Research in numerical modelling at the Hydrometcenter of Russia

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Hydrometcenter of Russia

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OUTLINES

1. Objective estimation of model errors due to unresolved scales
2. Model-error perturbation scheme for limited-area models
3. A new aerosol climatology: implementation to COSMO model and testing
4. An assessment of the new aerosol-cloud-radiation scheme
5. Updates of prediction systems based on SL-AV

Michael Tsyrulnikov and Dmitry Gayfulin

Objective estimation of model errors due to unresolved scales

Approach

For a low-resolution (coarse-grid) model in question, compute the model error with respect to a significantly higher-resolution (fine-grid) model.

That is, start the two models from "the same initial data", compute the two short-term tendencies and claim that their difference is the model error.

The fine-grid fields are upscaled (coarse-grained, smoothed) before being compared with the coarse-grid fields. *(Averaging over all fine-grid cells within each coarse-grid cell is performed.)*

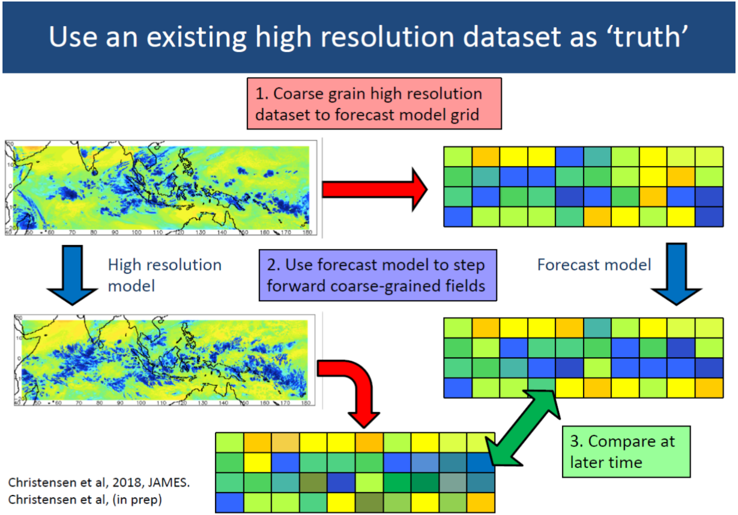
A lesson from the previous stage of the study

- Model errors due to convection appear to be too complicated (and organized) to be treated with a purely stochastic field model. A physical model is needed for this purpose.
- Recommendation: A stochastic convection parameterization is to be used to represent the impact of unresolved convection in an ensemble prediction system.

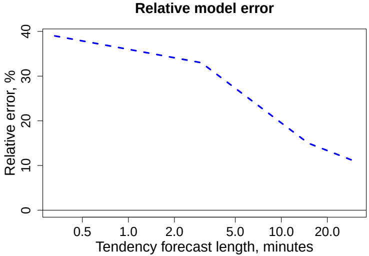
Setup

1. The lowRes model was COSMO-2.2km L65.
   The hiRes was COSMO-0.22km L65.
   Otherwise, the two models were the same.
2. Convection: we selected (presumably, non-convective) winter cases and switched off the convective parameterization.
3. Domain: 187*187 km in the North Sea.
4. The tendencies were computed after a 3–5h *pre-forecast*.
5. The length of the tendencies varied from 1 min to 30 min.

The default scheme (Christensen, WGNE33, 2018)



Magnitude of the estimated model error (relative to the total tendency) in the default scheme: T, 3D averaging



The resulting estimate of the model error strongly depends on the length of the initial tendency and falls only to some 10% for the 20-min tendency (which is too poor for an operational-class COSMO model to be taken as its error).

The culprit is the **initial shock** in the lowRes model started from **upscaled** hiRes fields.
The real model error is drowned in the initial model shock.

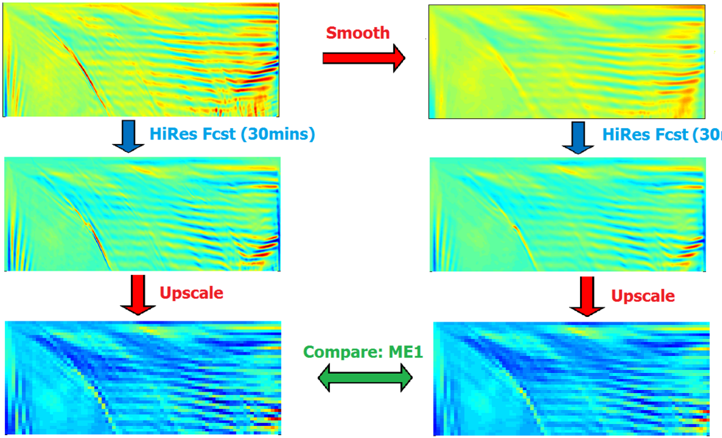
Fighting the imbalance

The proposed solution: split the model error into two components: ME1 and ME2:

