# Report on the realization of PT CCE

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# Priority Task "Consolidation of COSMO-EULAG"

Sub-tasks:

1. **Provision of COSMO-EULAG based on COSMO 5.05** (0.25 FTE)
2. **Improved consistency of COSMO-EULAG** (0.20 FTE)
3. **Climate simulations with COSMO-EULAG** (0.35 FTE)

Optimum version of C-E code was prepared at the end of July 2019, which prevented realization of the task 3.

# Task 1 (0.25 FTE)

**1. Provision of C-E based on COSMO 5.05**

1.1 Migrate code to COSMO 5.05

*Done*

1.2 Implement an exact restart in COSMO 5.05

*Done*

1.3 Perform verification for summer and winter months (1.1 & 2.2 km / 2.8 km grid, Alps / Poland, and without / with the nudging)

*Mostly done (except 1.1 km simulations)*

1.4 Compare results with COSMO R-K and ICON-LAM

*Not done for ICON-LAM - early ICON-LAM-PL 2.5 km results available only in August 2019*

# Task 2 (0.20 FTE)

**2. Improved consistency of C-E**

2.1 Replacement of the Bott TKE advection scheme by the MPDATA scheme

*Done*

2.2 Implementation of the zero-gradient b.c. for precipitating fields

*Done*

2.3 General cleaning of the code and an improvement of the computational efficiency

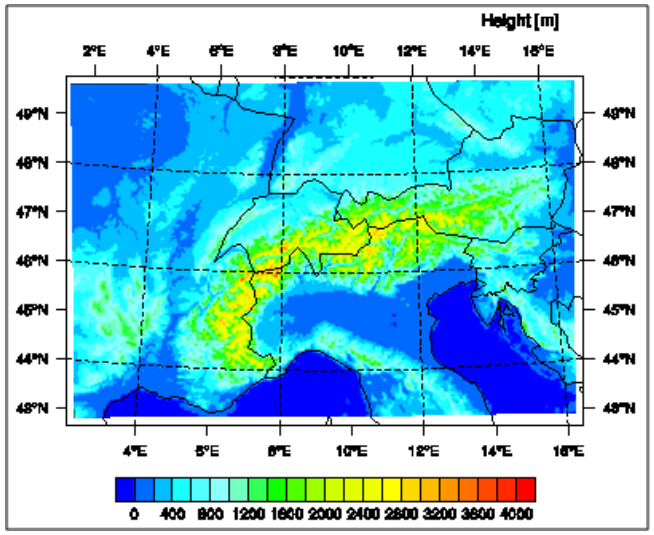
*Done, included revising of halo=1 code (initially implemented by Z. Piotrowski ~2015) and a revision of loop vectorization in X-direction. Around 20% speedup of the COSMO-PL-2k8 setup.*

Additional work: investigating dependency of verification scores on the choice of EULAG advection procedure (MPDATA-A vs. MPDATA-M).

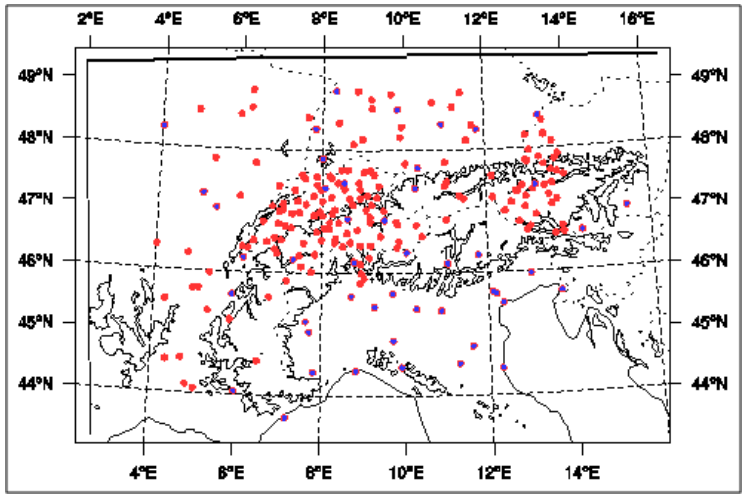
# Results of the experimental studies

Setup of experiments:

- The operational COSMO-2 domain used by Meteo-Swiss with 60 vertical levels (2013)
- Entire June 2013,  48-hour forecasts, VERSUS software
- Numerical and Smagorinsky diffusion are *turned off* for COSMO-EULAG




Topographical map of the domain




Station network for surface verification

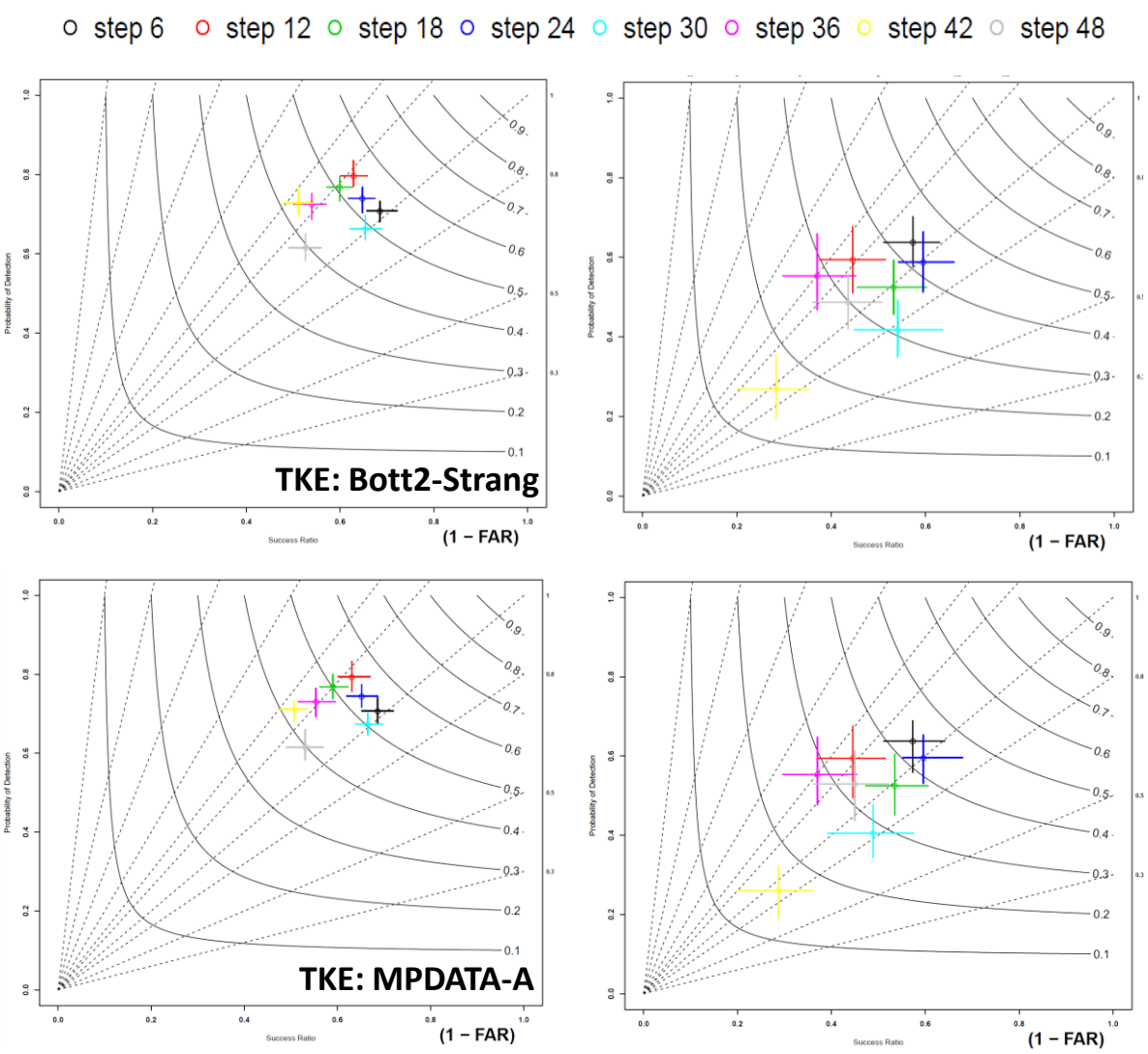
Experiments:

- Replacement of the Bott TKE adv. scheme by the MPDATA-A scheme
- Exact vs. Linearized formulation of moist buoyancy
- Selection of an optimal EULAG advection scheme

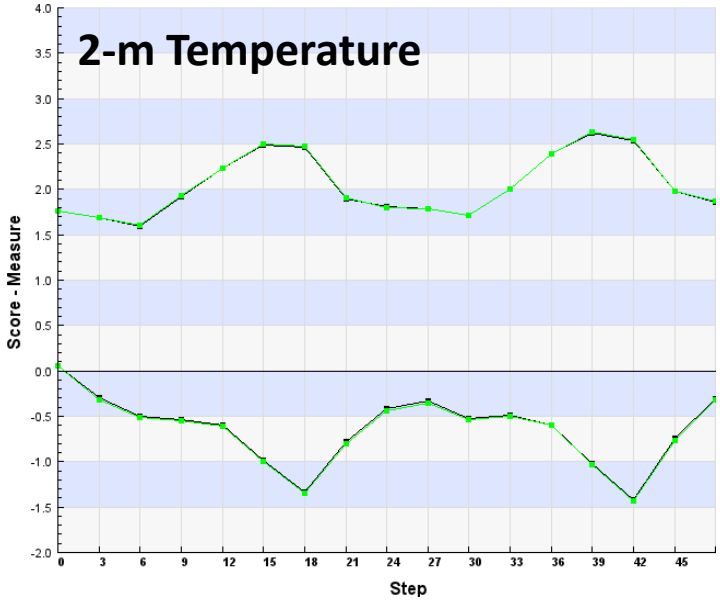
# Replacement of the Bott TKE adv. scheme by the MPDATA-A scheme

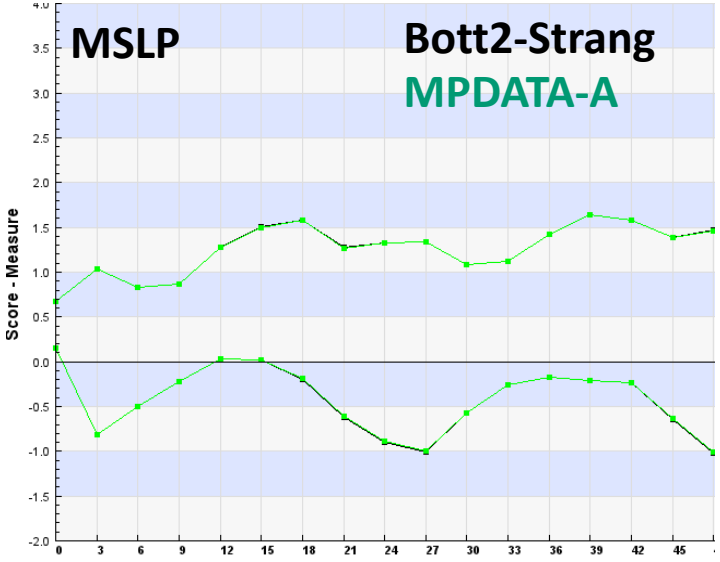
The verification scores of COSMO-EULAG do not alter significantly with that change.

**1 mm and more** **8mm and more**




Reliability diagrams for precipitation



# Exact formulation of moist buoyancy in the compressible C-E

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

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

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

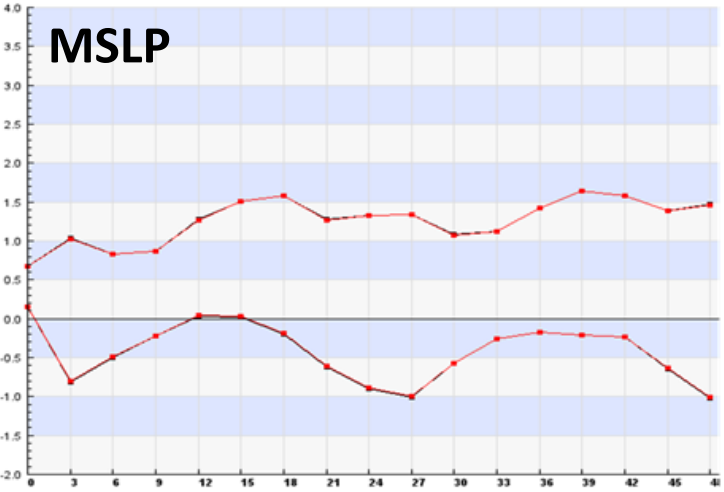
$$\theta_d \equiv \frac{1 + q_v/\epsilon}{1 + q_t}\,\theta$$

