
$$T'(x,z,t=0) = \Delta T \cdot e^{\frac{1}{2}\delta z} \cdot e^{-\frac{(x-x_c)^2}{d^2}} \cdot \sin \pi \frac{z}{H}$$

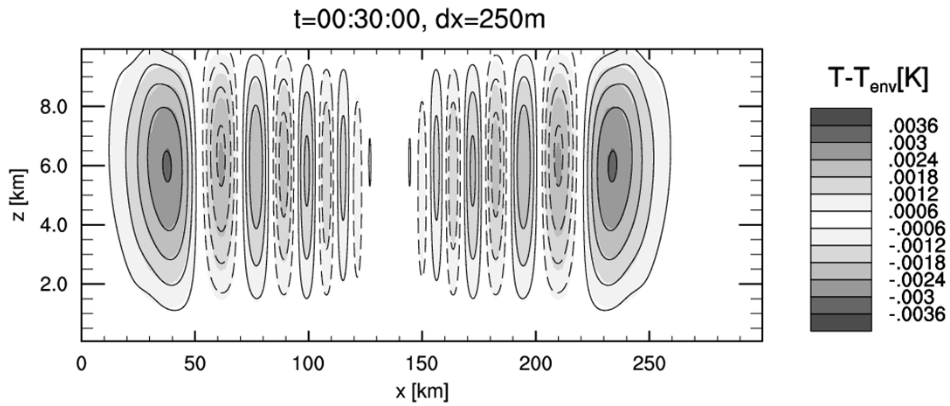
$$p'(x,z,t=0) = 0$$

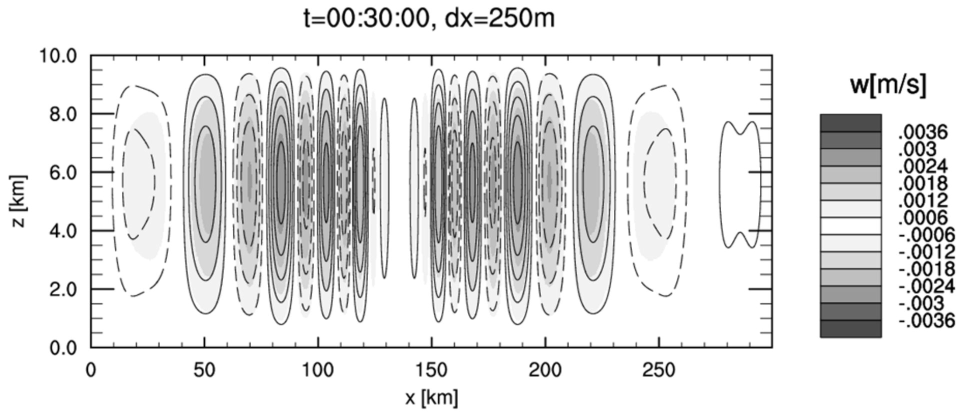
Small scale test
with a basic flow U_0=20 m/s,
f=0

Black lines: analytic solution
(Baldauf, Brdar (2013) QJRMS)

Shaded: COSMO







Test setup 2:
small scale test with advection (U0=20 m/s) and without Coriolis force

In COSMO: now divergence damping is necessary

Inspect resolutions:	2km,	1km,	500m,	250m,	125m
dt (COSMO)	10s,	5s,	2.5s,	1.25s,	0.625s
dt (ICON)	6s,	3s,	1.5s,	0.75s,	0.375s

