Analysis of the COSMO-EULAG Model Performance within PT CCE

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Introduction

COSMO Priority Project COSMO-EULAG Operationalization resulted in implementation of compressible EULAG dynamical core into the COSMO model structure. The resulting COSMO-EULAG (CE) model was thoroughly and successfully tested for a range of idealized and realistic experiments. In September 2018 a new PT Consolidation of COSMO-EULAG (PT CCE) was established with the aim to optimize meteorological performance of the model and to bring the developments back to the COSMO model trunk code.

The ongoing meteorological developments include:

- ✓ Replacement of the Bott scheme for TKE advection with the MPDATA scheme,
- ✓ Implementation of the exact buoyancy formulation,
- ➢ Directional splitting of the advection scheme [1],
- ➢ Optimal choice of the advection scheme for prognostic variables,
- ➢ Model verification for various weather conditions.

In SON several technical developments have been carried out:

- ✓ Implementation of CE into COSMO V5.05 framework,
- ✓ Development of model restart capability,
- ✓ Elimination of dependence of the model results on the MPI domain decomposition,
- ➢ Vectorization of loops in source code

The COSMO Technical Test Suite was applied for appropriate model testing.

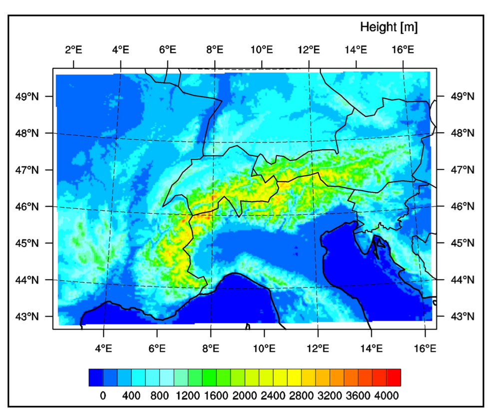
Experiments and Verification

- Four experiments were carried out to optimize model setup:

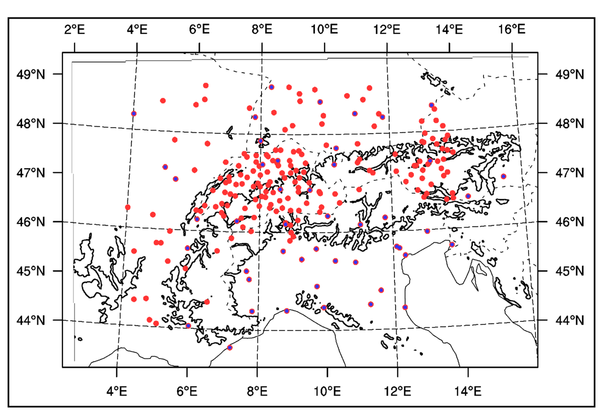
Adv.	Def	Ex. 1	Ex. 2	Ex. 3	Ex. 4
ρ	A	A	A	M	M
θ	A	A	A	M	M
V	M	M	M	M	M
qx	A	A	A	M	M
TKE	Bott2_S	A	Bott2_S	Bott2_S	M
Buoyancy	Linear.	Linear.	Exact	Linear.	Exact

- The experiments involve replacement of Bott TKE advection (Bott2_S) by MPDATA-A (A) (Ex. 1), replacement of linearised (Linear.) by exact buoyancy (Exact) (Ex. 2), replacement of MPDATA-A by MPDATA-M (M) (Ex. 3) and superposition of all modifications (Ex. 4)
- Verification for bias and RMSE is performed for the entire June 2013 and for 48-hour forecasts over Alpine domain using VERSUS
- The results for default configuration (Def) are compared with experiments for temperature at 2 m, sea level pressure, 36-hour forecast of upper wind; for precipitation performance diagrams compare PoD and FAR

Topographical map of the domain



Station network for surface verification



Common Settings

Dynamics:

- Numerical and Smagorinsky diffusion are *turned off* for Cosmo-Eulag
- dt = 10 s
- dx = 2.2 km
- Computational domain - the standard operational COSMO-2 domain used by Meteo-Swiss with 60 vertical levels (see above, 2013)

Microphysics:

- Standard one-moment COSMO microphysics parameterization including ice, rain, snow and graupel precipitation (*igsp* = 4)

Radiation:

- Calculated every 6 minutes
- Topographical corrections to radiation are *turned off* (*lradtopo* = F)

Turbulence and convection scheme:

- Default turbulence setup for high-resolution NWP (*itype_turb* = 3, *limpltkediff* = T)
- TKE advection is turned on (*lprog_tke* = T, *l3dturb*=F)
- Shallow convection parameterization is turned off (*lconv* = F)

