Status and plans of numerics in COSMO

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Deutscher Wetterdienst

Based on M. Baldauf et al.

New upper sponge layer based on Klemp et al., 2008, MWR

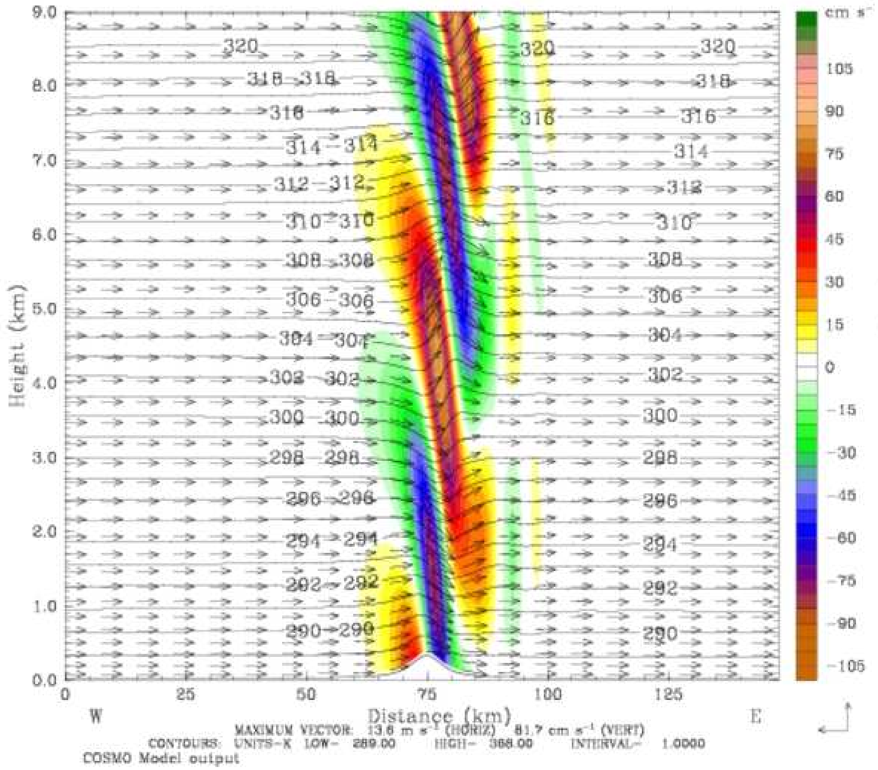
- Purpose: Prevent unphysical reflection of vertically propagating gravity waves at upper model boundary.
- Unlike conventional damping layers, only the vertical wind is damped; specifically this is done in the fast-wave solver immediately after solving the tridiagonal matrix for the vertical wind speed.
- Analytical calculations by Klemp et al. indicate very homogeneous absorption properties over a wide range of horizontal wavelengths.