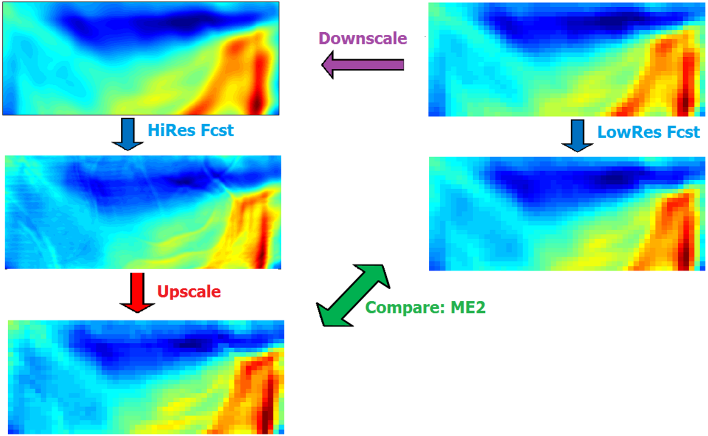
ME1 is the difference between forecasts of two hiRes models one of which starts from hiRes initial conditions and the other from smoothed initial conditions.

ME2 is the difference between forecasts of hiRes and lowRes models both started from lowRes initial conditions.

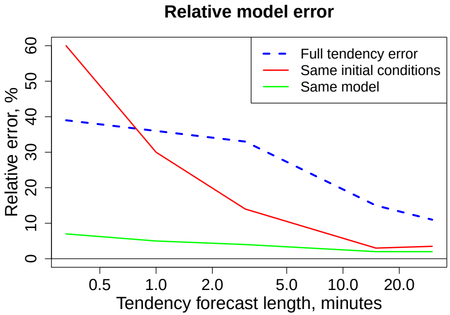
Computation of ME1 (start from a 3h hiRes pre-forecast, top-left)



Computation of ME2 (start from a 3h lowRes pre-forecast, top-right)



Magnitudes of ME1 and ME2 model-error components: T, 3D averaging



•Estimates of the two model-error components (ME1, green and ME2, red) fall to realistic 2% of the total tendency (in contrast to the default estimate of model error, the blue line).
•With ME1 and ME2, the spinup is seen to settle down more quickly than in the default scheme.
•So, 15-min or longer tendencies can be taken as initial-imbalance free, providing (hopefully) useful estimates of ME1 and ME2.

Model-error perturbation scheme for limited-area models

Elena Astakhova, Dmitry Gayfulin, Michael Tsyrulnikov

SPG : stochastic pattern generator

$$\left(\frac{\partial}{\partial t} + \mu\sqrt{1 - \lambda^2\Delta}\right)^3 \xi(t, s) = \sigma\alpha(t, s),$$

ξ is random field in question (model error)

α is the driving white noise (source of pure stochasticity)

t is time, s is the 3D or 2D spatial coordinate vector

Parameters:

σ controls the variance

λ controls the spatial length scale

μ controls the time scale.

The requirement implied: the 4D fields should obey the “proportionality of scales principle”: large spatial scales should be associated with large temporal scales and vice versa.

* *M.Tsyrulnikov, D. Gayfulin Meteorologische Zeitschrift, 2017*

AMPT: Additive Model-error perturbations scaled by Physical Tendencies

✓ AMPT relies on SPG as a source of spatio-temporal stochasticity

✓Each model variable (including humidity and cloud fields) is perturbed every time step on the vertical level in question with an independent SPG-generated 4D random field

✓The magnitude of the perturbation is an area averaged (in the horizontal) absolute value of the physical tendency |P| for the variable in question.

✓The perturbations are additive.

✓The spatial and temporal correlations are linked to each other using a characteristic speed (now 15 m/s)

AMPT tests with EPS

Ensemble system: COSMO-Ru2-EPS

Δx~2.2 km, L51, M10, fc+48h, IC&BCs from a clone of COSMO-LEPS for Sochi Olympics