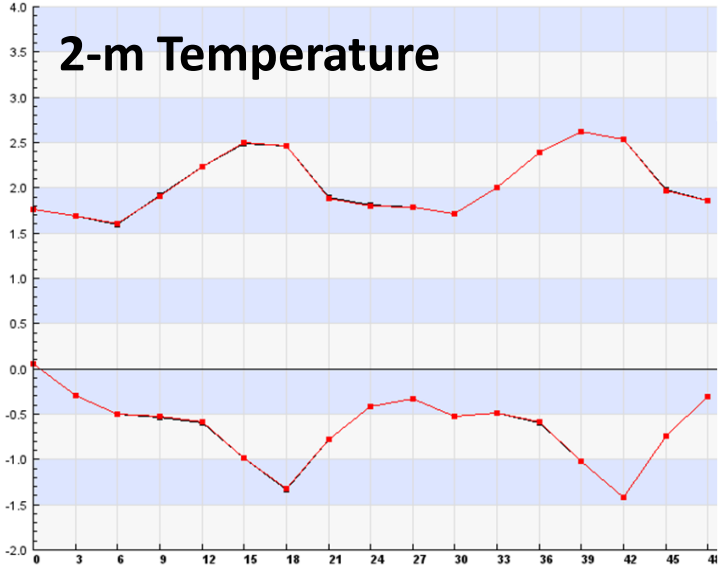
where $q_v$ is mixing ratio of water vapour, $q_t$ is the sum of mixing ratios of all water species, $\epsilon$ is the ratio of gas constants for dry air and water vapour and $\theta$ is the potential temperature.

# Exact formulation of moist buoyancy

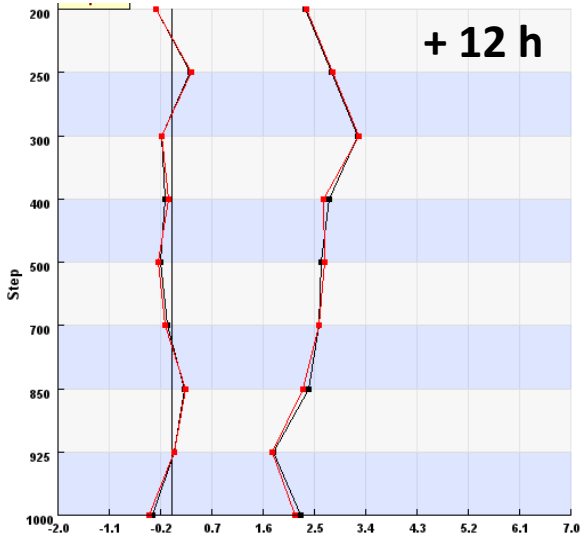
Virtually no differences in the 2m Temperature and MSLP verification scores.
Minor differences in the upper-air wind verification.

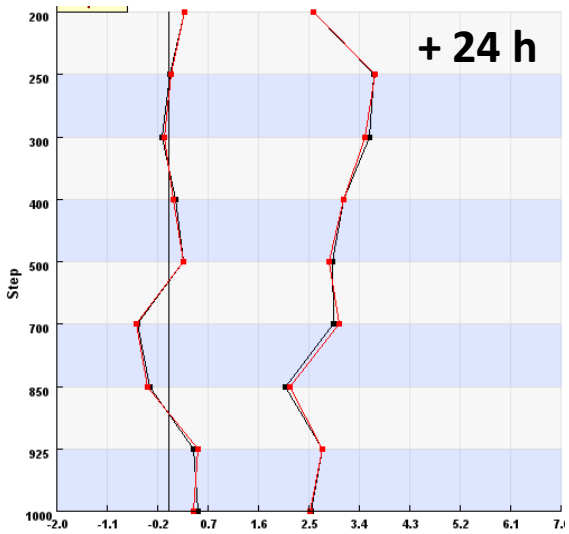
**Linearized moist buoyancy**
**Exact buoyancy**