work by G. Zängl

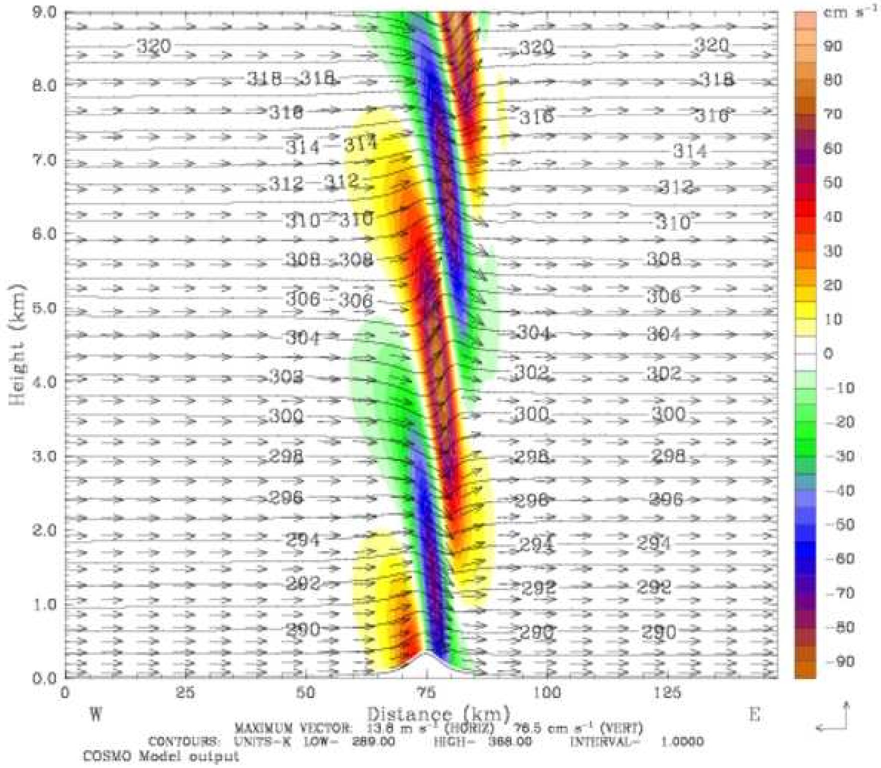
Quasi-linear flow over a mountain

u = 10m/s, h = 300 m, a = 5 km, Δx = 1 km;

Fields: θ (contour interval 1 K), w (colours) **t = 24h**



conventional Rayleigh damping, t_{damp} = 600 s



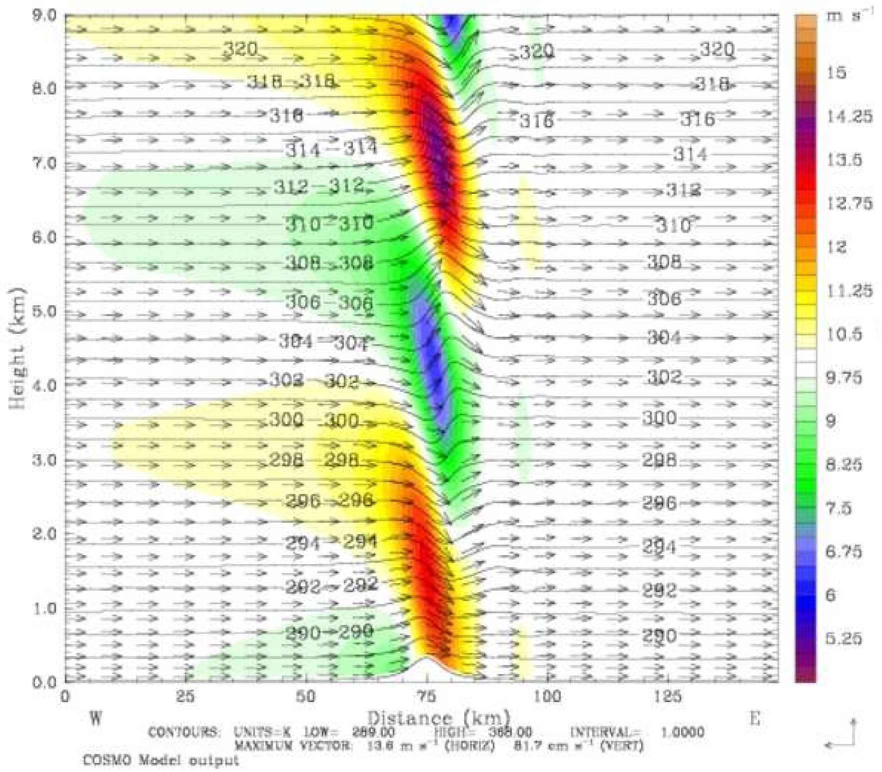
w damping, t_{damp} = 12 s

Depth of damping layer: 10 km; top of model at 22 km

Quasi-linear flow over a mountain

u = 10m/s, h = 300 m, a = 5 km, Δx = 1 km;