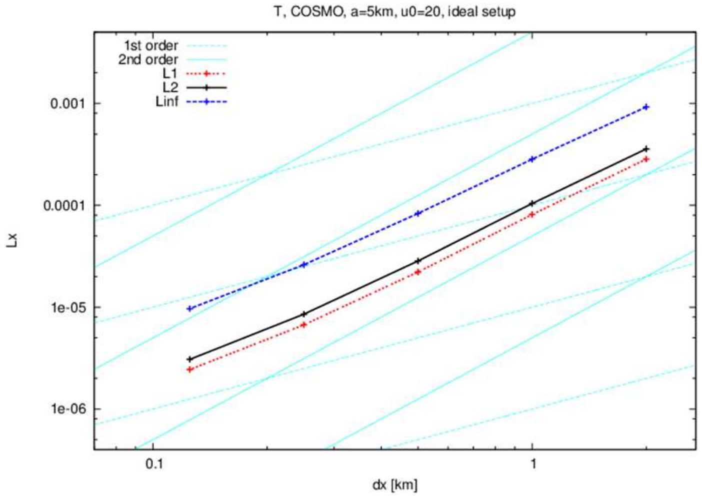
In the following convergence study compare:
COSMO: dx=grid mesh size, dt_small = dt/6
ICON: dx=length of triangle edge, dt_small = dt/5
for an equilateral triangle $\sqrt{A}$=dx * 0.658…

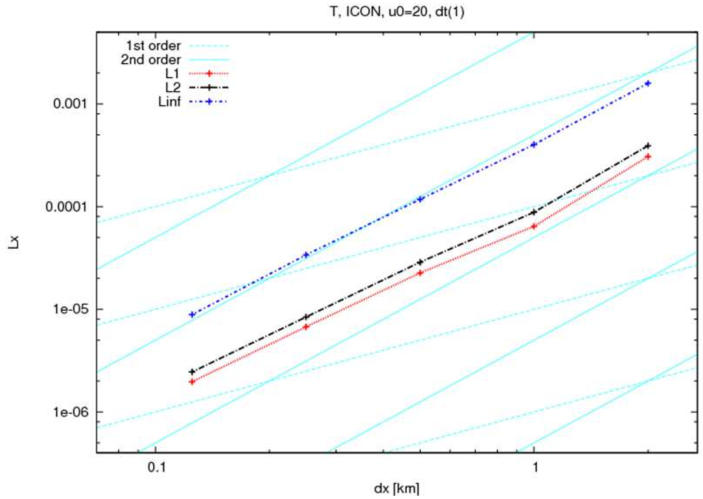
Convergence behaviour

COSMO

ICON

T'





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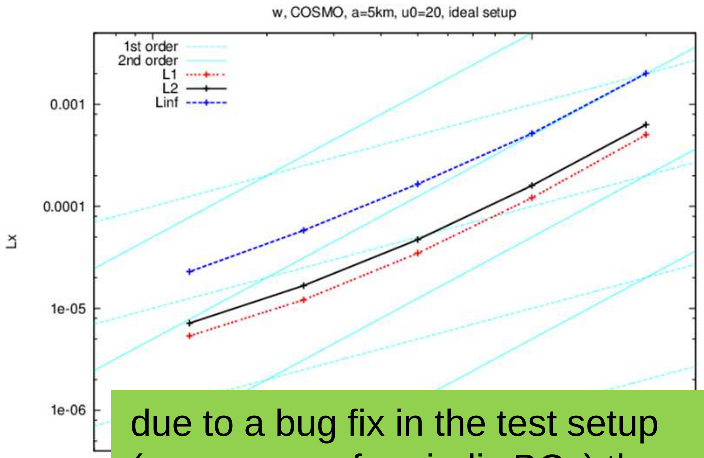
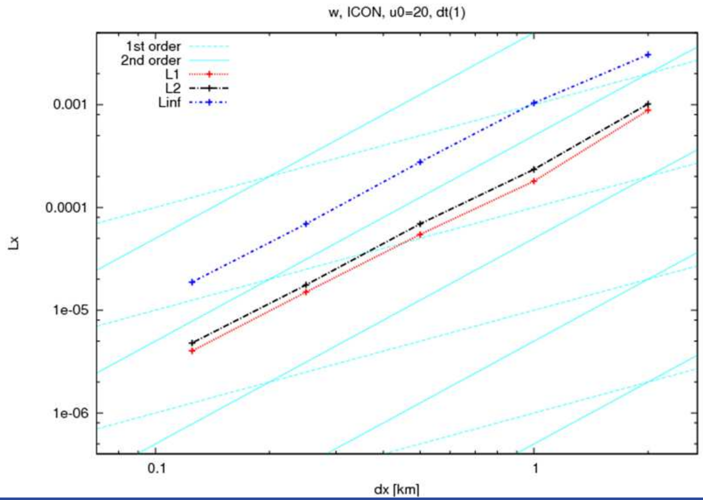


