CONSORTIUM FOR SMALL SCALE MODELING

COSMO

COSMO Priority Project (2009 – 2011)

Conservative Dynamical Core (CDC)

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Aims of the CDC priority project

- conservation properties of the dynamical core (*Thuburn, 2008, JCP*):
  - mass !!! most important
  - energy !!
  - momentum probably increasing importance for smaller scales
  - tracers !! important at least in convection resolving models

- should be able to handle steep orography

and of course overall:

- accuracy
- efficiency
- stability

Current dynamical cores of COSMO model (Leapfrog, RK) have no conservation properties for the dynamic variables mass, energy, momentum

Possible causes for limited use in steep terrain:

- Fast waves: not vertical implicit for metric terms (would go beyond tri-diagonal matrices)
- Metric tensor identities probably not fulfilled (Task 2.1 in CDC)
- Tracer advection: Bott-scheme is not multi-dimensional

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COSMO Priority Project
Conservative Dynamical Core (CDC)

Task 1: The anelastic (EULAG) approach

Testing the EULAG dynamical core as a prospective dynamical core of COSMO

Task 1.1: **Idealised tests of the EULAG dynamical core**

Simulate 2D and 3D idealized flows (flow over mountains, valley flows, ...)
Compare with COSMO results, laboratory flows and analytic solutions.

Test cases are defined in Task 3.1.

This task should give a first insight into the capabilities of the EULAG dynamical core and its possible advantages towards the current COSMO model.

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Task 1.2: Tests of the EULAG dynamical core for realistic flows over the Alpine topography

- case studies for different weather regimes
- real / idealised inflow
- with realistic orography (Alpine area, containing deep valleys)
- resolution ranging from 2.2 km, 1.1 km to 0.25 km
- No physics parameterizations!

Perform EULAG simulations and compare with COSMO/RK and COSMO/Leapfrog.

- Test computational efficiency and scalability of EULAG core
- Adapt the implicit solver to the model resolution and orography.

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Task 1.3: Tests of the EULAG dynamical core for realistic flows over the Alpine topography with simplified physics parameterisation

Simulate realistic flows over the Alpine topography, with resolution ranging from 2.2, 1.1 km to 0.25 km

Apply simplified parameterizations of basic subgrid processes:

- Moist processes: only simulated on explicit grid (i.e. no shallow convection parameterization, no moist turbulence)
- Simple microphysics (Kessler-scheme) in both models
- Turbulent diffusion with a one-equation (TKE)-model (not necessarily the same in both models)
- Simplified surface fluxes

Compare results between EULAG and COSMO/RK and COSMO/Leapfrog simulations.

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Task 1.4: Choice of the anelastic equation system

• Several different soundproof sets of equations have been published and are available in EULAG. The possible errors implied should be investigated and a recommendation for the best approximation to use for NWP should be given.

• Special focus should be given to the conservation of mass (i.e. ambiguity in the determination of the full pressure field), flows with finite-amplitude and non-linear perturbations with respect to the base state profile and the presence of large vertical gradients in the temperature field (i.e. inversions, tropopause).

• The other conservation properties (i.e. which mass/energy variables are conserved by which equation sets) should also be investigated.
Test the validity of conservation properties for mass, momentum and energy (possibly others like potential vorticity) in EULAG and COSMO. In COSMO a testing tool for conservation properties is available.

• Implementation of the Durran equations.

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Task 2: The compressible approach

Task 2.1: Metric tensor identities

Clear up the role of the ‘metric tensor identities’ *(Smolarkiewicz, Prusa, 2005)* and if they can empower the model to handle steep orography. Can they be applied directly to improve the current COSMO model formulation?

Task 2.3: Fully 3D, i.e. non-direction splitted, conservative advection scheme

Implement a fully 3D, i.e. non-direction splitted, conservative advection scheme into COSMO, e.g. MPDATA from the EULAG model.
Test this scheme with prescribed velocity fields in mountainous terrain, to show the transport properties also in terrain-following coordinates.

Task 2.2: Complete FV-solver for the EULER equations

Starting point: *Jameson (1991) Am. Inst. Aeronaut. Astron.*

Finite volume discretization of the Euler-equations → conservation of mass, momentum, energy(?)
Implicit scheme → helps in steep orography

This dynamical core is more in the state of an early-development stage model, therefore implementation into COSMO can be started relatively early after answering the most basic questions.

