Progress of CELO Priority Project

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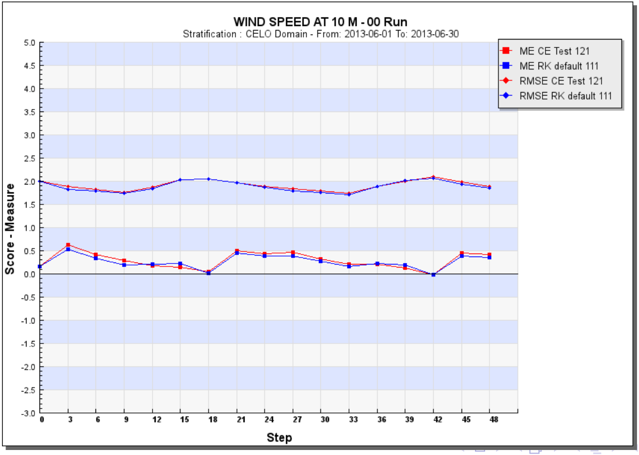
March 3, 2015

Recent key advancements in CELO

- VERSUS implementation and verification study that compares Runge-Kutta to COSMO-EULAG forecasts (with parameterizations not yet tuned; including upper air verification)[Task 1 and 4]
- Reformulation and optimization of the consistent anelastic/compressible EULAG DC [Task 2,3, and 4]
- Feasibility study on implementation of EULAG implicit compressible core for COSMO using reformulated and optimized consistent EULAG dynamical core [STC request]
- Evaluating Alternate Direction Implicit preconditioner [Task 2]
- Porting GPU implementation of key EULAG DC components to multinode [Task 3]

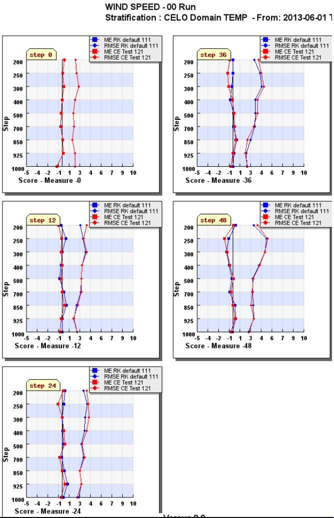
Verification study - wind speed and direction

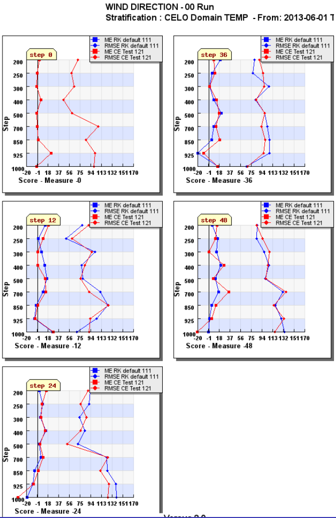
We analyze June and November 2013 forecasts for 48 h at 2.2 km with COSMO-EULAG and Runge-Kutta cores. In this presentation, only the results for June are shown, as the results of two cores for November are very close.
Wind speed verification scores are similar for both June and November.



Verification study - upper air wind speed

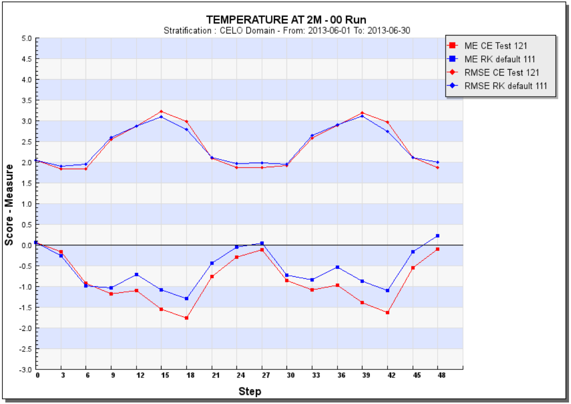
Upper air wind speed mean error and wind direction RMSE is slightly lower in COSMO-EULAG near the surface, slightly larger near the top of the domain.

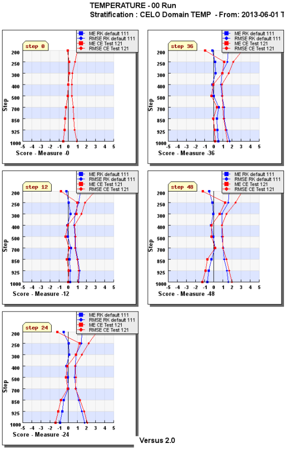




Verification study - temperature

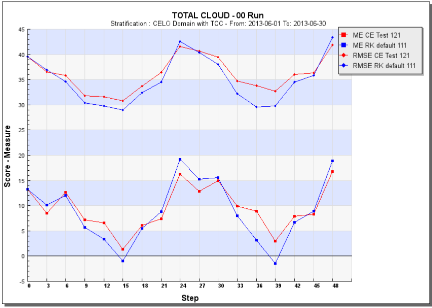
2m temperature error for June is smaller in Runge-Kutta except for the nighttime, For November, COSMO-EULAG temperature error is smaller than in Runge-Kutta. Source of bias near the top of the domain is unknown.