Domain: Sochi region

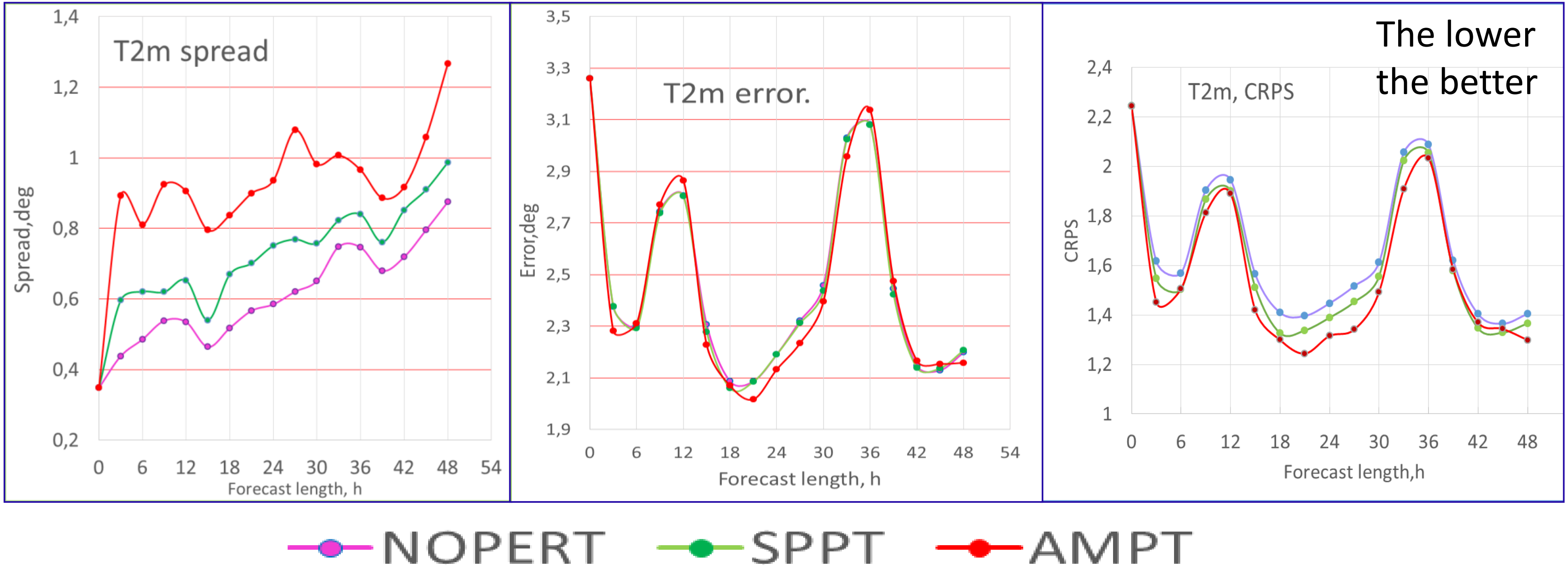
Period: February-March 2014

Initial time: 00 UTC

Verification: against meteorological station observations (about 40 stations). Nearest grid-point for temperature and wind

Single precision runs

AMPT tests with EPS



Positive effect on T2m, neutral on wind and precipitation

New aerosol climatology in COSMO model

Previously available aerosol datasets:

- **Tanre climatology** (Tanre et al., 1984) – *in operational model version*
- **Tegen climatology** (Tegen et al., 1997) – *optional for operational use*

New aerosol datasets tested:

- **MACv2 climatology** (Kinne et al., 2019) – recently implemented to the code
- **CAMS ECMWF aerosol reanalysis** (5 types and mix coefficient similar to Tegen climatology) – used for experiments only

Experiment set up:

Simulation domain 13200x6600 km (Eurasia), 13 km grid spacing

24-h forecasts

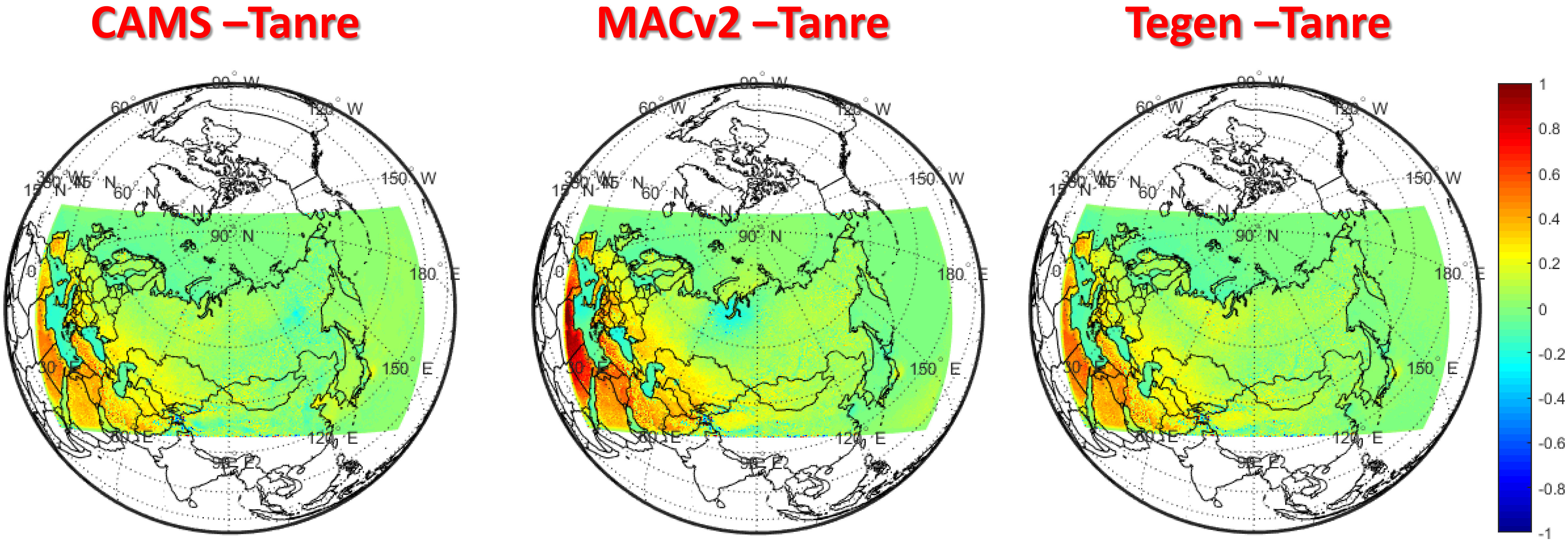
Period - January, April, July, October 2017

T2m, T850, T500, low level cloud

N.Chubarova, J.Khlestova, A. Poliukhov, M.Shatunova. *The work was done within the COSMO Priority Project T2(RC)2*