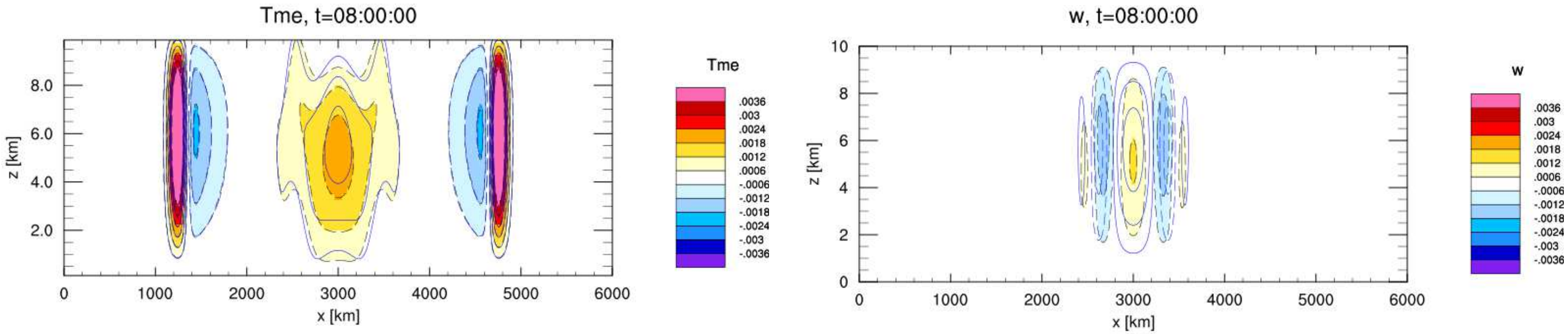


due to a bug fix in the test setup (proper use of periodic BCs) the COSMO result is now better than that described in *BB2013*

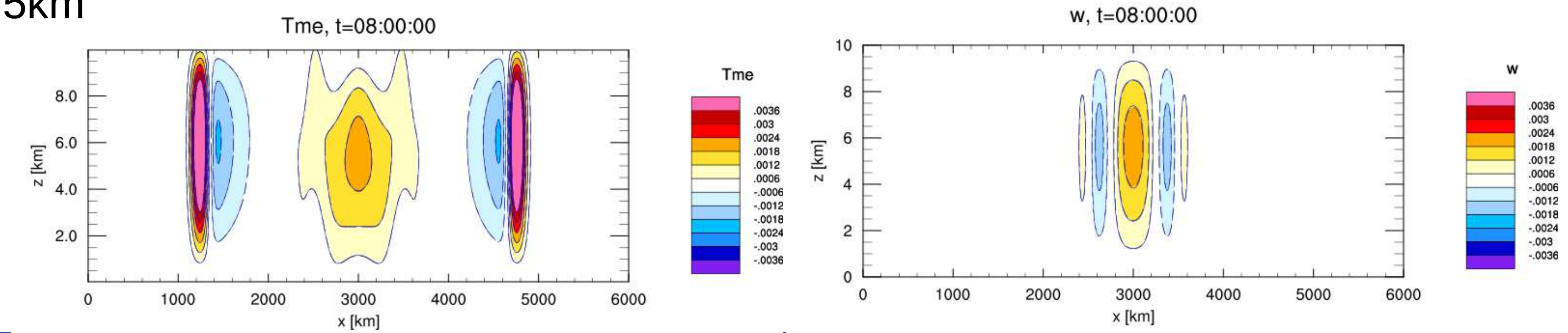
Large scale test without advection but with Coriolis force