Spatial scheme:
Central schemes with added artificial viscosity and upwind schemes can be adopted for spatial discretisation. Higher order schemes are more accurate, but lower order schemes at higher resolution could turn out to be more efficient, particularly when implemented on vector hardware architectures.

Task 3: Assessment of dynamical cores

Task 3.1: Maintenance of idealized test cases

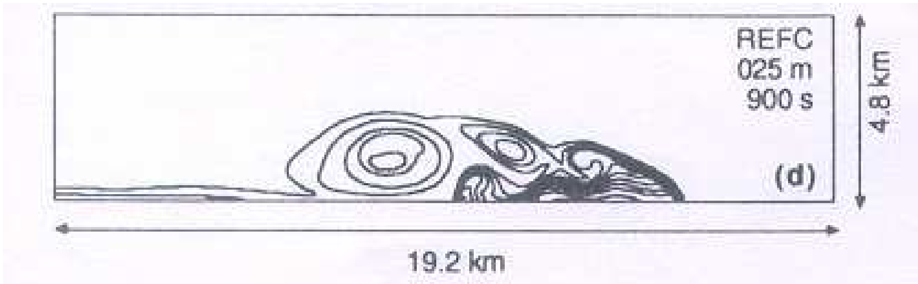
Several idealised test cases are already available.

Carry out these tests ‘at the push of a button’ and compare automatically with reference solutions.

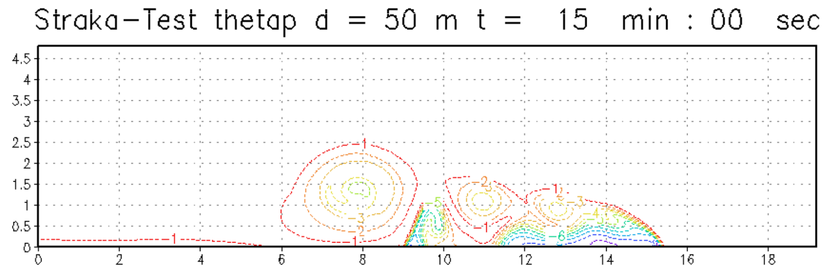
0. advection test + nonlinear dyn. *(Schär et al. (2002))*
1. Atmosphere at rest *(G. Zängl (2004) MetZ)*
2. Cold bubble *(Straka et al. (1993))* (unstationary density flow)
3. Mountain flow tests (stationary, orographic flows)
   - *3.1 Schaer et al. (2002),* sect. 5b (for EULAG cite *Wedi ,Smolarkiewicz (2004))*
   - *3.2 Bonaventura (2000) JCP*, e.g. linear solution developed *(Baldauf, 2008a)*
4. Linear Gravity waves *(Skamarock, Kemp (1994), Giraldo (2008))*
5. Warm bubble *(Robert (1993), Giraldo (2008))*
6. Moist, warm bubble *(Weisman, Klemp (1982) MWR)*

Test of the dynamical core: density current *(Straka et al., 1993)*

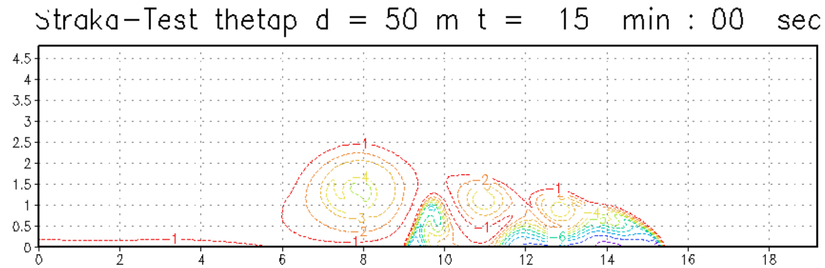
θ‘ after 900 s. (Reference)
by *Straka et al. (1993)*