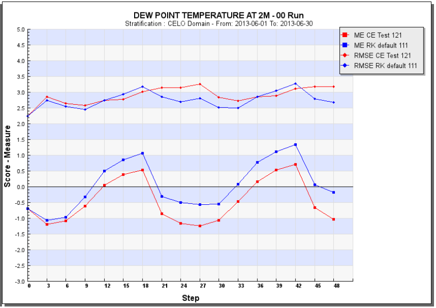




Verification study - total cloud cover and dew point temperature

Total cloud cover errors are smaller for Runge-Kutta except for the nighttime; dew point temperature errors are smaller in Runge-Kutta except for the afternoon. The errors are comparable in November verification.



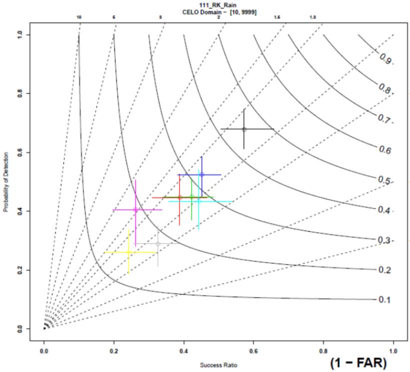


Verification study - rain +10.0 range

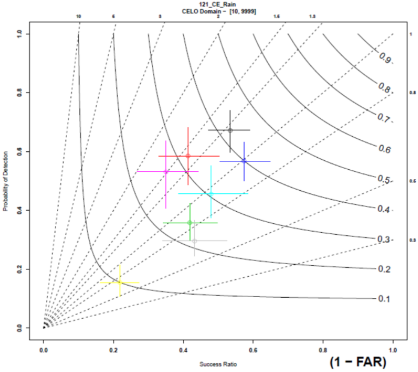
Rain scores are comparable for both June and November, COSMO-EULAG scores are higher for +10.0 range in June.

Avg.	CE	RK
1-FAR	.43	.39
POD	.45	.44

Runge-Kutta



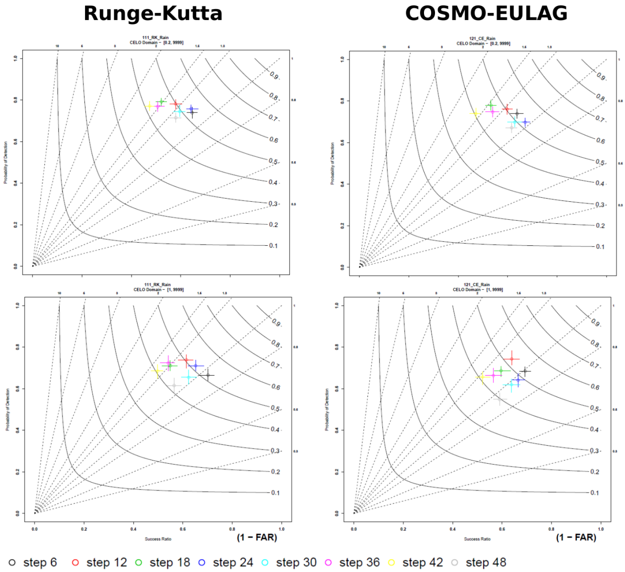
COSMO-EULAG



○ step 6 ○ step 12 ○ step 18 ○ step 24 ○ step 30 ○ step 36 ○ step 42 ○ step 48

Verification study - rain +0.2 and +1.0 range

For small rain ranges in June and November results are very similar.



Feasibility study - theoretical considerations

Increased complexity of implicit compressible formulation of EULAG dynamical core:

- Three more dynamical variables to advect in compressible core (density, Exner perturbation, full potential temperature)
- Three components of the implicit operator result in triple cost of gradient divergence evaluation in implicit solver
- Necessity to evaluate nine iterative solver coefficients and auxiliary preconditioner variables at each timestep

Favourable features of implicit compressible formulation"

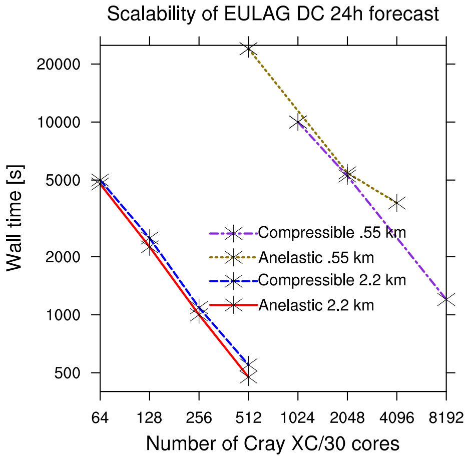
- Minimal accuracy requirements from implicit solver, resulting in much less dependence on global reductions
- Largest workload is then on advection, which can be heavily optimized, as shown by the external study, and further treated as a black-box inside tracer module

Feasibility study - numerical experiment

- The most recent version of EULAG model with anelastic and implicit compressible core was run on (trimmed) MeteoSwiss COSMO 2.2 km domain using time-varying, realistic initial and boundary conditions from COSMO with 2.2 and 0.55 km resolution.
- Simulation employed pure dynamical core without moist model or diffusion operator (no surface fluxes).
- The original domain was reduced to first 512x256 grid points to accommodate EULAG parallelization scheme, 64 vertical levels.
- Scalability test was performed up to 64x64 MPI process grid on CSCS Piz Daint Cray XC 30.