Fields: θ (contour interval 1 K), u (colours)　　　　　**t = 24h**



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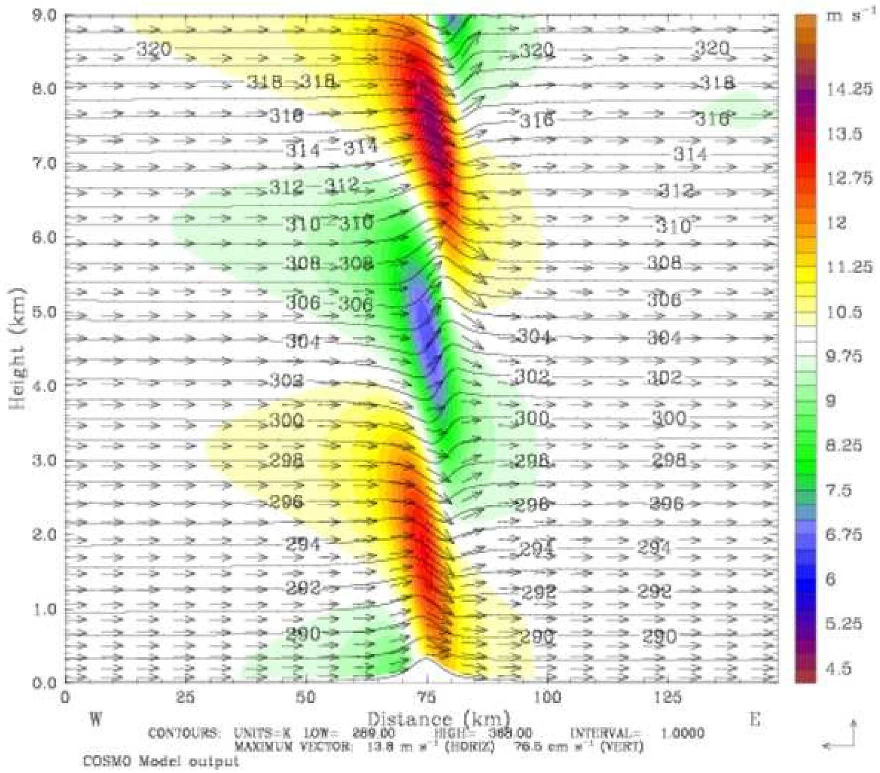