The effect of various aerosol climatologies

The monthly averaged difference in 24-h T2m forecasts. July 2017

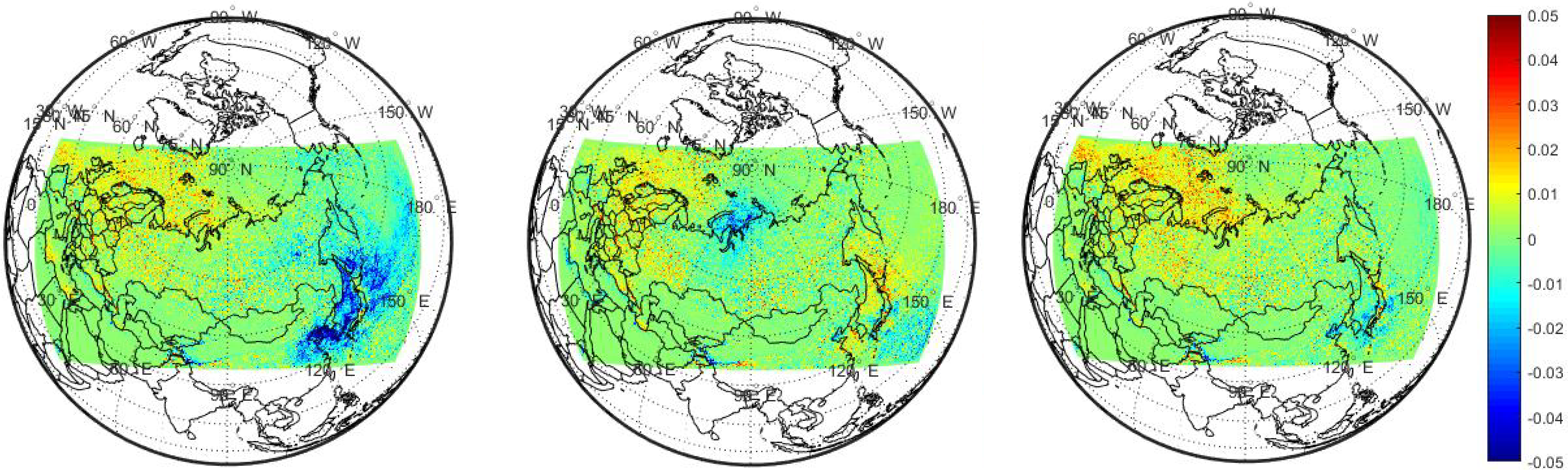


Significant T2m growth for all climatologies wrt to operationally used (up to 1K for MACv2) in North Africa and south Europe

The effect of various aerosol climatologies

The monthly averaged difference in low-level clouds. July 2017

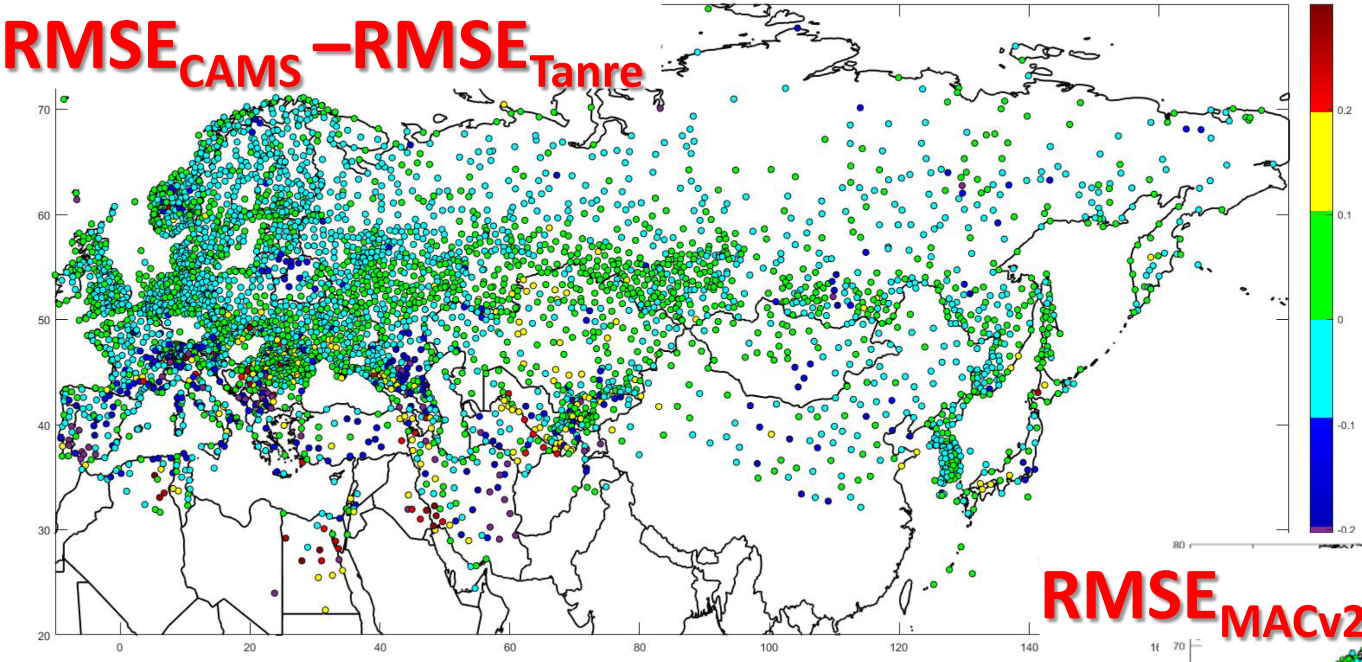
CAMS –Tanre | **MACv2 –Tanre** | **Tegen –Tanre**