Soil model:

- Multi-layer soil model is used (*lsoil* = T, *lmulti_layer* = T, *lforest* = T)

Formulation of buoyancy force

The exact form of the buoyancy force in the momentum equation of compressible EULAG is:

$$\boldsymbol{B} = -\boldsymbol{g}\,(\theta_d - \theta_a)/\theta_a$$

where θ_d is density potential temperature, θ_a is potential temperature of a hydrostatically balanced ambient state (to be chosen arbitrarily), and $\boldsymbol{g}$ is gravitational acceleration, while

$$\theta_d \equiv \frac{1 + q_v/\epsilon}{1 + q_t}\,\theta$$

where q_v is mixing ratio of water vapour, q_t is the sum of mixing ratios of all water species, ϵ is the ratio of gas constants for dry air and water vapour and θ is the potential temperature.

Until now a linearized version (of an anelastic type) of the buoyancy force was used within COSMO-EULAG

$$\boldsymbol{B} = -\boldsymbol{g}\,(\theta - \theta_a)/\theta_a - \boldsymbol{g}(1 + q_v/\epsilon - q_t)$$

This is now replaced by the exact formulation and the effects are verified for convective weather over Alpine domain in June and compared with the default configuration.

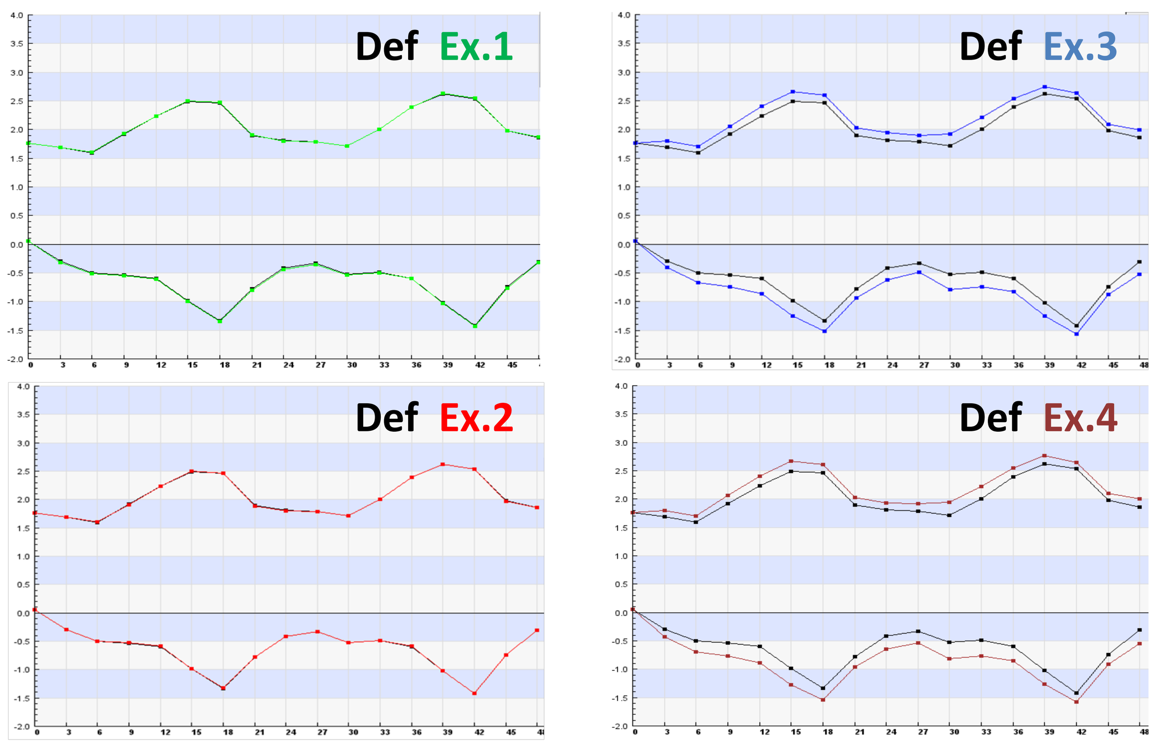
Advection Schemes MPDATA-A and MPDATA-M

MPDATA is a conservative nonlinear advection procedure of COSMO-EULAG. It is an iterative scheme which at its first step transports the model variables using a first-order accurate flux-form upwind scheme. The second step corrects the error of the first one via advection of the same model variables and using the same upwind procedure, but with the corrective velocities which ensure overall second-order accuracy of the scheme.