ICON results: (colors and black dotted lines: ICON, blue lines: analytic sol.)

dx=10km



dx=2.5km

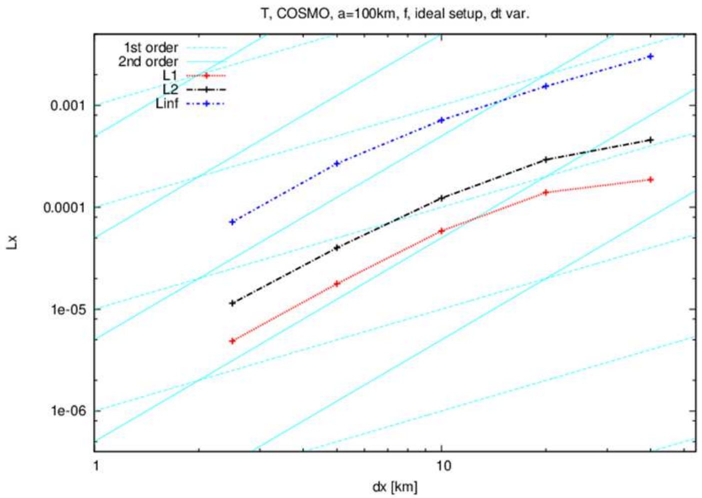


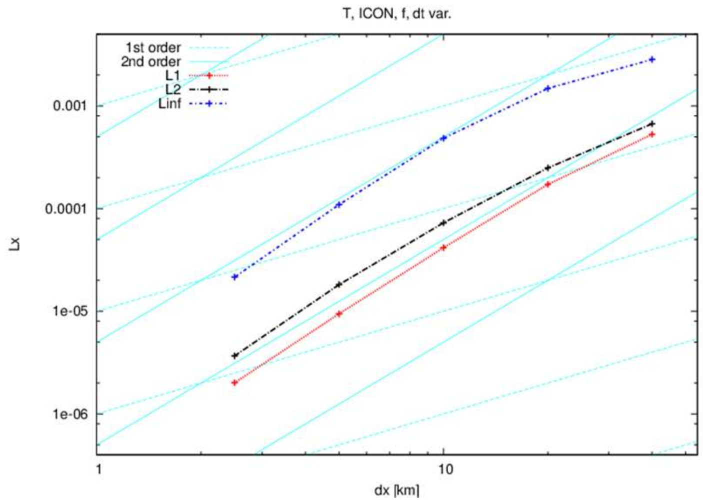
Convergence behaviour

COSMO

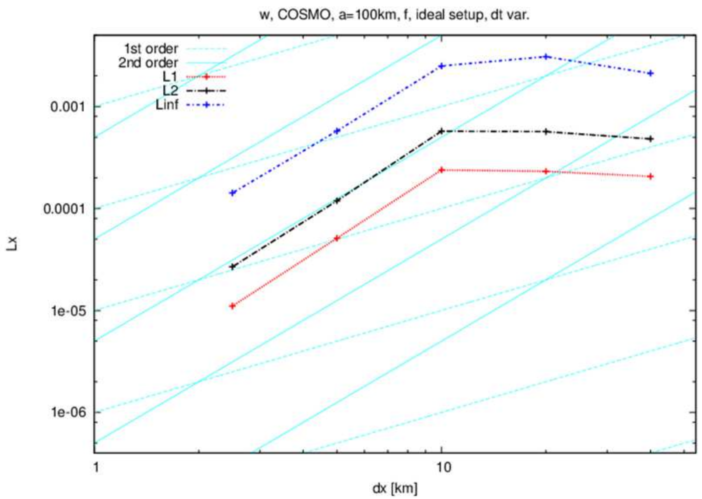
ICON

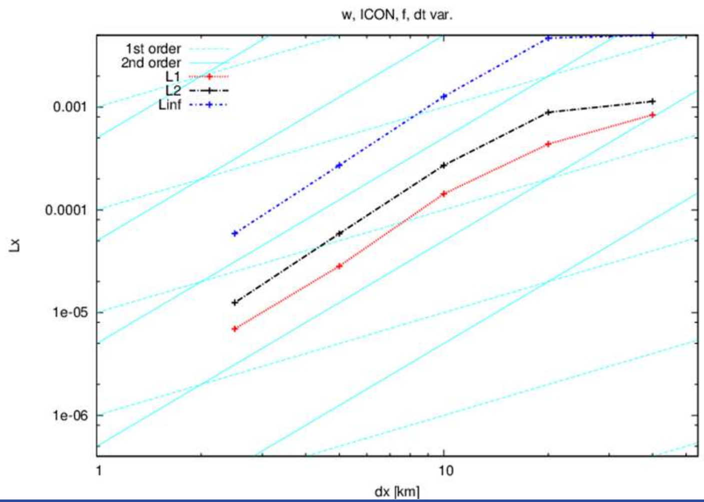
T‘





w





Summary for the linear wave test

- Test 1 (only fast waves):
  ICON shows nearly 2nd order convergence.
  COSMO shows nearly 2nd order only in T, but less in w
  → w error is smaller in ICON for fine resolutions
