Progress of CELO Priority Project

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3rd year of CELO Priority Project

- Preliminary integration of the implicit compressible EULAG dynamical core within COSMO [Task 1 and 3]
- Verification highlights of anelastic and compressible COSMO-EULAG (with parameterizations not yet tuned; including upper air verification)[Task 1 and 4]
- Daytime convection development study [Task 1]
- High resolution forecast over coarse topography [Task 1]
- Performance remarks[Task 3]

Preliminary integration of the implicit compressible EULAG dynamical core

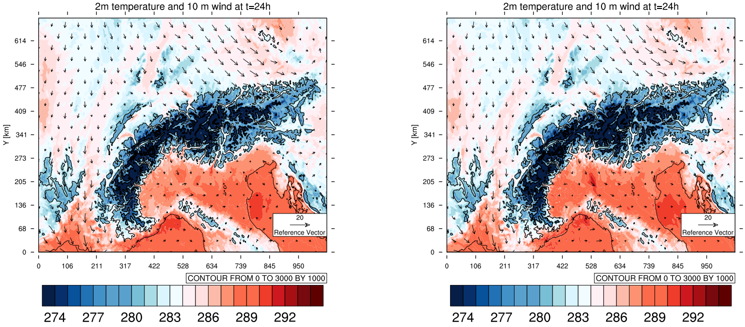
- Mesoscale weather simulations at 2.2 km and 0.55 km with EULAG standalone implicit compressible core were highlighted at the COSMO Users Seminar 2015, along with the promising scalability study within .55-2.2 km range.
- In the second part of the COSMO year, COSMO-EULAG was first transferred to COSMO 5.1.
- Furthermore, COSMO-EULAG was extended to accommodate implicit compressible option; (adiabatic) pseudoincompressible and explicit compressible options became automatically available as well.
- Today we present the first comparison of 24h forecast of COSMO-EULAG implicit compressible, anelastic and COSMO Runge-Kutta, along with short-period verification study

Preliminary integration of the implicit compressible EULAG dynamical core cont.

- Integration of the implicit compressible involved reorganization of the dynamical core, sourcing from the experiences of the evolution of EULAG model performed earlier.
- Anelastic and implicit compressible dynamical core share their main components (advection, implicit solver), so the increase of the source code complexity is only limited.
- All important stencils of COSMO-EULAG are now in the form that facilitates the adaptation to GPU. Special stencils for the boundary conditions of the iterative solver demands GridTools functionality for CUDA adaptation.

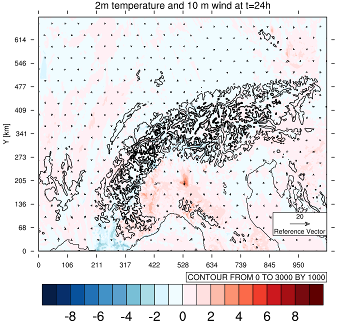
COSMO-EULAG implicit-compressible and Runge-Kutta 24h forecast for 01.06.2013.

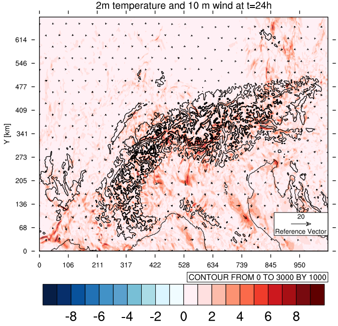
Horizontal crossection presenting 2 m temperature and vector wind field at 10 m level. Left panel presents COSMO-EULAG compressible results, whereas right panel presents COSMO-RK results.



COSMO-EULAG implicit-compressible and Runge-Kutta 24h forecast for 01.06.2013.

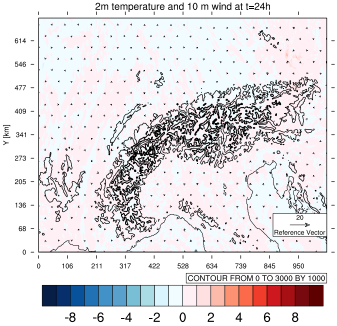
Left panel presents the difference between COSMO-EULAG compressible and Runge-Kutta temperature at 2 m at a time=24h, right panel presents the difference in 10 m wind magnitude.