5% reduction over the Yellow Sea and the Sea of Japan seas (for CAMS) and over the Kara Sea (for MACv2)

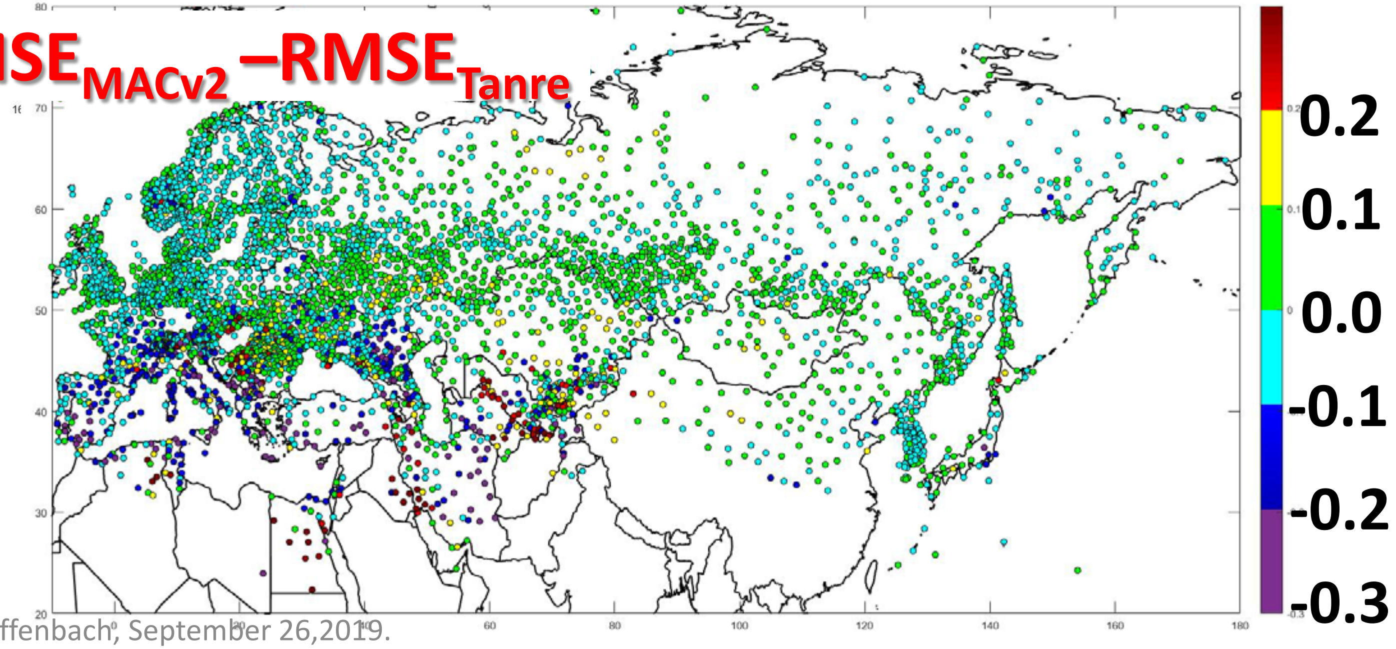
The effect of various aerosol climatologies

$RMSE_{CAMS} - RMSE_{Tanre}$



The significant differences ($|\Delta RMSE| > 0.3$) were observed in **South Europe, south part of the European territory of Russia, Central Asia, Northern Africa**