- Test 2 (FW + advection):
  ICON behaviour is similar to test 1.
  COSMO convergence order is slightly reduced
  for coarse resolutions ICON errors are a bit larger than in COSMO,
  for fine resolutions a bit smaller
- Test 3 (FW + Coriolis):
  both models show 2nd order convergence;
  but the errors are smaller in ICON

→ This task is almost finished

Task 2. Ability to handle real-/semi-idealised cases reasonably well

M. Shatunova, G. Rivin (RHM), G. deMorsier (MCH)

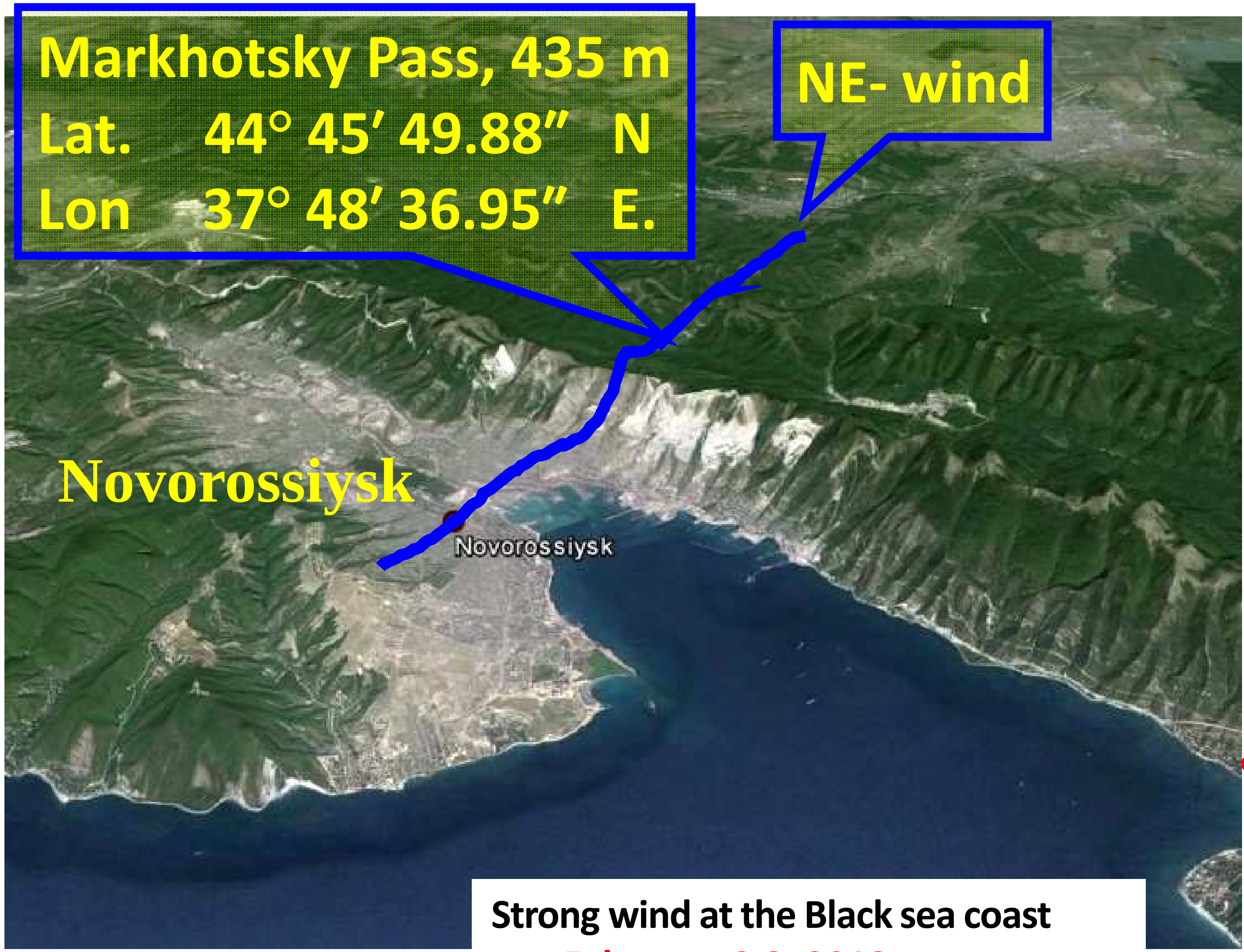
Until now, only test cases defined:

- strong advective case: storm ‚Elon', 9-10 Jan. 2015   (MeteoCH)
- Bora event: 6-8 Feb. 2012 (possibly also 19 Feb. 2016)   (RHM)

Necessary next step:

bring ‚limited area' mode of ICON into official version and distribute it.

Strong wind (Bora) in Novorossiysk



Strong wind at the Black sea coast

- **February 6-8, 2012**
  bora event in Novorossiysk
  with Vmax= 44 m/s ***> 150 km/h,***

February 2012, Novorossiysk

Task 4: Identification of differences in dynamical core formulations and their assessment

Status:

Stability analysis (mixed von-Neumann/normal mode analysis, beyond those in *Zängl et al, 2015*) of the ICON dynamical core took place.
Presentations at SciCADE 2015, Potsdam, and Gung-Ho meeting 2015, Exeter *(Baldauf).*

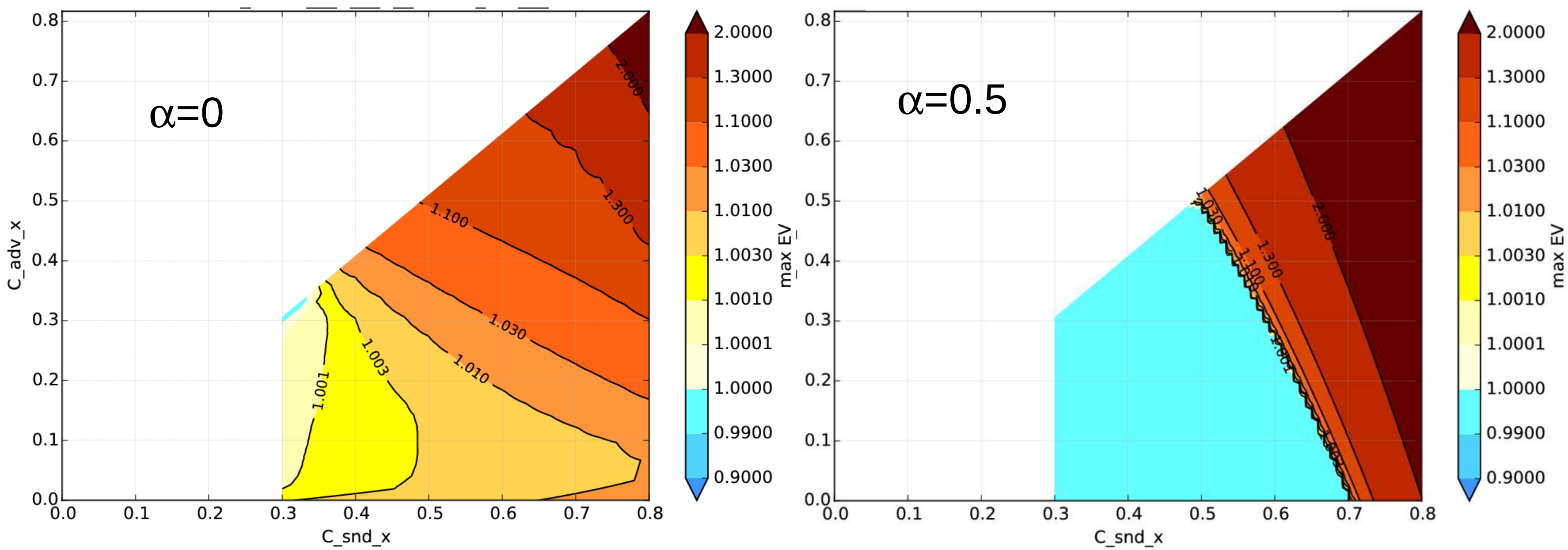
Plans:
investigate influence of the implicit divergence damping in the pressure gradient off-centering/extrapolation.

Example: influence of pressure gradient time-level averaging

$$\frac{u^{n+1*} - u^n}{\Delta t} = -U_0 \delta_x u^{n*} + c_p \Theta_0 \, \delta_x \left((1+\alpha) \pi'^n - \alpha \pi'^{n-1} \right)$$

(analogous in corrector step)

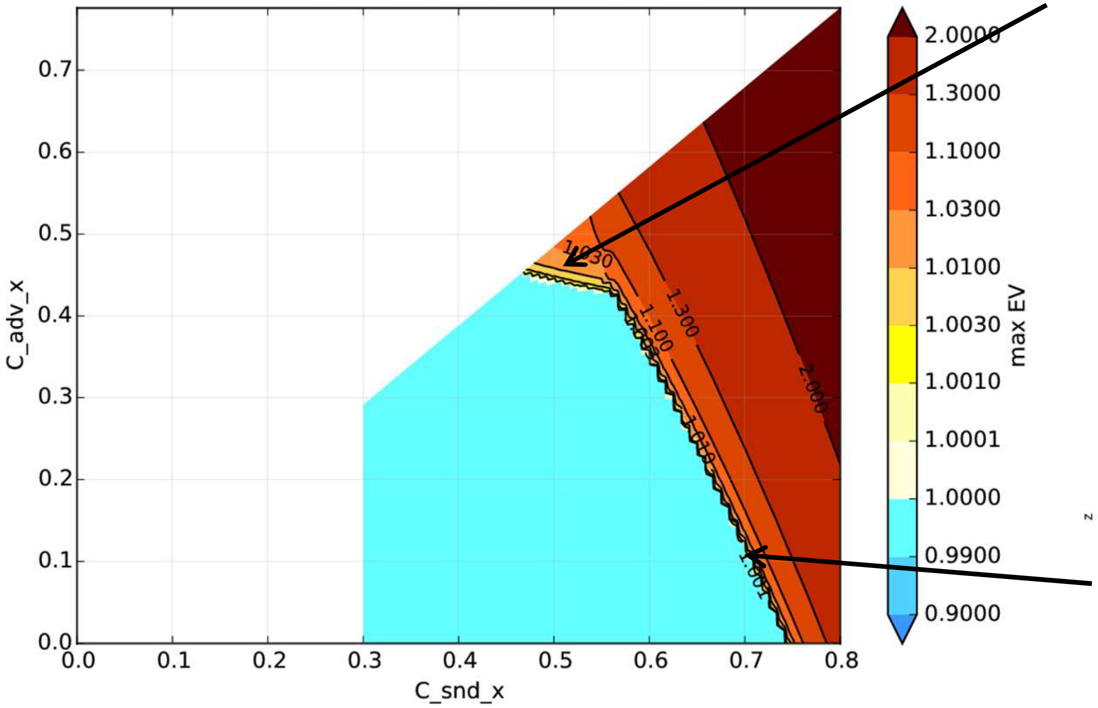
… acts like a divergence damping (*Klemp et al. (2007) MWR*)