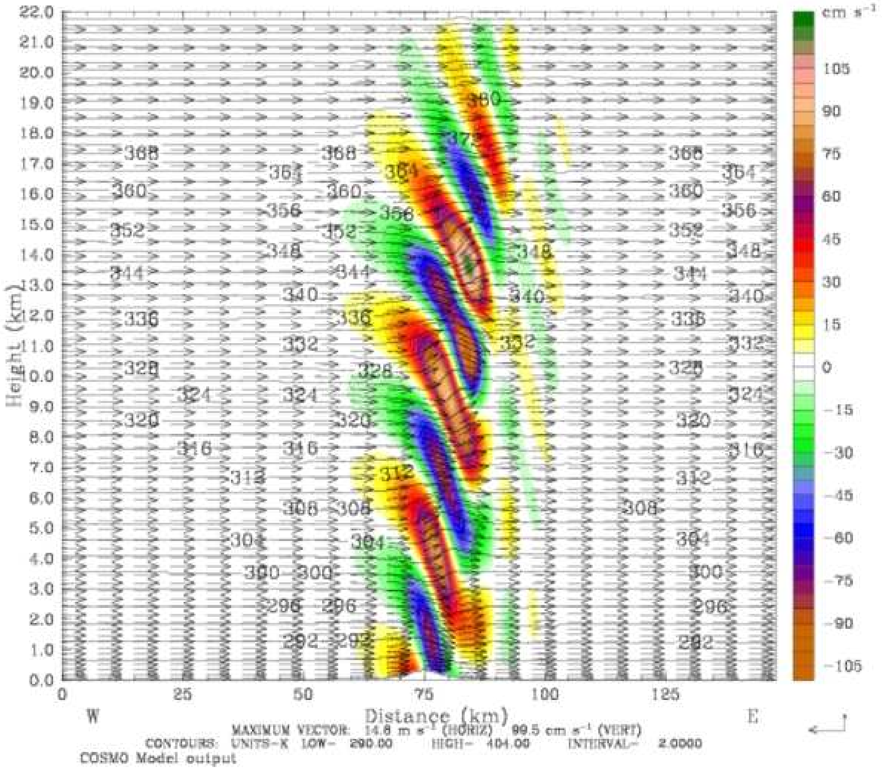
w damping, t_{damp} = 12 s

Depth of damping layer: 10 km; top of model at 22 km

Quasi-linear flow over a mountain

u = 10m/s, h = 300 m, a = 5 km, Δx = 1 km;

Fields: θ (contour interval 2 K), w (colours) **t = 24h**



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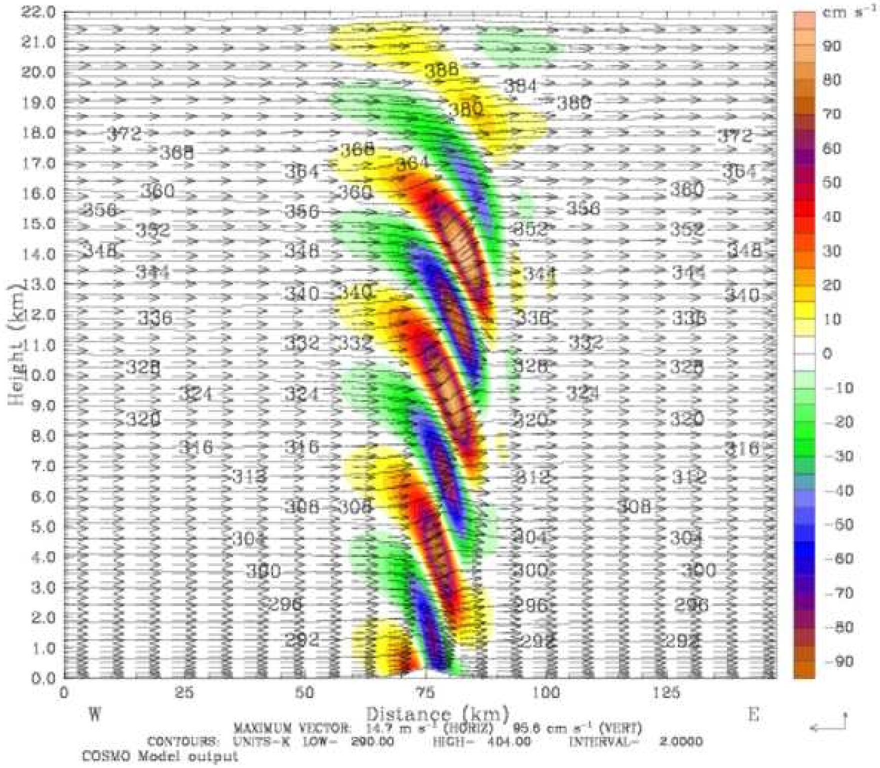


w damping, t_{damp} = 12 s

Depth of damping layer: 10 km; top of model at 22 km

Higher order discretization in the vertical for the Runge-Kutta scheme

Improved vertical advection for the dynamic var. u, v, w, T (or T'), p'

motivation: resolved c*onvection*

- → vertical advection has increased importance => use scheme of higher order (compare: horizontal adv. from 2^{nd} to 5^{th} order)
- → => bigger w (~20 m/s) => CFL-criterium is violated => implicit scheme or CNI-explicit scheme

up to now: implicit (Crank-Nicholson) advection 2^{nd} order (centered differences)

new: implicit (Crank-N.) advektion 3^{rd} order → LES with 5-band diagonal-matrix

but: implicit adv. 3^{rd} order in every RK-substep needs ~ 30% of total computing time!