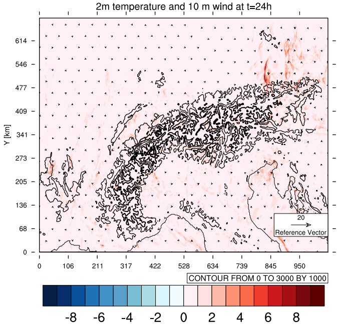




COSMO-EULAG implicit-compressible and ANELASTIC 24h forecast for 01.06.2013.

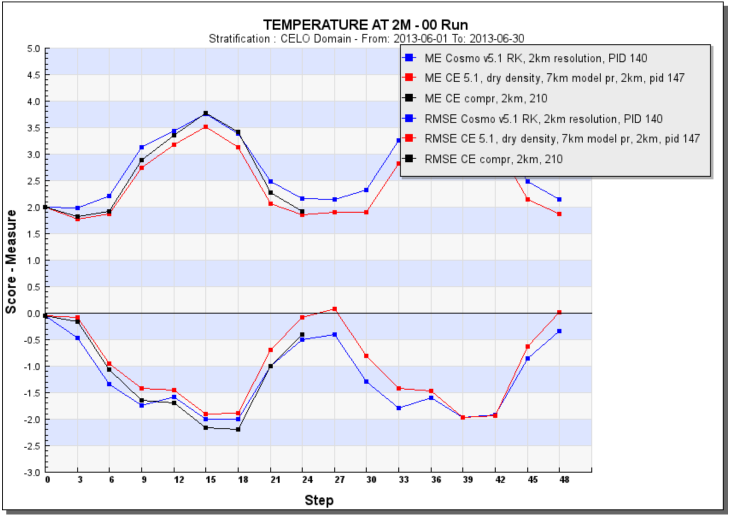
Left panel presents the difference between COSMO-EULAG compressible and COSMO-EULAG anelastic at 2m at a time=24h, right panel presents the difference in 10 m wind magnitude.





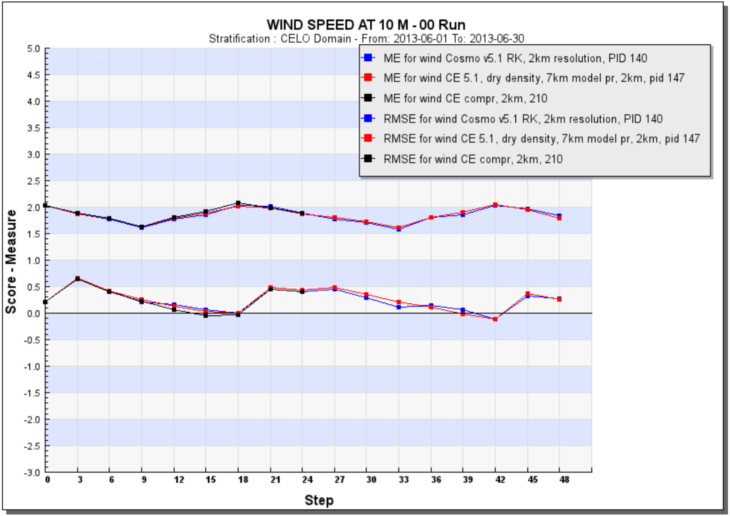
Verification study - temperature at 2 m

COSMO-EULAG anelastic score is the highest, whereas COSMO-EULAG compressible scores **black** are closer to the Runge-Kutta scores.



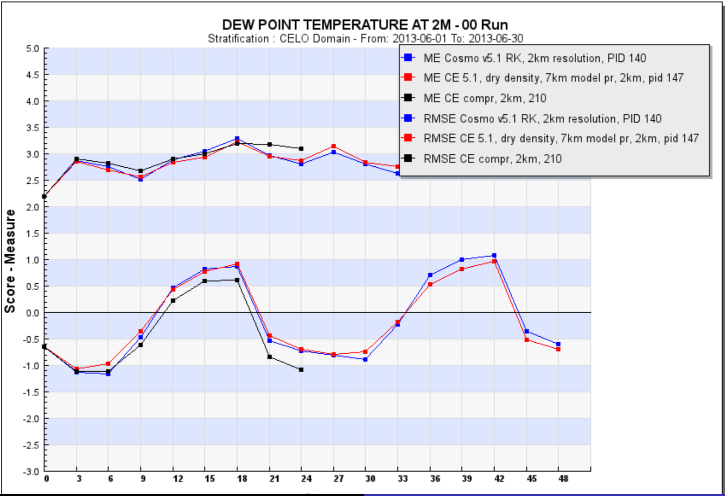
Verification study - wind at 10 m

For small rain ranges in June, Wind speed scores are very similar for all three dynamical cores.