A variant of MPDATA implements an additional gauge transformation which adds to a model variable an arbitrarily large constant. As discussed by Smolarkiewicz and Clark (1986), the gauge transformation in the limit of infinitely large constant leads for regular grids and for regular signals to a better representation of the advected field and is formally close to the third-order accuracy.

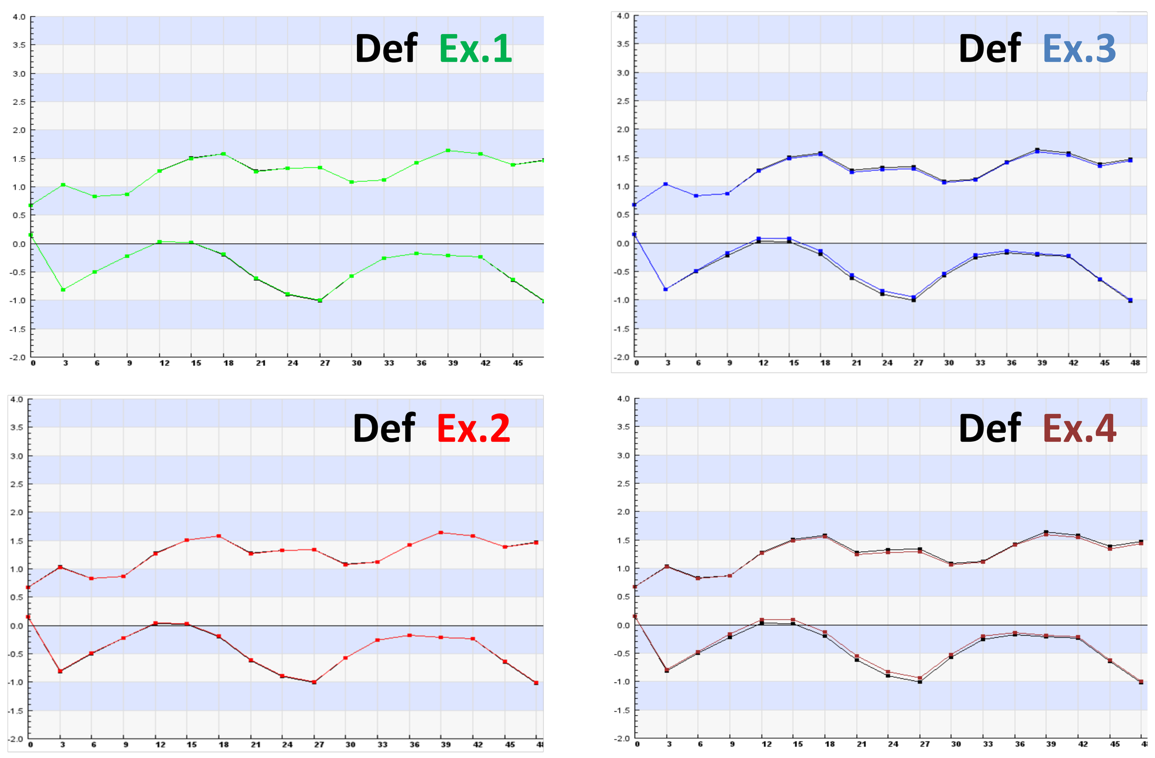
Current work compares results of the standard setup of the advection procedure, called MPDATA-A, with infinite gauge procedure, called MPDATA-M, for the convective weather over Alpine domain in June. Both procedures use their non-oscillatory options (Smolarkiewicz and Grabowski 1990). The control experiment uses MPDATA-A for advection of all model variables except momentum, for which MPDATA-M is used, and the new setup uses MPDATA M for all model variables including TKE.