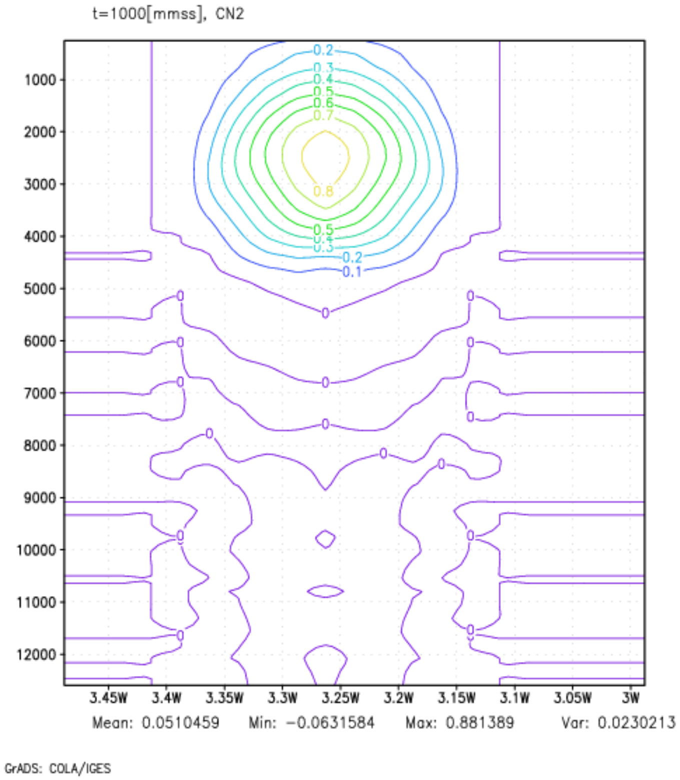
→ plan: use outside of RK-scheme (splitting-error?, stability with fast waves?)

work by M. Baldauf

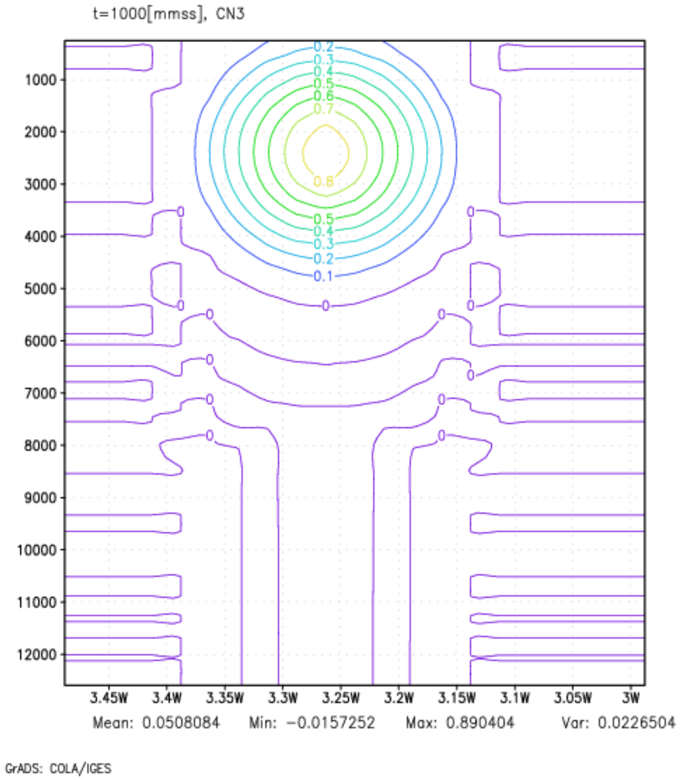
Higher order discretization in the vertical for the Runge-Kutta scheme

Comparison of the two implicit vertical advection schemes
Test with constant vertical velocity (w ~ 10 m/s); initial cone distribution

implicit cent. diff. 2nd order



implicit cent. diff. 3rd order



Higher order discretization on unstructured grids using Discontinuous Galerkin methods

DWD: Baldauf, Univ. Freiburg: Kroener, Dedner, Brdar
2009 start, 2011 report

- DFG priority program 'METSTRÖM' **(http://metstroem.mi.fu-berlin.de).**
- Goal: New dynamical core for the COSMO-model.
- Discontinuous Galerkin methods (achieve higher order, conservative discretizations).
- Building of an adequate library, DUNE: *Distributed and Unified Numerics Environment*.
- ***DUNE: http://www.dune-project.org/***.
- Density, momentum and total energy as prognostic variables.
- The work with the COSMO-model will start at the end of 2009.
- Basic research if these methods can lead to efficient solvers for NWP models.