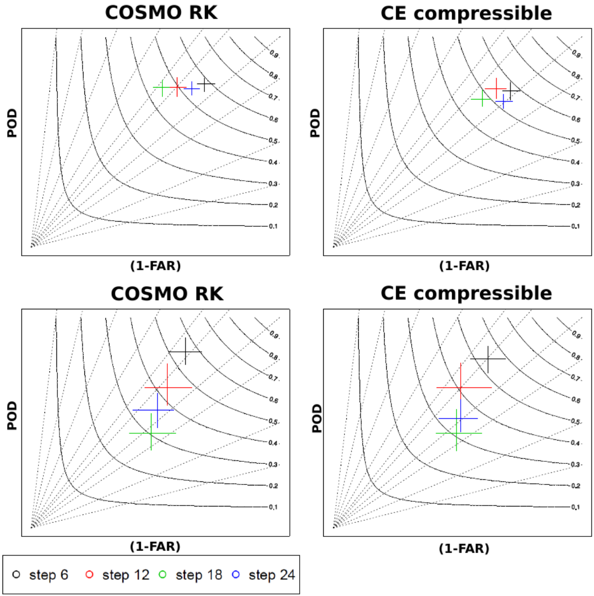


Verification study - dewpoint temperature at 2 m

For small rain ranges in June, COSMO-EULAG anelastic and Runge-Kutta scores are very similar, whereas COSMO-EULAG compressible scores are favourable in the afternoon but diverge in late evening.



Verification study - rain for +1. and +10.0 ranges



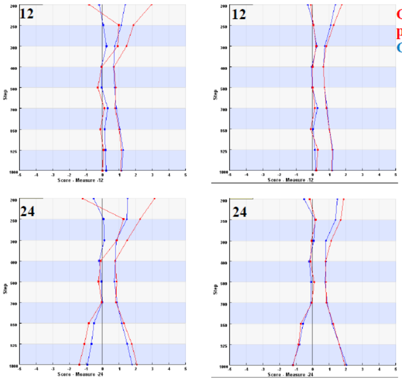
Rain verification scores between COSMO-EULAG and Runge-Kutta cores are similar, with COSMO-EULAG scores slightly higher at noon for +1.0 range, (upper plots), and slightly lower for + 10.0 range, (lower plots).

Verification study - corrected upper air scores

With the suitable adjustment of the COSMO-EULAG reference profiles, the upper air scores at higher altitudes improved considerably.

Temperature : June 2013

COSMO-EULAG v. 4.26
COSMO-RK v. 4.26 (old F-W)



COSMO-EULAG v. 5.1 (vert. profile)
COSMO-RK v 5.1 (new F-W)

Conclusions

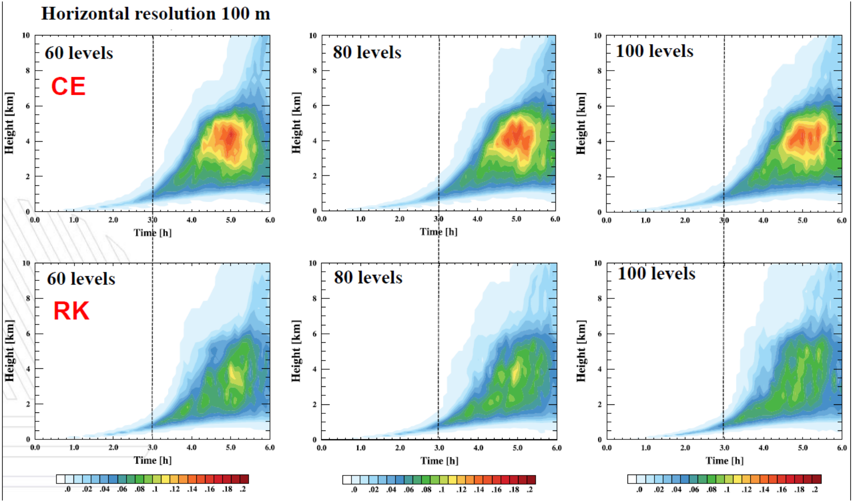
- COSMO-EULAG implicit compressible core is now preliminarily integrated and is able to produce forecasts.
- Implicit compressible forecasts seem to be closer to anelastic forecasts than to the Runge-Kutta forecasts.
- COSMO-EULAG verification scores are mostly comparable to Runge-Kutta
- Wind scores are the most similar, temperature, dew point temperature and total cloud cover sometimes slightly better in Runge-Kutta; this probably results from the tuning of the parameterizations as it depends on the time of the day.
- Rain verification scores for high ranges slightly better in COSMO-EULAG.