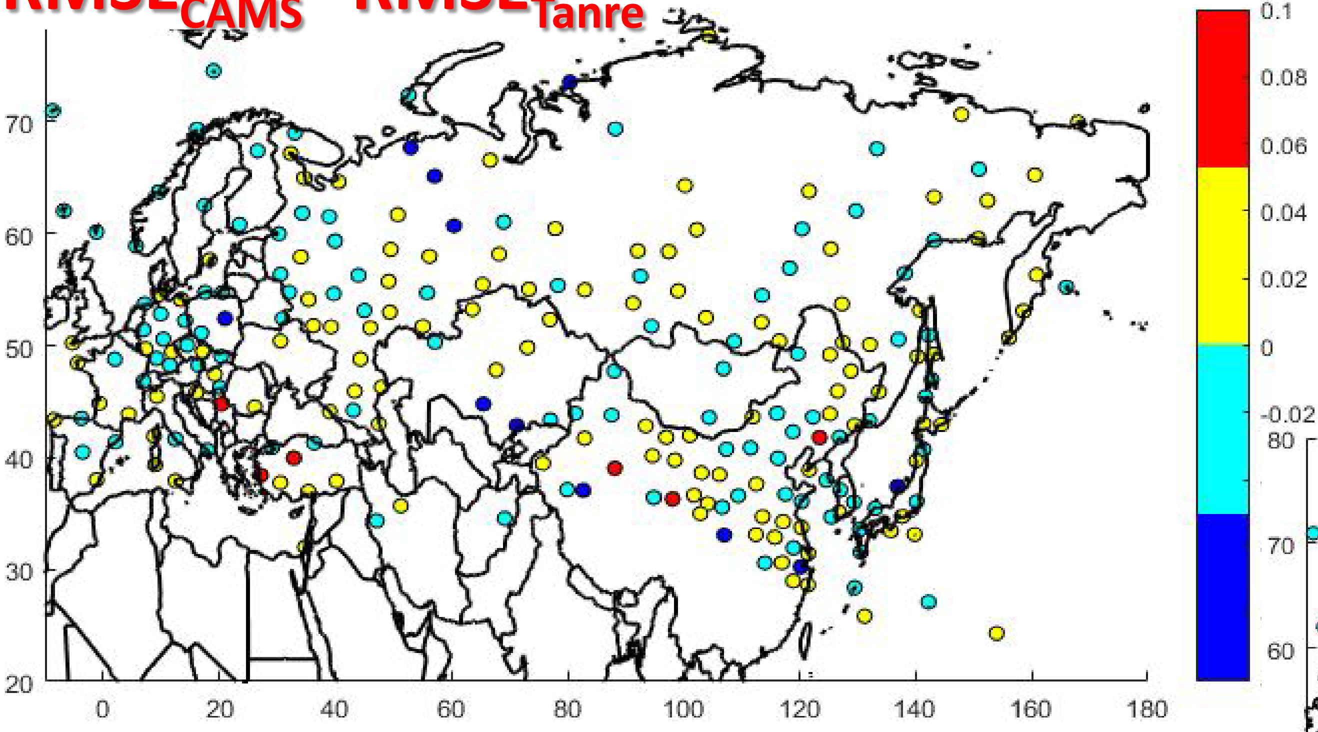
$RMSE_{MACv2} - RMSE_{Tanre}$



T2m, July 2017
Verification against SYNOP data
4510 stations

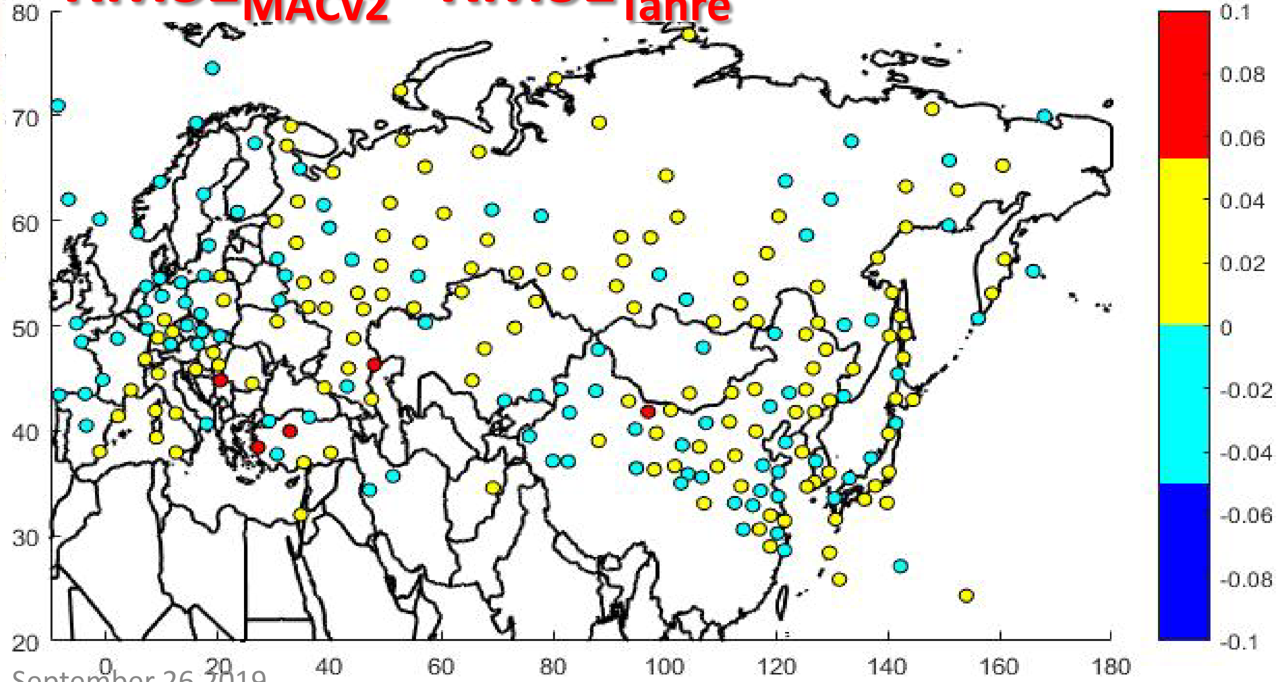
The effect of various aerosol climatologies

$RMSE_{CAMS} - RMSE_{Tanre}$



Smaller effect and neutral on average.