Discontinuous Galerkin Method

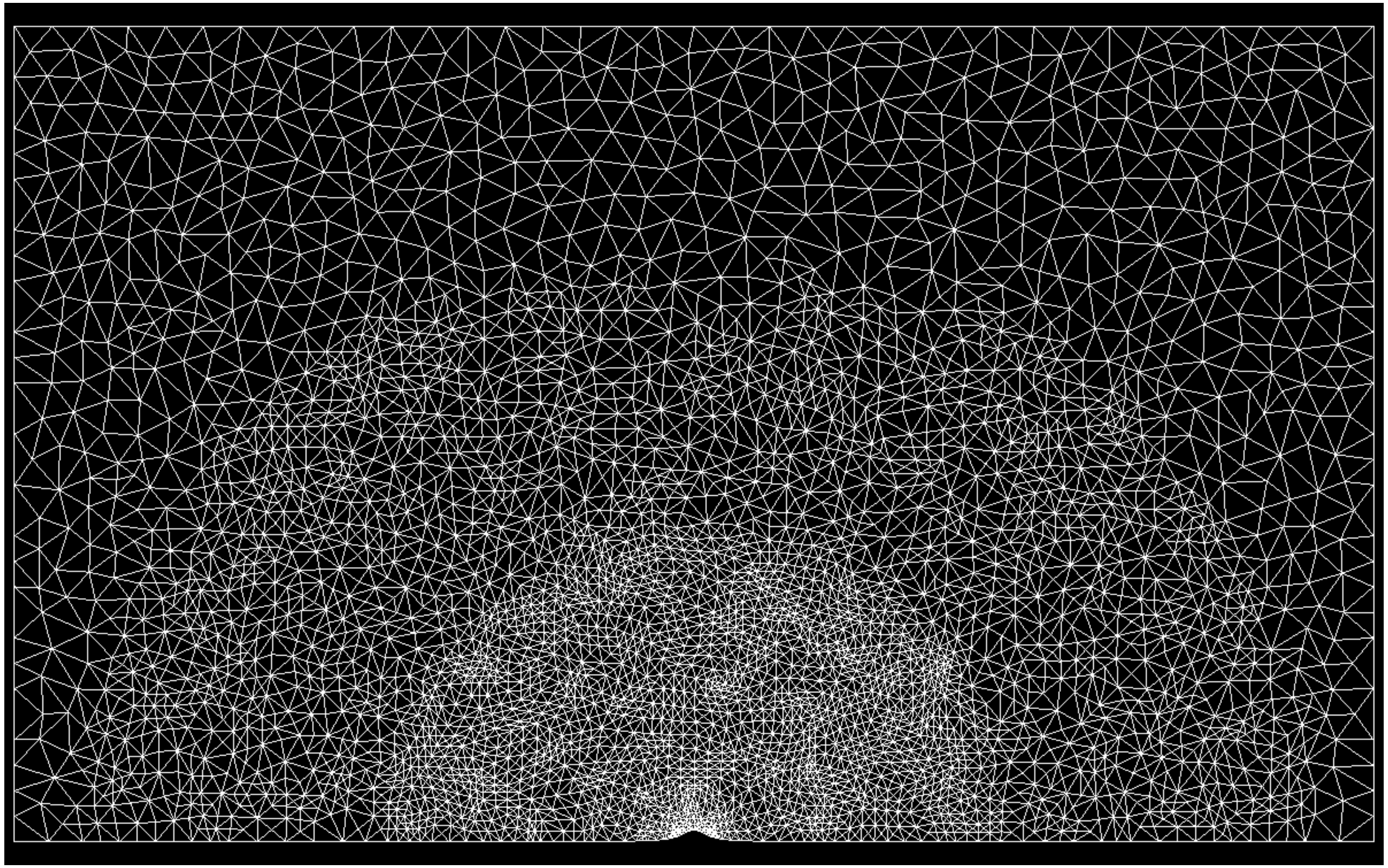
• Seek weak solutions of a balance equation
(correspondance to finite volume methods → conservation)
• Expand solution into a sum of base functions on each grid cell
(correspondance to finite element methods)