Temperature at 2m



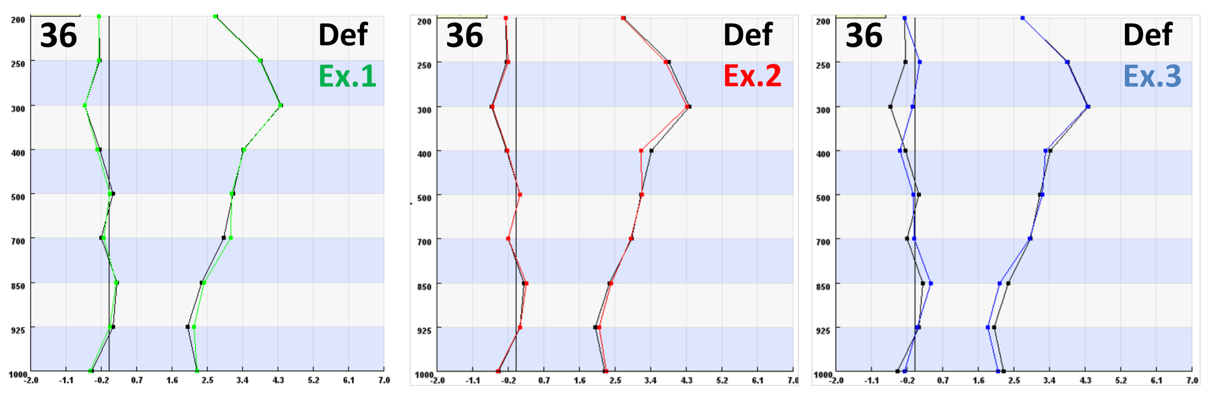
For 2m temperature an implementation of the TKE advection by the MPDATA scheme (Ex. 1) slightly increases the magnitude of bias and RMSE while the exact buoyancy (Ex. 2) practically does not affect the scores. Substituting of MPDATA-A by MPDATA-M (Ex. 3) significantly increases the magnitude of errors. Implementation of all changes (Ex. 4) also increases the magnitude of the errors

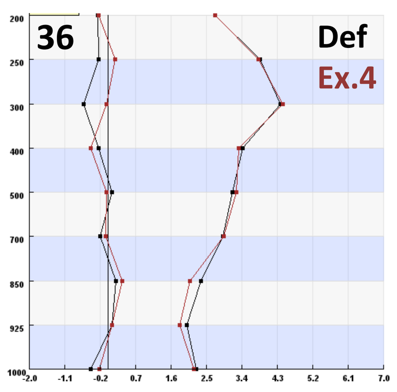
Pressure Reduced Mean Sea Level



For surface pressure an implementation of the TKE advection by the MPDATA (Ex. 1) keeps the scores similar with slightly smaller magnitude of MPDATA errors at night. The scores are also very similar and with slightly better bias for the exact buoyancy (Ex. 2). Substituting of MPDATA-A by MPDATA-M (Ex. 3) slightly improves the scores. Implementation of all changes (Ex. 4) also generally improves the sores (except the bias at 12 and 15 hours of the forecast).