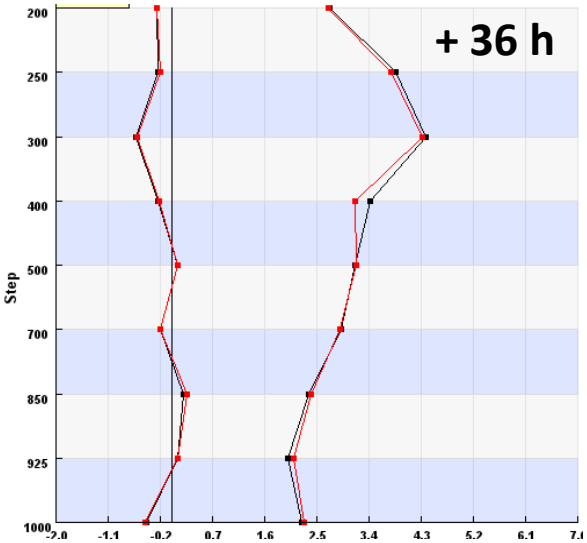


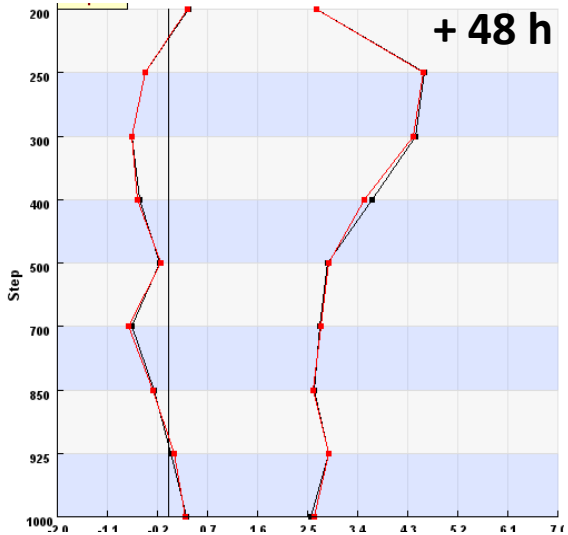




**Upper-air wind**



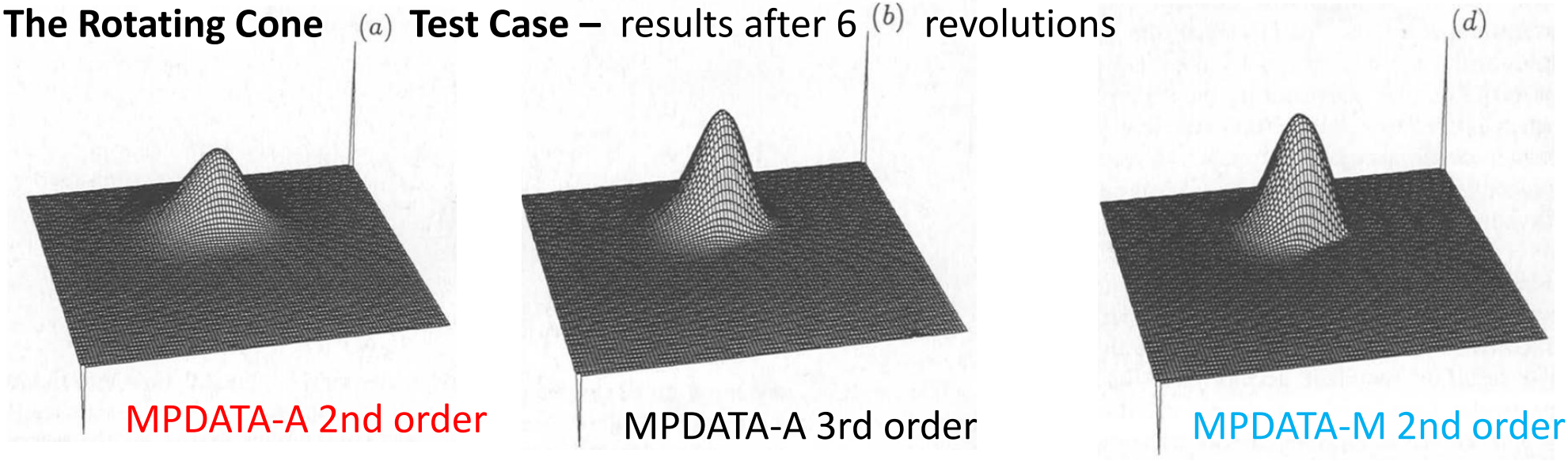



# Selection of an optimal adv. sch. (MPDATA-A vs. MPDATA-M)

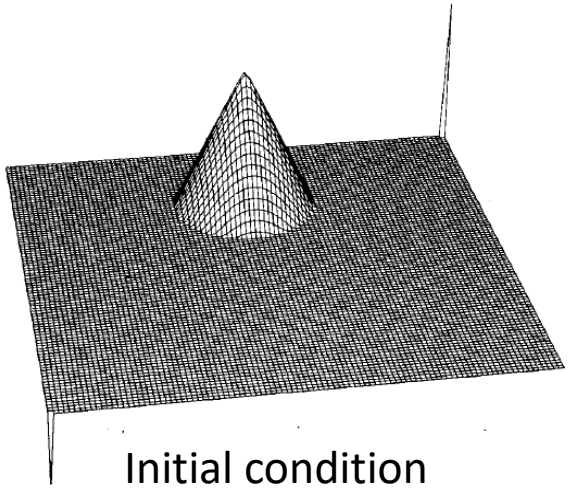
**The Rotating Cone Test Case –** results after 6 revolutions




MPDATA-A 2nd order

MPDATA-A 3rd order

MPDATA-M 2nd order

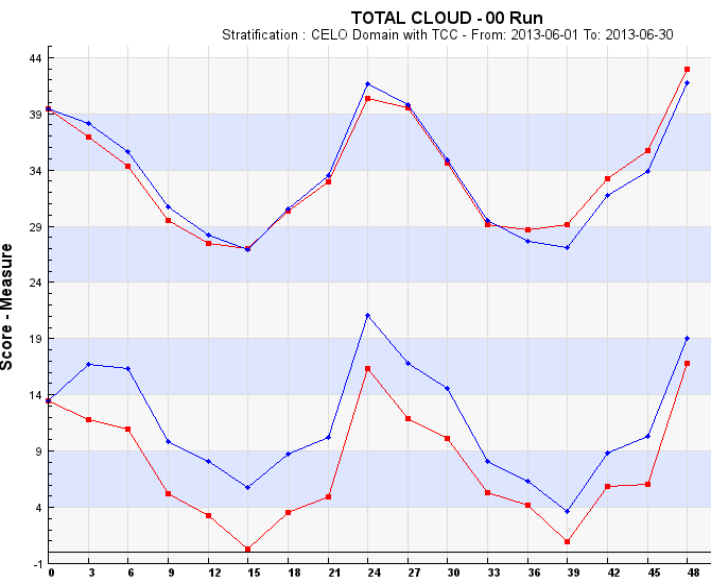


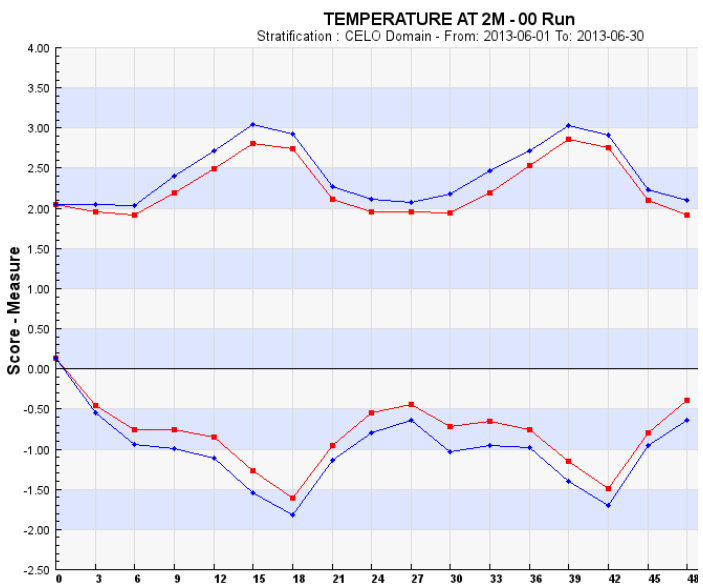
Initial condition

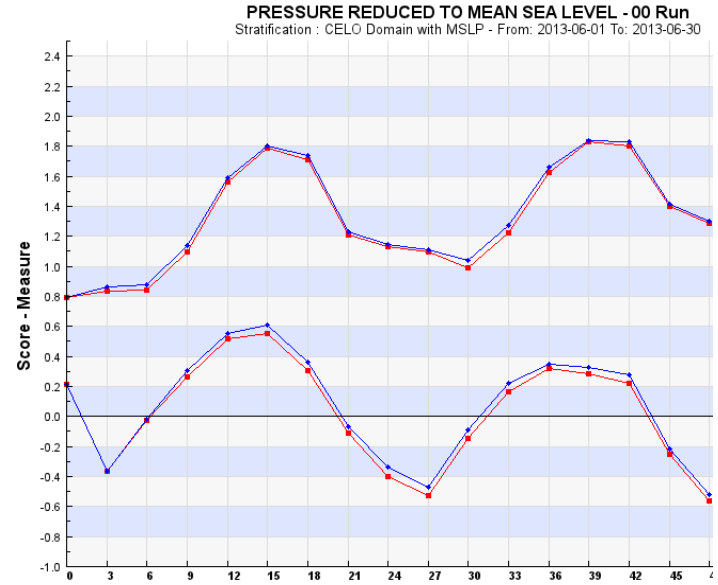
| | MPDATA-A 2nd order | MPDATA-M 2nd order |
|---|---|---|
| Advected field | $\psi$ | $\Psi+c$, $c \rightarrow \infty$ |
| Accuracy | Lower | Higher |
| Diffusion | More | Less |