• DG discretization in space → arbitrary high order possible
• useable on arbitrary grids → suitable for complex geometries
• discontinuous elements → mass matrix is block-diagonal
• in combination with an explicit time integration scheme
(e.g. Runge-Kutta → RKDG-methods) → highly parallelizable code

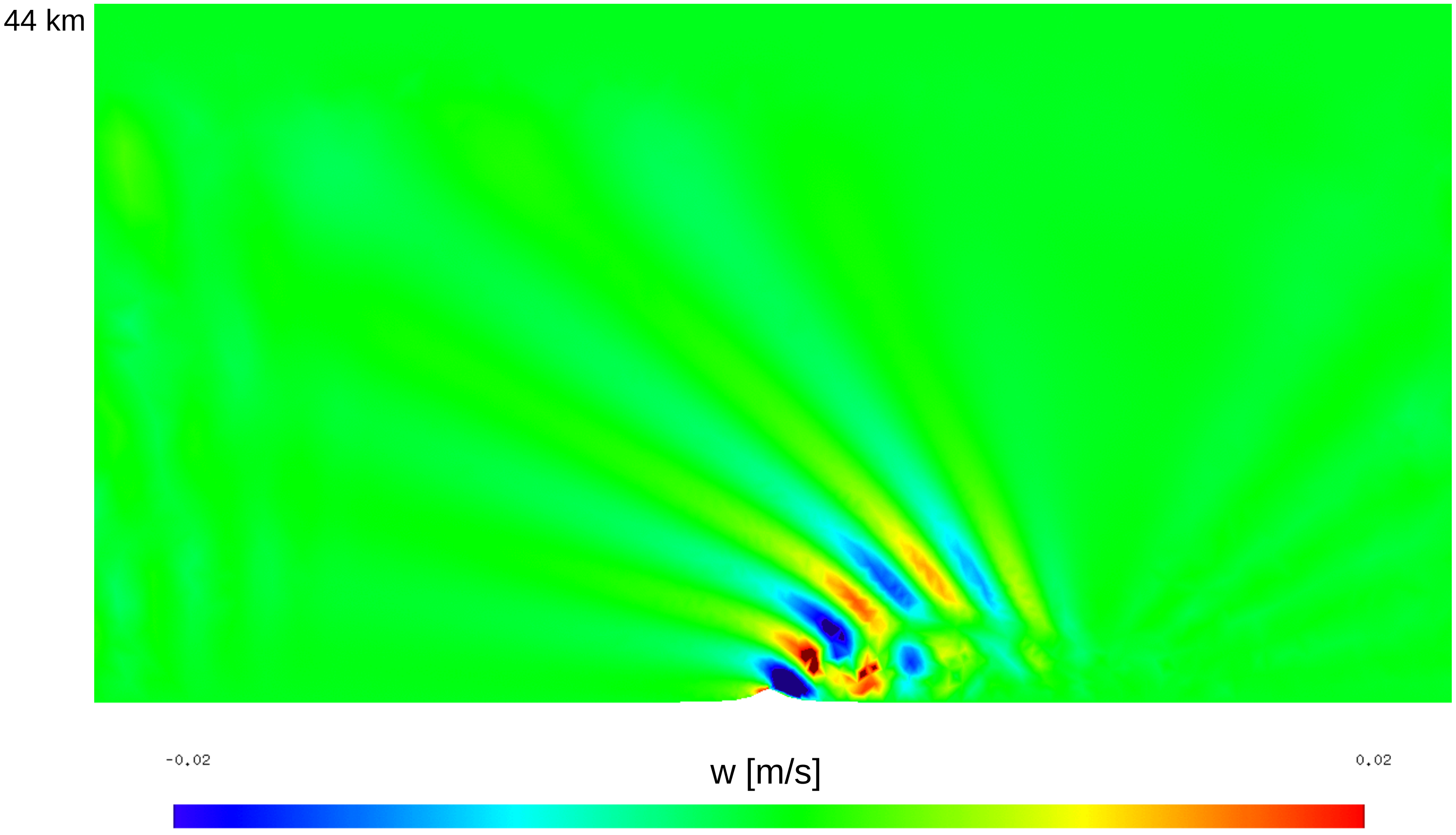
but: how to solve vertically expanding sound waves efficiently?