$RMSE_{MACv2} - RMSE_{Tanre}$



T500, July 2017
Verification against upper air sounding data

Summary 1

- A significant effect of aerosol climatology on 2m-temperature was found (up to 0.5 K, mostly in the regions with high probability of dust aerosol - North Africa, Middle East, Central Asia)
- The influence of aerosol climatology on T500, T850, low clouds is rather small
- MACv2 can be successfully applied for short-range forecasting

Assessment of the new scheme for aerosol-cloud-radiation interaction in COSMO model

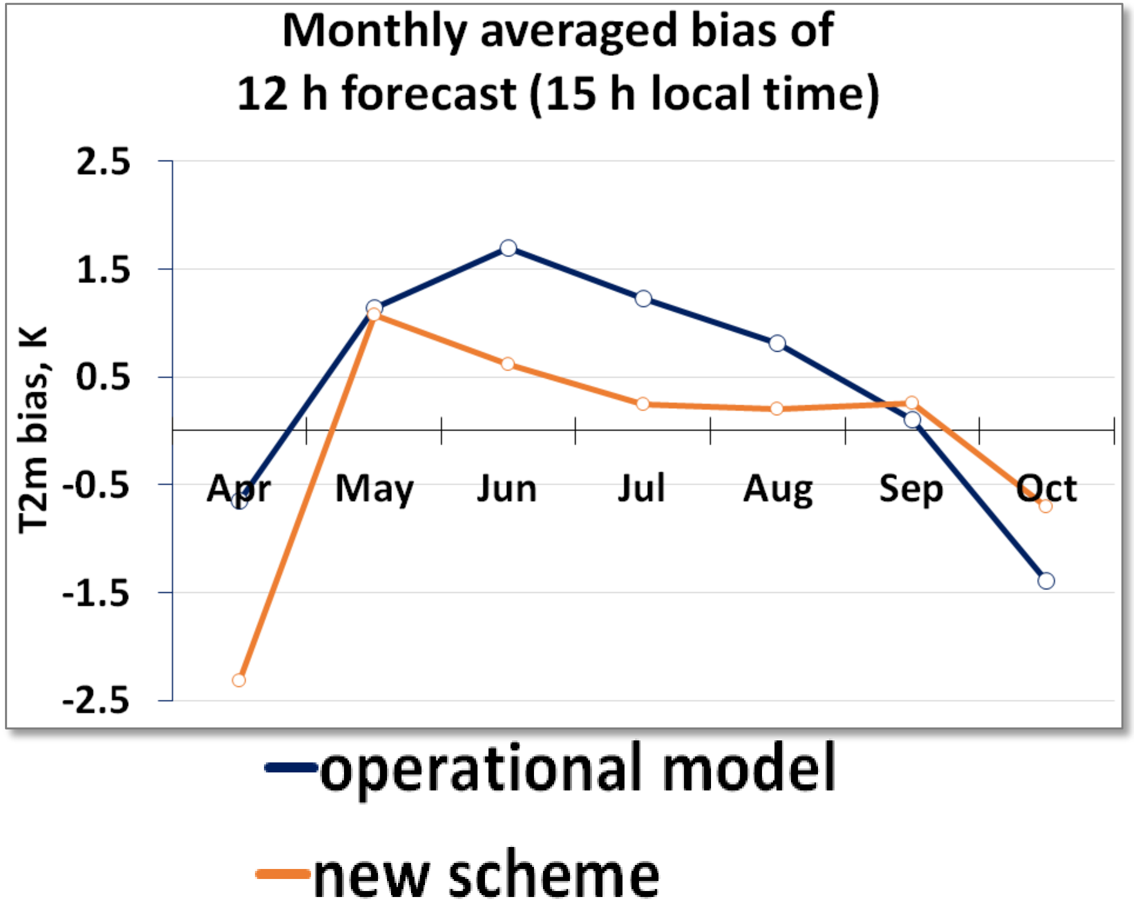
The new aerosol-cloud-radiation interaction scheme allows to calculate:

- **effective radius of cloud particle** PDF in dependence on cloud particle number which is a function of cloudbase updraft speed and aerosol number density (Segal, Khain, 2006)
- **cloud optical properties** in dependence on cloud water/ice content and cloud particle size

N.Chubarova, J.Khlestova, A. Poliukhov, M.Shatunova. *The work was done within the COSMO Priority Project T2(RC)2*

Assessment of the new scheme for aerosol-cloud-radiation interaction in COSMO model