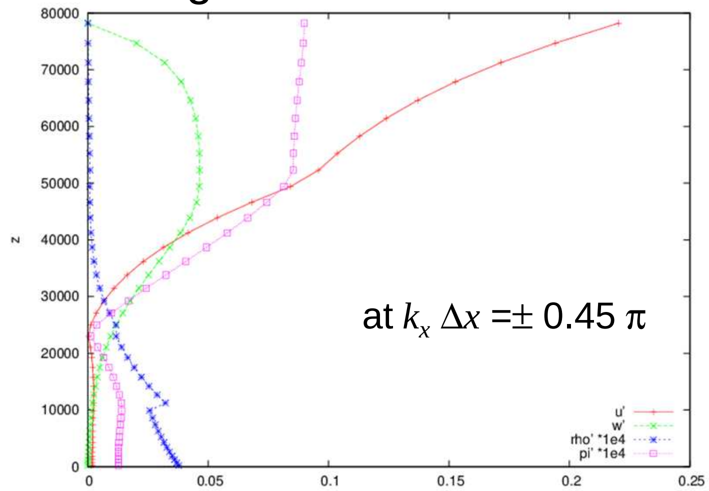


isothermal atmosphere, unstretched grid

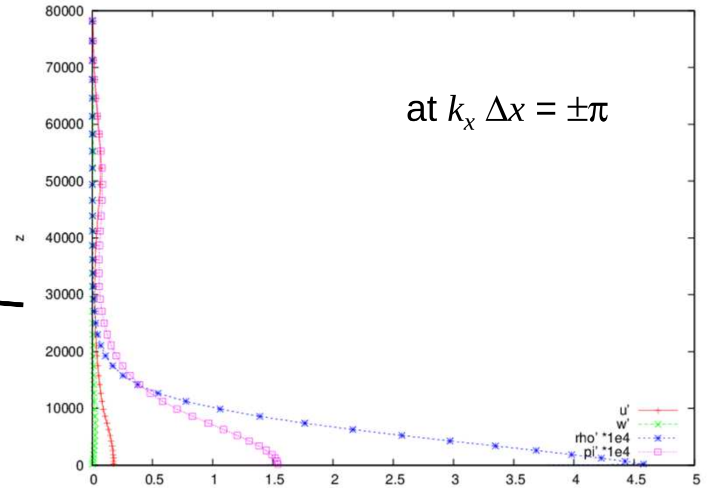
Example:
Standard atmosphere stratification
vertically stretched grid, H_{top}=80km
no explicit damping mechanisms

eigenvector structure:





at $k_x \Delta x = \pm 0.45\,\pi$



at $k_x \Delta x = \pm\pi$

Task 3. Scalability/Performance suitable for operations as well as for future supercomputing platforms

Nothing done yet

Task 5. Suitability of ICON dynamical core for other applications than NWP (climate, chemistry, ...) compared to the COSMO model

Until now only one volunteer to assess ICON-ART (Roshydromet).
Volunteer(s) from CLM community are welcome, too!