Example of a triangulation for 2D-flow over a mountain, produced with DUNE

(D. Kröner, A. Dedner, S. Brdar, Univ. Freiburg)



Nonhydrostatic flow with Discontinuous Galerkin Method (polynomials of order 2), preliminary results



Future plans (towards ~2015), Part I

Model-resolutions for weather forecast of 1 ... 1.5 km
(cp. UKMO with 1.5 km ‚on demand‘ for GB)

→ Main requirements for the model:

- again steeper orography
- upper boundary condition
- (stronger) resolved convection
- 1D-Turbulence → 3D-Turb.
- Radiation: slope dependency, ...

numerical aspects

physics-dynamics-coupling

physical aspects

data assimilation
verification
EPS
...

Future plans (towards ~2015), Part II

The dynamical cores of COSMO-model do not have any explicit conservation properties.
Conservation: general guiding principle in designing a model.

Conservation of (Thuburn, 2008, Some conservation issues for the dynamical cores of NWP and climate models):

- mass !!!
- energy !!
- momentum
- tracers !!

Strategical advantages:

- general trend in atmospheric modelling (Bacon et al., 2000, Skamarock, Klemp, 2008)
- collaboration with C-CLM ('climate COSMO')
- collaboration with COSMO-ART (chemical/aerosol modelling)

Future plans (towards ~2015), Part III

Methodology: **Finite-Volume-Methods**

- are well established in CFD (LeVeque, 2002, ...)
- become increasingly important in atmospheric modelling

Advantages:

- conserve the prognostic variable
- high flexibility
- positive definite, if desired (by flux limitation)
- can handle steep gradients in the solution (e.g. by flux correction)
  (even shocks and other discontinuities, however these are not so important in atmosphere)
- Could have advantages in steep orography
  (example in: Smolarkiewicz et al. (2007) JCP)
- applicable on arbitrary unstructured grids
  in this project, a structured grid is planned

Future plans (towards ~2015), Part IV

Deliverables

Until Q2/2009:

- derivation of equation set in flux form;
  adapted for resolutions Δx=500 m … 3 km.
- choice of prognostic variables: ρ, $\rho\mathbf{v}$, $E_{int}=\rho c_V T$ or $\rho\Theta$ or E_{tot}?
  (*Gassmann & Herzog, 2008,* Towards a consistent numerical compressible nonhydrostatic model using generalized Hamiltonian tools).
- choice of base state.
- coordinate system (terrain following or tilted cells in a Cartesian framework)
  These items have to be investigated in close connection with the possible discretizations (spatial and temporal).

Future plans (towards ~2015), Part V

Until Q1/2010

Preliminary version with the focus on spatial discretization;

- i.e. formulation of fluxes, limiters.
- but in a fully explicit way, no time-splitting, perhaps with RK-time integration.
- fully 3D schemes, no direction splitting.
- In particular appropriate advection schemes should be available (examples: MPDATA, Godunov-type methods, ...).
- At this stage possible advantages for use in steep orography can be investigated.
- Parallel development of improved upper boundary conditions.

Until Q3/2011

- Fully useable and optimized version available.
- Possible time integration methods available:

1. fully explicit (to test spatial discretization).
2. horizontal explicit, vertical implicit (is absolutely necessary to get efficiency).
3. time splitting.