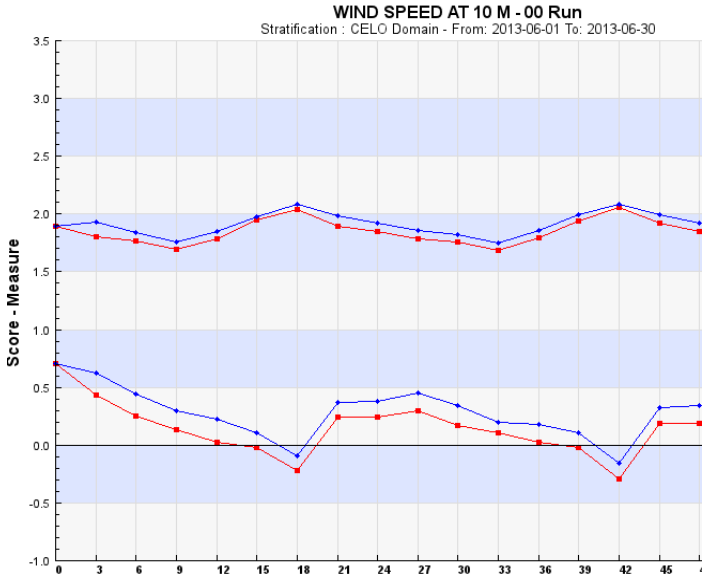
Smolarkiewicz and Clark (JCP, 1986),
Smolarkiewicz and Grabowski (JCP, 1990).

# Selection of an optimal adv. sch. (MPDATA-A vs. MPDATA-M)



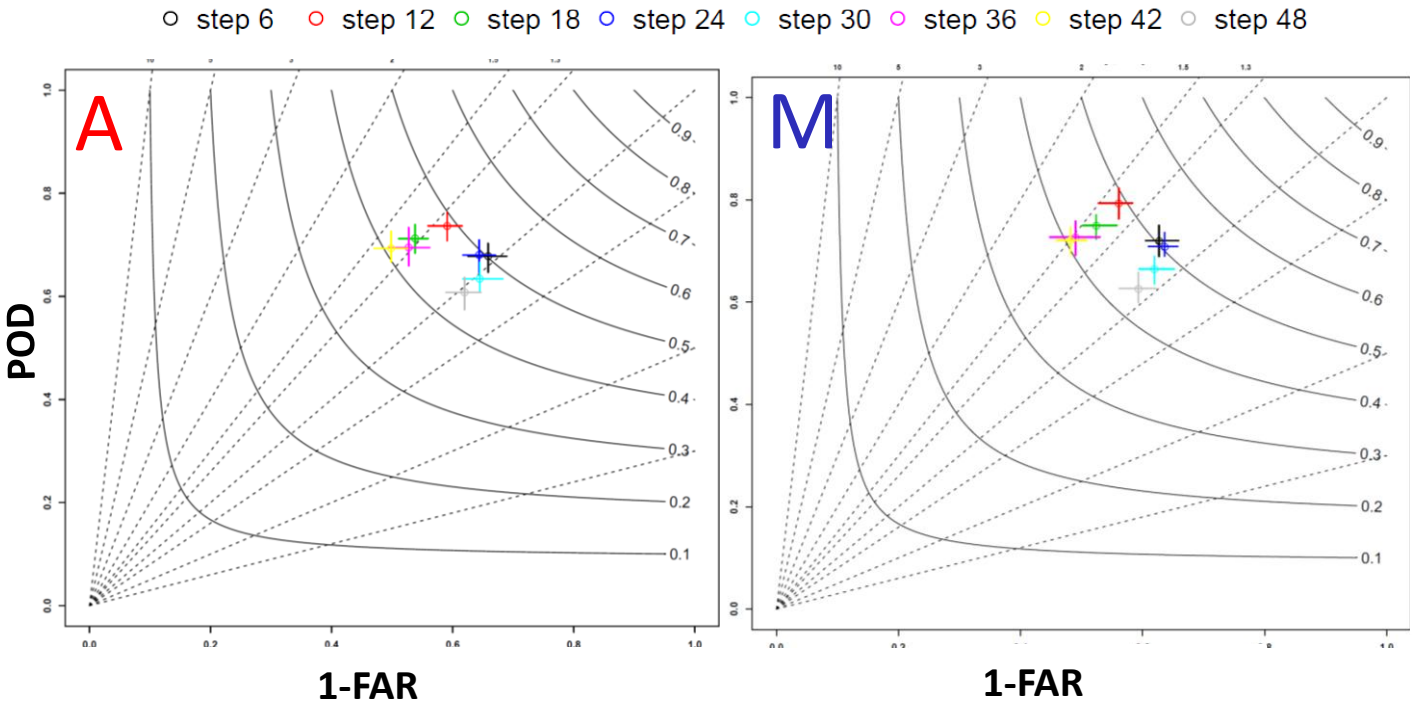



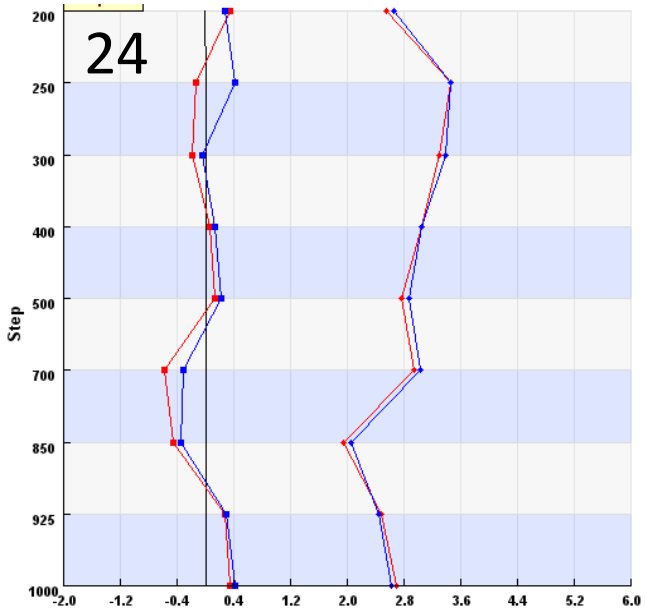

- For the 2-Temperature, MSLP, and 10-m Wind Sp. option A outperforms M
- For the TCC A outperforms M, except only the 36-48 h for RMSE