COSMO with
RK3 + upwind 5^{th} order



COSMO with
RK2 + upwind 3^{rd} order



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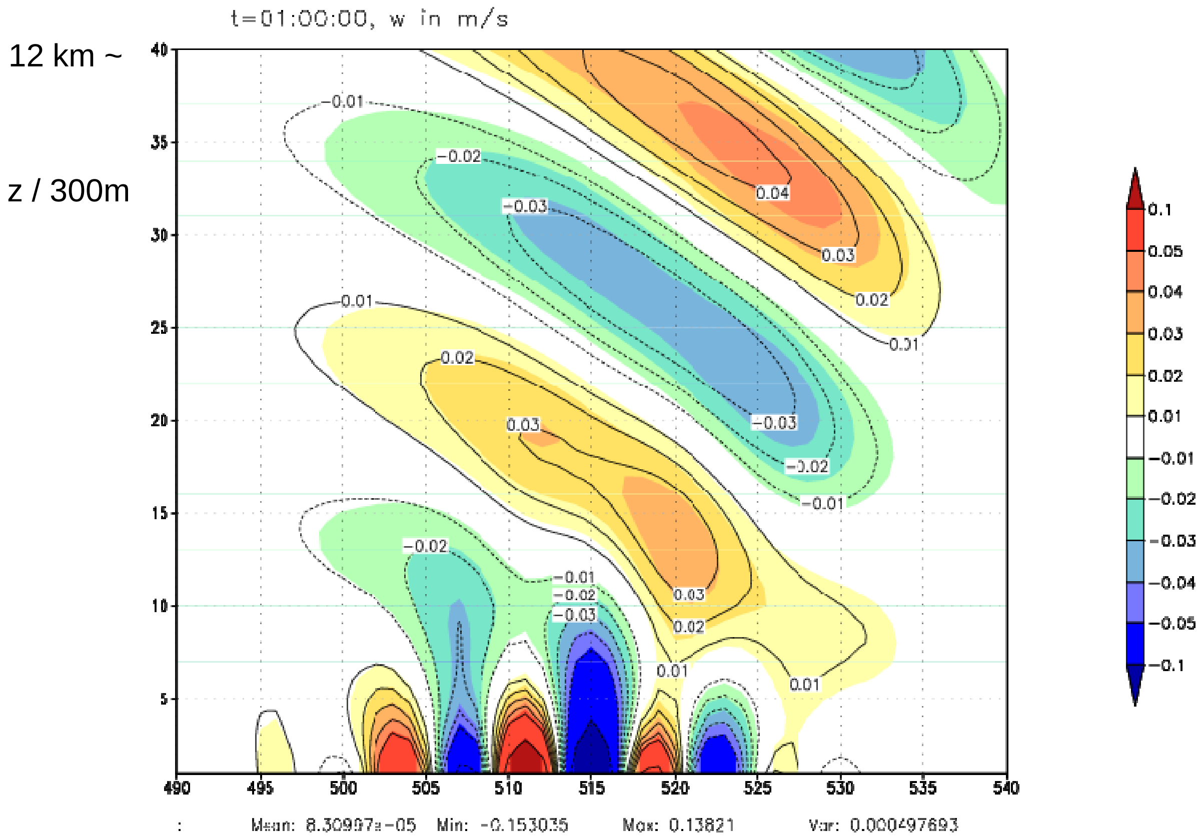
Mountain flow (*Schär et al. (2002) MWR*)

a = 5 km / l=4 km
h= 25 m
u=10 m/s
T(z=0)=288 K
N=0.01 1/s
dx=500 m
dz=300 m



Comparison with analytic solution (black lines) from *Baldauf (2008) COSMO-Newsl*.

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Task 3.2 Collection and maintenance of semi-idealized test cases

A test bed with some semi-idealized (quasi-realistic) tests (steep mountains, valley flows, deep convection, …) should be maintained also with a documentation about the specific weather situation and what should be expected by the simulation.

Input format: GRIBs from COSMO-model (e.g. 7 km) for the Alpine region.

A competition between the current and newly developed dynamical cores by these tests will be essential to decide the further direction of developments.

For a broad acceptance it is advisable to include several groups in these tests.

Task 3.3: Decision tree for Steering Committee

In former projects concerning the development of a new dynamical core it has been proven to be rather difficult to decide about the continuation or the abort of the project, due to a lack of clear decision criteria. Here such a decision tree (a cascade of benchmarks) shall be set up.

Task 3.4: Verification of the whole model

A verification of the model by real observation data (Synop, upper air, radar data). Probably such a verification is only useful for a model with the full set of parameterizations.