Upper-air Wind

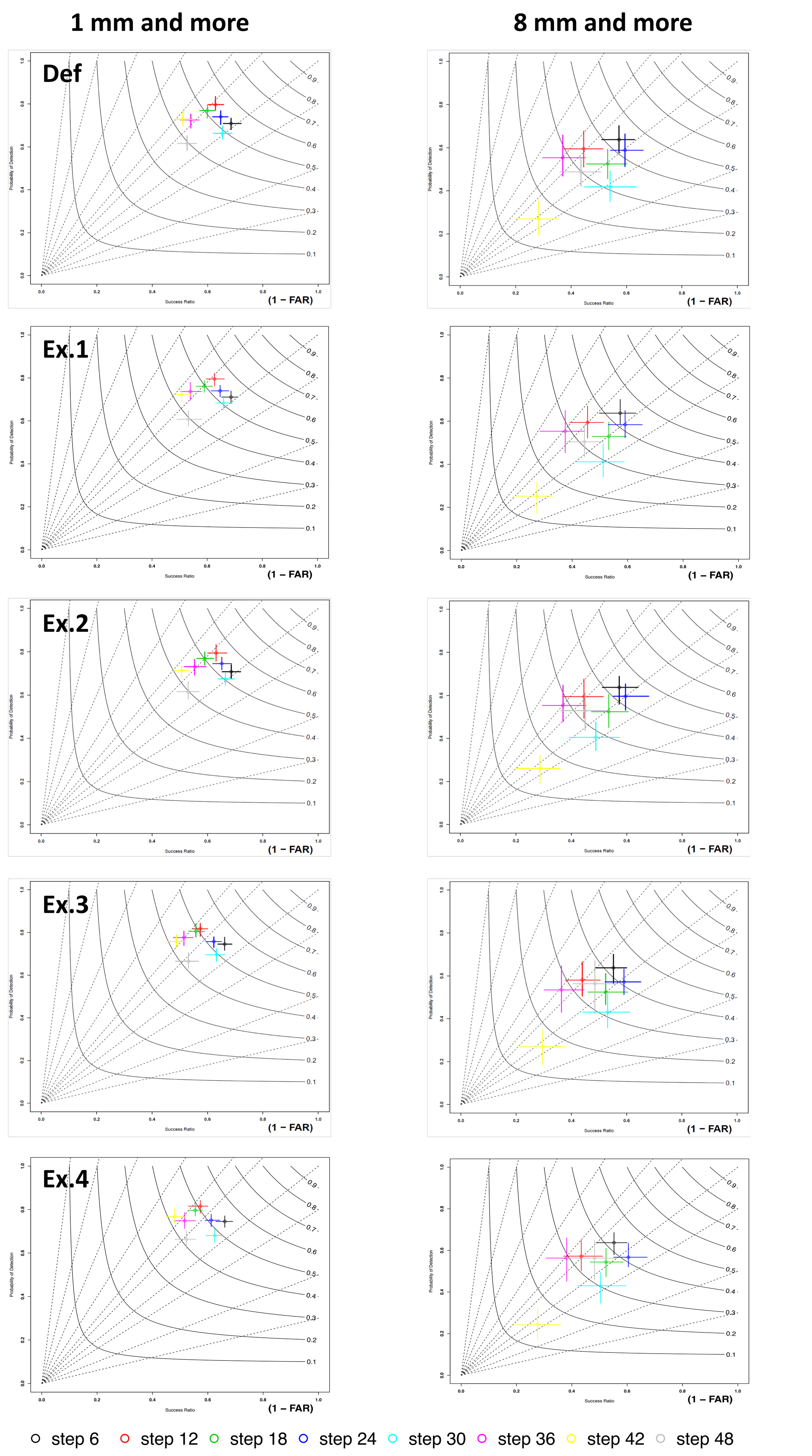




For 36-hour forecast of upper wind an implementation of the TKE advection by the MPDATA (Ex. 1) does not systematically change the bias while the RMSE is slightly bigger in lower troposphere.

The similar applies for the exact buoyancy (Ex. 2). Substituting of MPDATA-A by MPDATA-M (Ex. 3) also does not systematically alter the bias (except improvement in high troposphere) but improves the RMSE in lower troposphere. Implementation of all changes (Ex. 4) improves the RMSE in lower troposphere.

Precipitation



For precipitation of 1 mm and more an implementation of the TKE advection by the MPDATA (Ex. 1) and implementation of the exact buoyancy (Ex. 2) do not significantly affect the scores. On the other hand, substituting of MPDATA-A by MPDATA-M (Ex. 3) generally improves the PoD on the cost of increasing FAR. The latter effect is observed when all the changes are implemented (Ex. 4).

For precipitation of 8 mm and above the experiments 1 to 3 do not significantly alter the default scores with an exception for 42 to 48 hour forecast with MPDATA-A replaced by MPDATA-M (Ex. 3) for which both PoD and FAR are better. The latter effect is also observed when all the changes are implemented (Ex. 4).

Technical Developments

Restart: Implementation of the restart function required to increase the number of saved fields. These additional fields are stored using the COSMO module for I/O operations, in the same binary file. In case of the Intel compiler the restart is exact if only a relatively low optimization level is used (-O1).

Results and domain decomposition: An option was developed to calculate simulations in such a way that the results are independent from the MPI domain decomposition. Since that requires additional global communication and a relatively low optimization level (-O1 for Intel) this is not turned on by default.

General comments

Substitution of the TKE advection using the Bott scheme by the MPDATA and implementation of exact buoyancy do not alter the verification scores of COSMO-EULAG significantly.

On the other hand, the substitution of the advection scheme MPDATA-A by MPDATA-M noticeably changes the verification scores. The results are not unambiguous: the scores for 2m temperature are worse in terms of bias and RMSE while PoD for precipitation in the range from 0.1 mm and more to 1.0 mm and more is improved but on the cost of higher FAR. The scores for other parameters are similar but tend to be slightly better for surface pressure and 2m dew point temperature (not shown).

Superposition of all changes results in verification scores similar to that for substitution of MPDATA-A by MPDATA-M, alone.

Further work will include testing and verification of COSMO-EULAG for autumn-winter type of weather.

REFERENCES

[1] FVM 1.0: a nonhydrostatic finite-volume dynamical core for the IFS, Kühnlein et. al., *Geosci. Model Dev.* (12), 2019.
[2] Smolarkiewicz, P.K., Clark, T.L., 1986. The multidimensional positive definite advection transport alorithm: Further developments and applications. *J. Comput. Phys. 67*, 396-438.
[3] Smolarkiewicz, P.K., Grabowski, W.W., 1990. The multidimensional positive definite advection transport alorithm: nonoscillatory option. *J. Comput. Phys.* 86, 355-375.