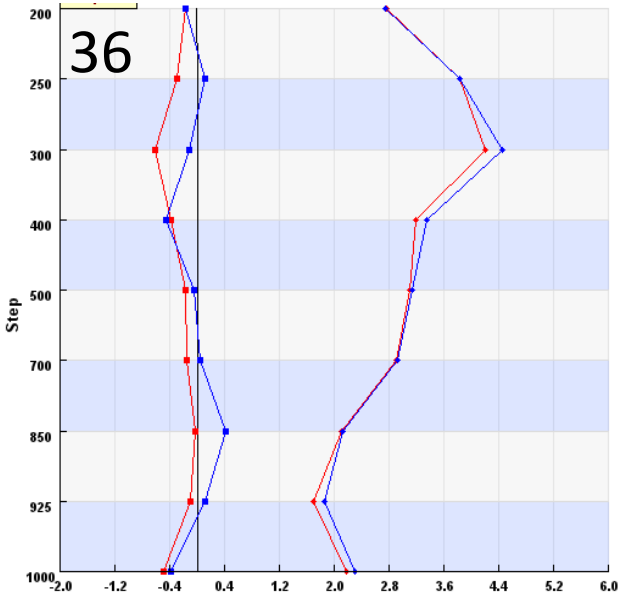
# MPDATA-A vs. MPDATA-M

## Precipitation: 1mm and more




## Upper-air wind speed



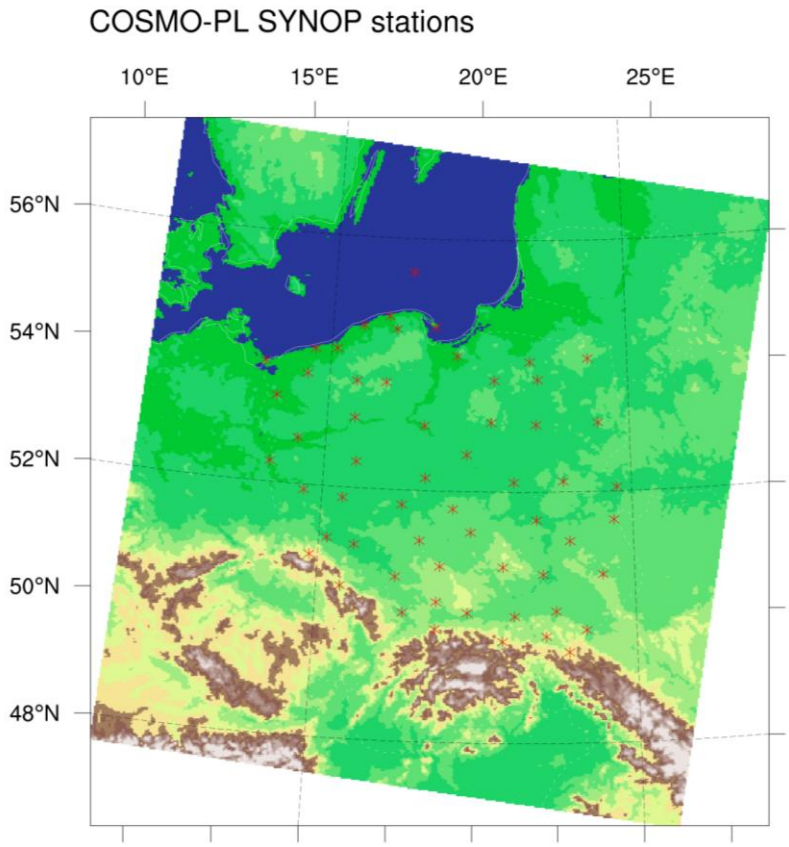

- For upper-air wind speed RMSE is usually lower for A
- A provides precipitation forecasts with slightly improved frequency bias
- Additionally: in the A simulations lower vertical velocities within convective updrafts are observed (not shown)

**COSMO-EULAG with the more diffusive scheme, MPDATA-A, provides forecasts having slightly better verification scores.**

# Semi-operational forecasts for Poland (with nudging)

Setup

- The domain of COSMO-2.8-PL
- 48-long forecasts with 4-hour nudging window
- C-E version 5.05 used with the setup updated between winter and summer



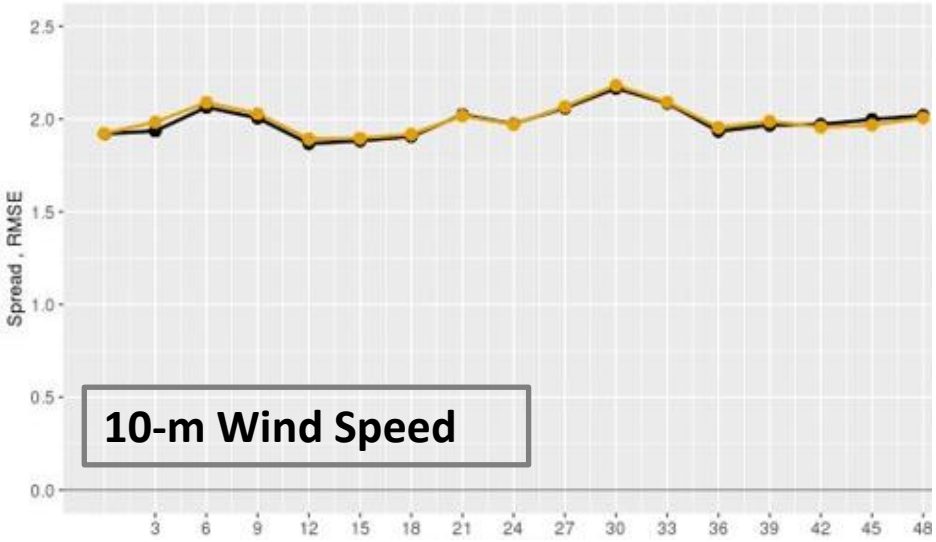

Verification (HARP software)