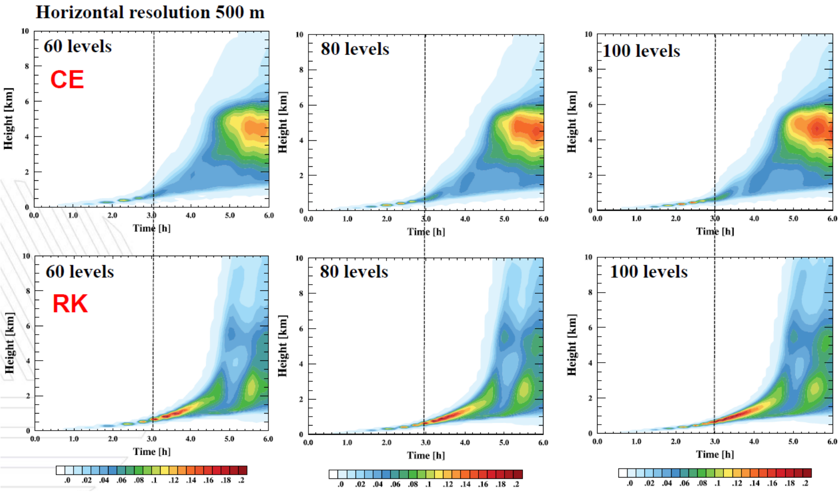
Daytime convection development - experiment setup

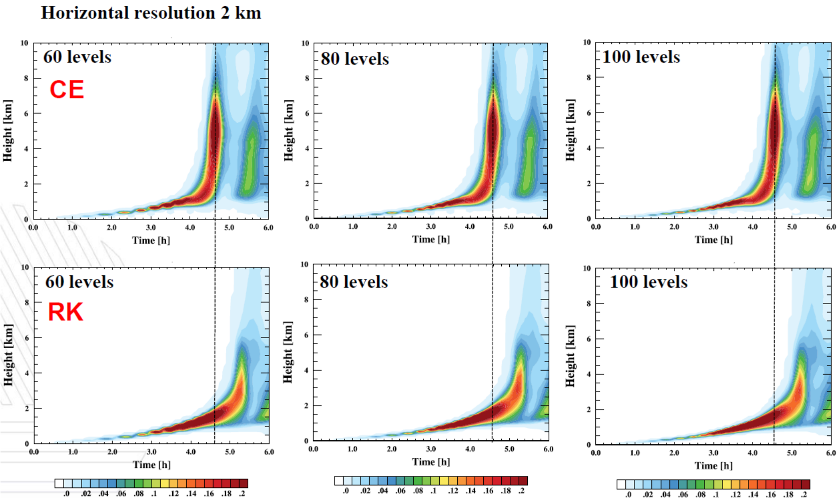
The focus is on the 6 h period between sunrise and early afternoon. This period is characterized by the formation and growth of a well-mixed convective boundary layer from the early morning temperature and moisture profiles as the surface sensible- and latent-heat fluxes increase after sunrise.

- Initial soundings from Grabowski et al 2006 linearly interpolated to the COSMO grid.
- Periodic lateral boundary conditions.
- Surface latent and sensible heat fluxes applied as analytical functions of time plus 10% random noise.
- Temperature and moisture random perturbation added below 1 km height with the amplitude of 0.1K and 0.1g/kg every 15 min.
- No radiative cooling.
- Shallow convection parameterization switched off.
- Subgrid-scale turbulence based on 1-D TKE diagnostic closure.

Domain-averaged cloud condensate evolution.




Horizontal resolution 500 m
60 levels
CE
80 levels
100 levels
60 levels
RK
80 levels
100 levels
Height [km]
Time [h]
.0 .02 .04 .06 .08 .1 .12 .14 .16 .18 .2

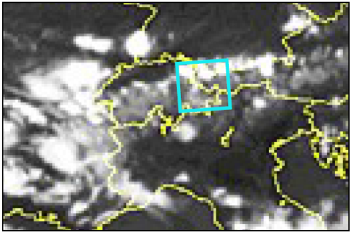

Horizontal resolution 2 km
60 levels
CE
80 levels
100 levels
60 levels
RK
80 levels
100 levels
Height [km]
Time [h]
0.0 1.0 2.0 3.0 4.0 5.0 6.0
0 2 4 6 8 10
.0 .02 .04 .06 .08 .1 .12 .14 .16 .18 .2

Influence of effective topography resolution on high resolution forecast

The 2.2 km resolution CE weather forecast for the 19th July 2013 is used as a base for a LES-type CE simulations in 100 m horizontal grid resolution in a limited mountainous subdomain (see details in the table below, left). The new simulations starts at 6:00 UTC and last till 24:00 UTC.