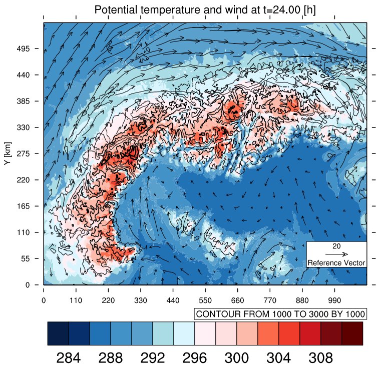
Computational cost of anelastic and compressible cores

Resolution	dx = 2.2 km, dt = 10 s	dx = 0.55 km, dt = 5 s
Subdomain	8x8x64 grid points/core	32x32x64 grid points/core
Compressible time	550 s	5250 s
Anelastic time	475 s	5450 s



Compressible vs. anelastic flow realization at .55 km resolution

Qualitatively, results of the anelastic (left panel) and compressible (right) flow realization after 24 h simulated time agree very well. Note that simulation employed no surface fluxes (e.g. friction).



Remarks on the accuracy of the iterative solver

- Elliptic/Helmholtz solver of EULAG employs physically-based exit condition.
- The tougher the condition, the stiffer the adjustment of the flow to the prescribed boundary conditions.
- It is unclear what is the optimal stiffness for best forecast scores, this will be evaluated in the Task 4 of CELO using verification.
- If higher degree of accuracy is needed, newly developed ADI preconditioner for anelastic and compressible core can be used.
- For example, for three preconditioner iterations, replacing first explicit Jacobi iteration in x direction by implicit inversion (i.e. two dimensional ADI xz) reduces number of solver iterations almost twice for 2.2 km forecast.
- Stronger preconditioning is especially beneficial for adjustment of the flow from large scale initial condition during the first few hours.

External activities - PanthaRei (ECMWF)

- PantaRhei project at ECMWF explores possible new dynamical core that from the algorithmic-numerical point of view may be viewed as horizontally unstructured derivative of EULAG model.
- Global dry conservative dynamical core using consistent anelastic/compressible formulation is now completed and ready for research.
- Possible common effort of ECMWF, Member countries and Poland within proposed "ESCAPE" Horizon 2020 project, project start subject to funding decision in autumn 2015.
- The project includes the development of dynamical core algorithms and accelerator techniques; backporting of the developments to mesoscale models including COSMO-EULAG is in the project plan.

GPU and Intel Xeon Phi port of EULAG

Rewrite for GPU and IntelMIC processors within National Science Centre grant "Methods and algorithms for organization of computations in the class of anelastic numerical models for geophysical flows on modern computer architectures with realization in the EULAG model"

- EULAG dynamical core components (anelastic version) are now ported to multi-GPU clusters with good scalability. Xeon/Xeon Phi port also shows very significant speedup as compared to the original Fortran version.
- GPU implementation bases on OpenMP and CUDA, the iterative solver is implemented using stencil approach in C++ (but not STELLA).
- In the next few months, we expect merged, usable dynamical core implementation.

Extending CELO project plan to EULAG compressible dynamical core

- Possible new Task 5 of CELO should include: introducing two level density throughout the COSMO-ULAG code and extending the iterative solver formulation with new Helmholtz equation-specific operators and custom preconditioner. This has already been done for EULAG standalone and needs to be transferred to COSMO-EULAG along the transition to COSMO 5.x with ICON physics.
- The optimal formulation of boundary conditions and ambient profiles for the implicit compressible core needs to be evaluated.
- Depending on the forecast scores, it may be feasible to perform testing, tuning and optimizations for both cores or for the implict compressible core only.

Conclusions

- COSMO-EULAG verification scores are comparable to Runge-Kutta, despite lack of parameterization tuning
- Wind verification scores are the most similar, temperature, dew point temperature and total cloud errors are sometimes slightly lower in Runge-Kutta; tuning of the parameterizations may further influence these.
- Rain verification scores, especially for high ranges look promising in COSMO-EULAG
- Compressible simulation of Alpine flow using COSMO initial and boundary conditions has been successfully run using standalone EULAG and compared with the anelastic solution
- Implicit compressible core of EULAG offers competitive performance due to different accuracy requirements of the iterative GCR solver
- Newly developed preconditioner extends flexibility of the iterative solver configuration and can provide improvement in convergence speed if higher accuracy is needed