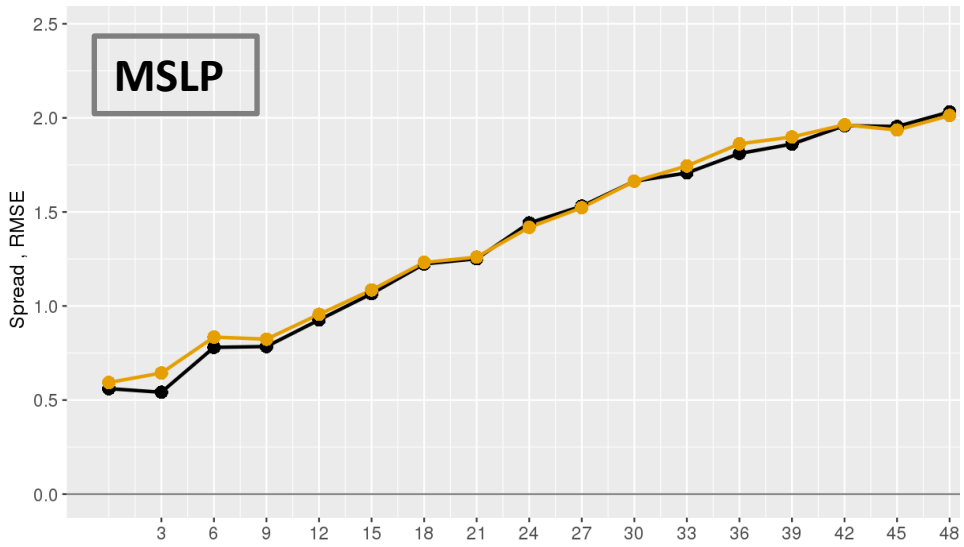
- With COSMO R-K ver. 5.01 (operational)
- ~60 surface synoptic stations (right)
- Root Mean Square Error is shown
- 15 January till 14 February 2019
- 25 July till 24 August 2019

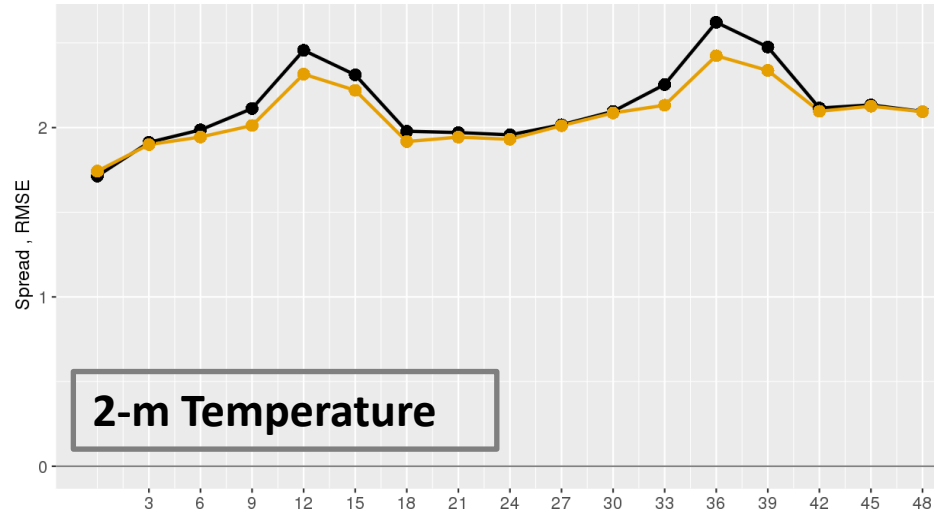
Computational performance of C-E

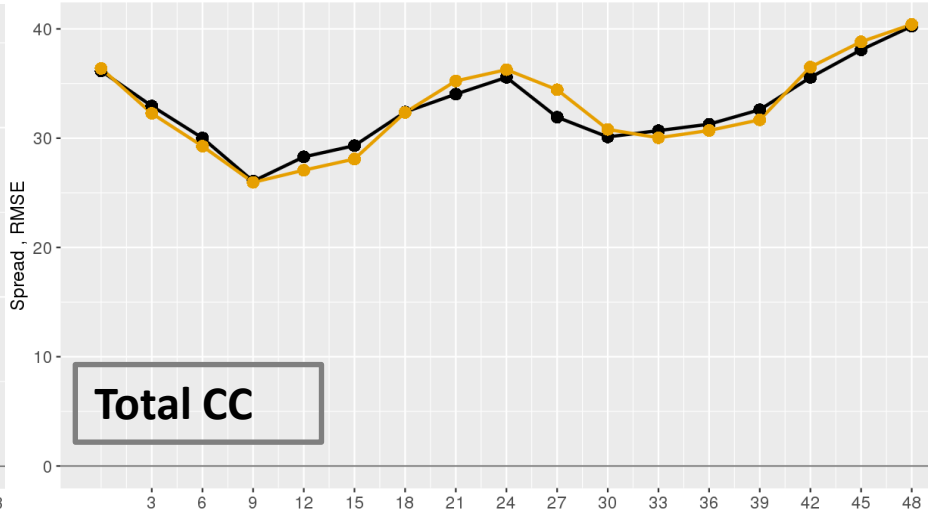
- Around 160 % of the COSMO R-K computational time