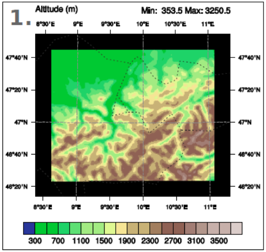
The deep convective clouds formation at 15:00 UTC in the northern part of the computational domain (light blue rectangle) is shown in the MSG 10.8μm IR image (below, right). After 20:00 UTC the deep convection phase terminates.

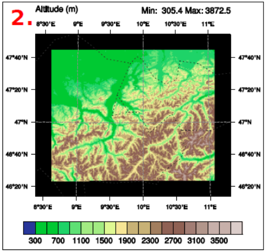
Resolution	**100 m**
WE x NS	1860 x 1500
Vertical levels	61
Domain height	~23.5 km
Lateral absorber	5.8 km
Sponge base height	15 km
Initial and b.c.	CE 2.2 forecast
Forecast period	18 hours, starting at 6:00 UTC
Turbulence param.	Smagorinsky-Lilly
The freq. of rad. coefficients calc.	6 minutes

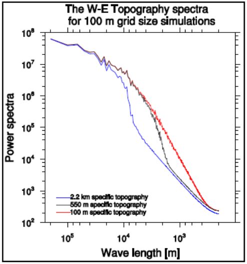


Two distinct topographies are used for LES type simulations :

1. Topography specific to 2.2 km grid resolution interpolated to 100 m grid (below, left)
2. Topography specific to 100 m grid size (below, middle)



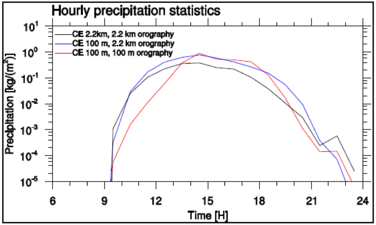


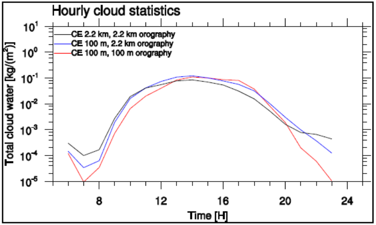


Precipitation

For LES studies introduction of realistic topography (100 m) resulted in later onset and earlier termination of deep convection, smaller precipitation amount and significant differences in flow pattern, especially in the lower tropospheric area (comparing to 2.2 km orography).

Total precip. from 6 till 24 UTC [kg/m²]	
CE 2.2 km	1.7
CE 100 m with 2.2 km orography	3.5
CE 100 m with 100 m orography	2.9





Conclusions

- High resolution (100 m) simulations with anelastic COSMO-EULAG with coarse-scale and fine-scale topography show the importance of the detailed terrain representation, which seems to match the general experience of the Alpine modelling community.
- In principle, fine-scale topography contributes to later onset and earlier termination of convection.
- Studies of daytime convection development, within the context of the deep convection initiation suggest that the COSMO-EULAG dynamical core at 500 m resolution matches the high-resolution reference results more closely than the Runge-Kutta core.
- At 2.2 km resolution, both Runge-Kutta and COSMO-EULAG dynamical cores delay the onset of convection, less in COSMO-EULAG core

Remarks on the COSMO-EULAG compressible model performance and GPU adaptation

- Currently, for 2.2 km integration with 20 s timestep, the time-to-solution of implicit compressible and Runge-Kutta cores are the same.
- Further optimizations are possible and will be done and the development with the maximum timestep allowed by the CFL is needed.
- GPU anelastic EULAG standalone adaptation is currently still single node, but should be completed within the next 2 months
- Stencil formulation of COSMO-EULAG has been reviewed (thanks to Carlos); estimated resources to port COSMO-EULAG to GridTools matching the standards of MeteoSwiss is 1 FTE of the reasonably experienced C++ programmer.
- Contributions of numerical algorithms from PantaRhei project of ECMWF are already incoming and being implemented.