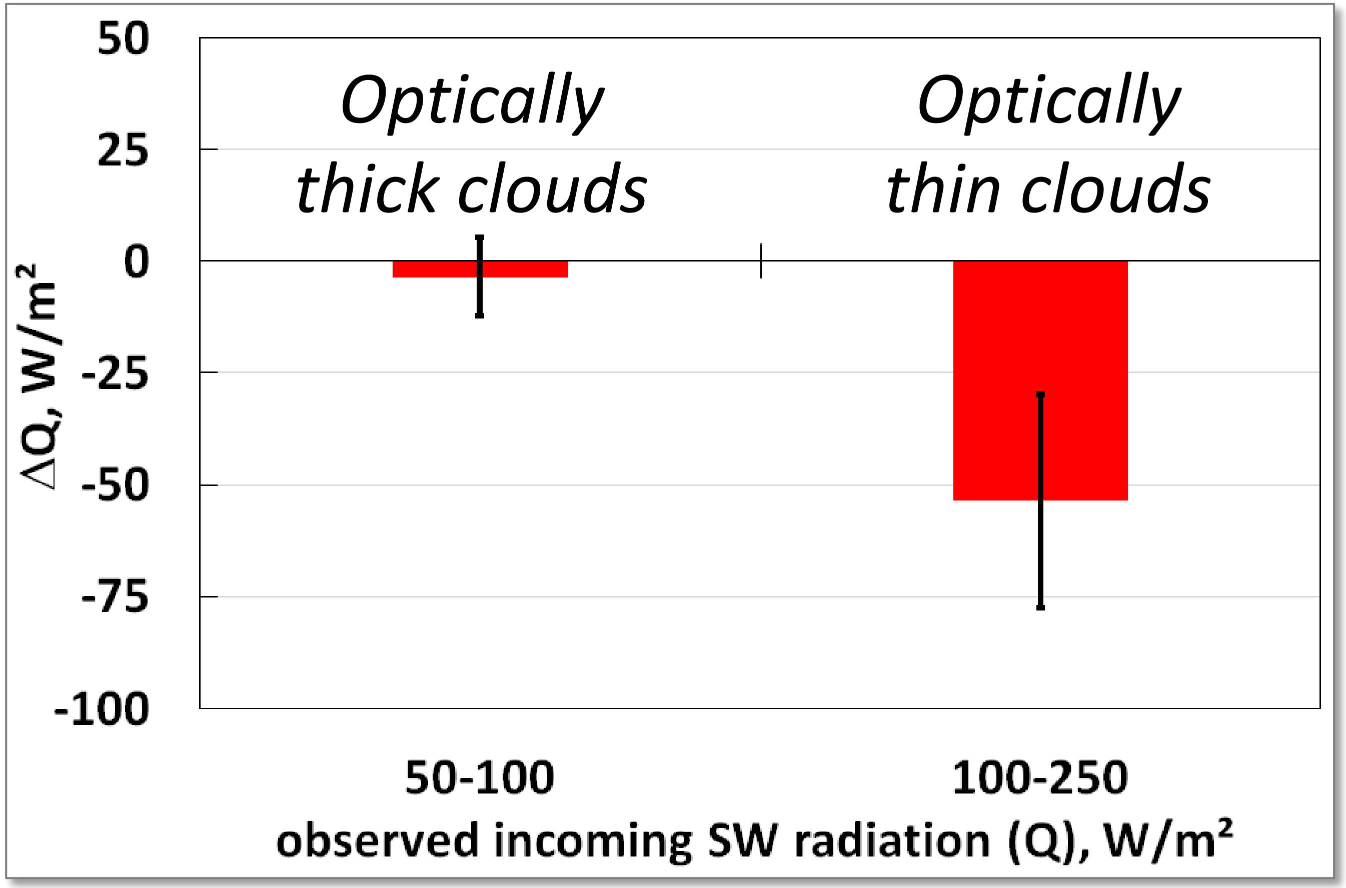
- **Simulation domain 900x1000 km, 2.2 km grid spacing (Moscow region)**
- **Period April-October 2018**
- **All-sky conditions**
- **24-h forecast, start at 00 UTC**
- **Verification against SYNOP (147 stations)**



Noticeable improvement of the day-time T2m forecast!

Assessment of the new scheme for aerosol-cloud-radiation interaction in COSMO model

- Verification of incoming SW radiation (Q) against observations at the Meteorological observatory of the Moscow State University
- Period April-October 2018
- Overcast conditions (the direct solar radiation flux was zero)
- Sun elevation was more than 25°



Correct prediction of cloud microphysics is important for forecasting incoming SW radiation in the case of optically thin clouds!

Summary 2

- T2m forecasts for Moscow region during the daytime were noticeably improved with the new aerosol-cloud-radiation scheme.
- The skill of the simulated incoming SW radiation Q depends on the magnitude of Q. The importance of correct prediction of cloud microphysics for rather thin clouds is evident.

Updates of prediction systems based on SL-AV

Long-range

- Resolution 1,4x1,125° lon-lat, 28 levels
- Uppermost level at 5 hPa
- 1.5-3 km resolution in the stratosphere
- SW and LW radiation: Ritter, Geleyn 1992 (1+1 band)
- Boundary layer – improved version of Geleyn 1982
- ISBA surface scheme
- 4 months forecast in 40 min at 8 cores of Cray XC40

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- Resolution 0,9x0,72° lon-lat, 96 levels
- Uppermost level at 0,04 hPa
- 500-700 m resolution in the stratosphere
- SW radiation: CLIRAD SW, LW radiation: RRTMG LW (11 + 16 spectral bands)
- Boundary layer: Bastak-Duran et al JAS 2014
- Marime stratoculumus, sea-ice T
- INM RAS mulilayer soil scheme
- 4 months forecast in 40 min at 480 cores of Cray XC40

Medium-range

- 51 levels
- resolution in longitude 0,225°, in latitude from 0,16° in NH to 0,245° in SH

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- 104 levels with the top level at 0.05 hPa
- Horizontal grid with ~10 km resolution in midlatitudes

Mikhail Tolstykh, Rostislav Fadeev, Vladimir Shashkin,Gordey Goyman,Svetlana Makhnorylova

Thank you for your attention !