# Poland – winter verification



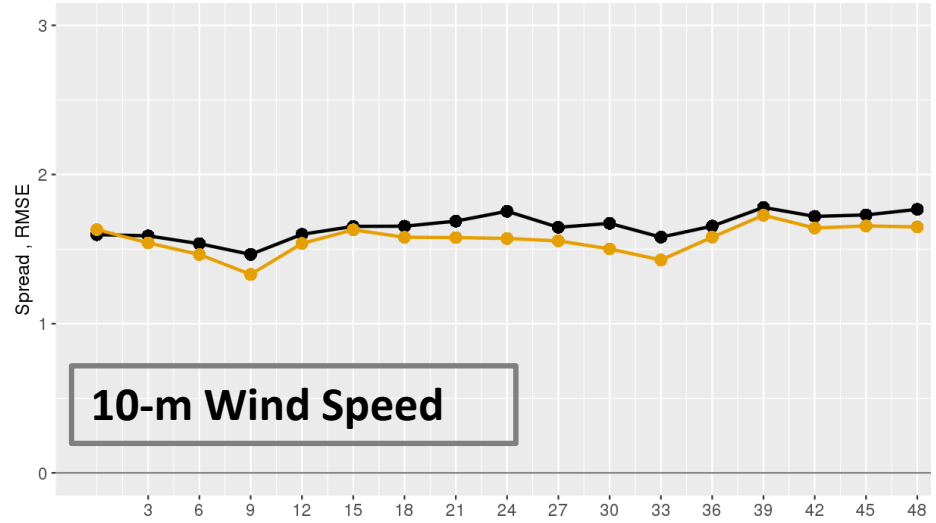



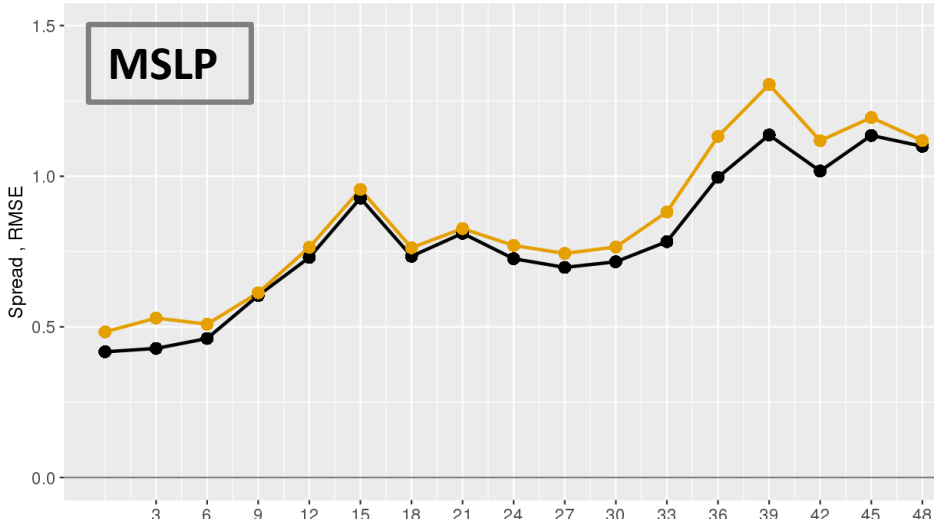



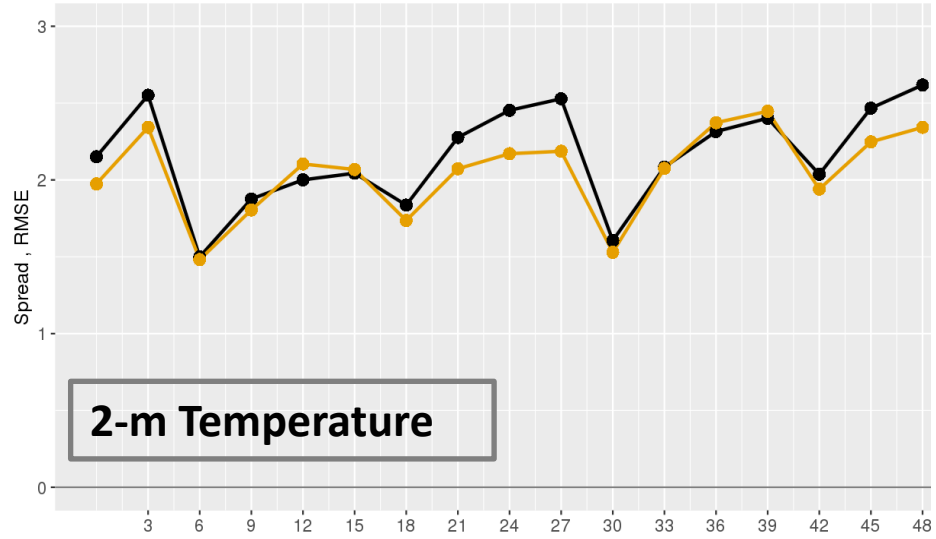

The RMSE scores for winter are very similar.

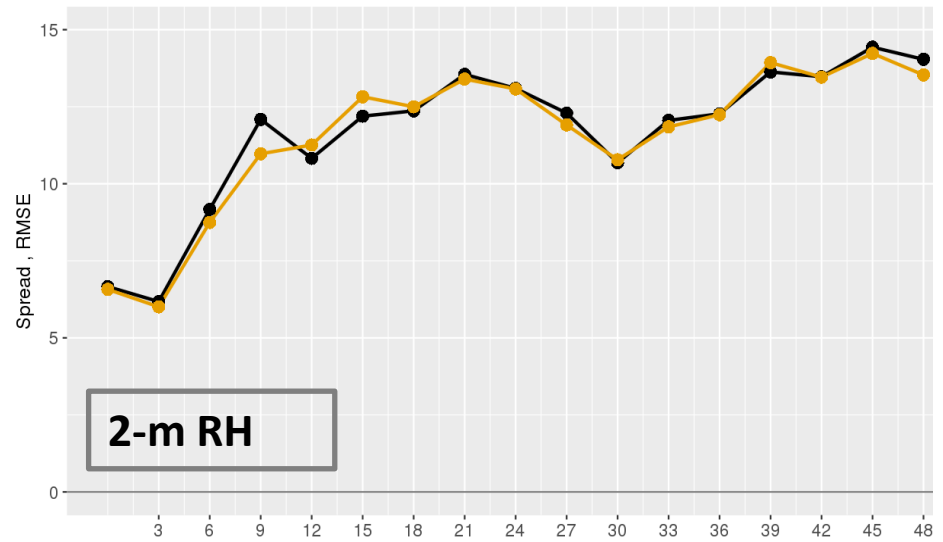
**COSMO R-K ver. 5.01**
**COSMO-EULAG (ver. 5.05)**

# Poland – summer verification




- For 10-m wind speed and 2-m temperature the RMSE is slightly lower for C-E
- For MSLP the RMSE is slightly lower for C R-K

**COSMO R-K ver. 5.01**
**COSMO-EULAG (ver. 5.05)**

# Summary

1. Consistent, optimized and extensively tested COSMO-EULAG ver. 5.05 was prepared and passed to Michael Baldauf and Uli Schaettler
2. The computational performance was slightly improved
3. The Scientific Documentation and the User Guide were revised and updated; a publication is being prepared
4. COSMO-EULAG works semi-operationally in IMGW-PIB since winter 2019 with nudging and with competitive verification scores
5. Future work may involve comparison of COSMO-EULAG and ICON-LAM for high spatial resolutions (over Poland) and with more advanced verification
6. Future work may also focus on computational efficiency: split-advection (following ECMWF research) and sub-stepping for horizontal advection (similarly to the Bott scheme)