NUMERICAL WEATHER PREDICTION
and related problems of TURBULENCE AND CLIMATE MODELING:
current state and further development

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Тема НИОКТР 125032004255-7

1. WEATHER

G.I. Marchuk.
Physics of the atmosphere and ocean and the problem of weather forecasting
// Meteorology and hydrology, 1976, No. 10, pp. 3-14.

"Weather forecasting is one of the central problems of science, actively influencing many sectors of the national economy, such as agriculture, public utilities, aviation, etc. Improving the quality of weather forecasting almost immediately leads to increased economic efficiency... and... results in benefits amounting to hundreds of millions (GSR: now billions) of rubles."

1977

https://wmolcdnv.ecmwf.int/

ВМО: ОЦЕНКИ T850 для 2012-2026, севернее 20^0N

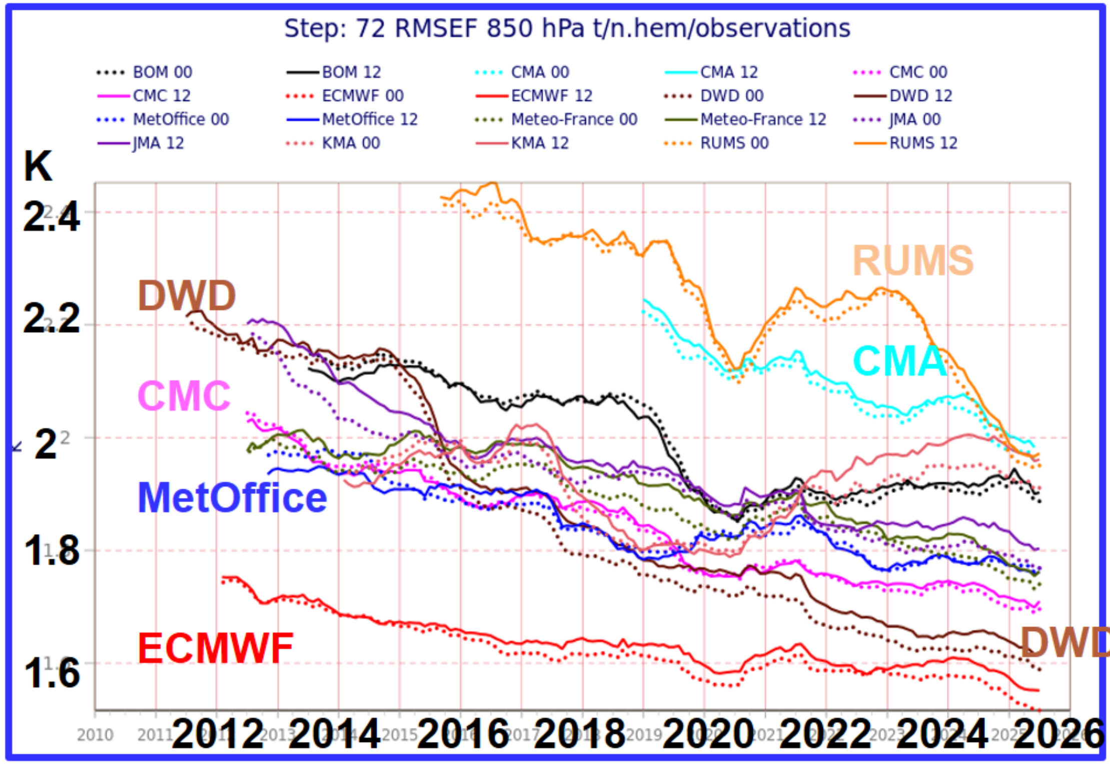
ПРОГНОЗ на 72 час.

https://wmolcdnv.ecmwf.int/

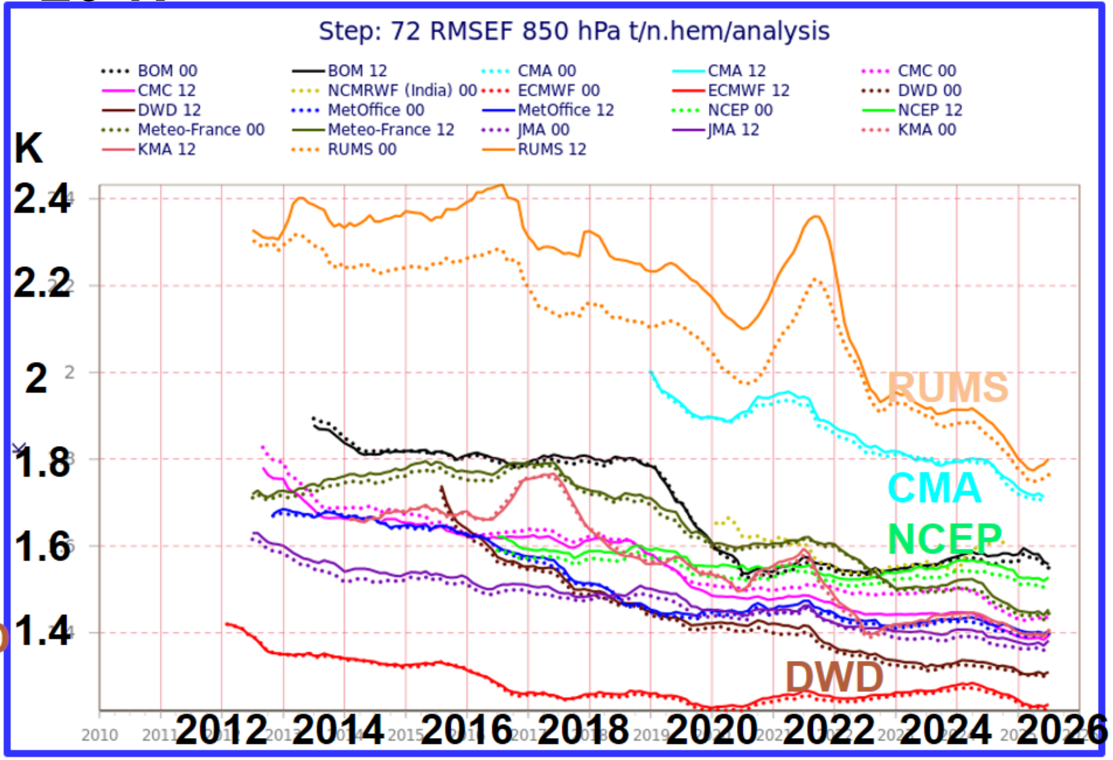
СРЕДНЕКВАДРАТИЧЕСКОЕ отклонение

RMSE, 72 h, > 20^0N

СРАВНЕНИЕ с НАБЛЮДЕНИЯМИ



СРАВНЕНИЕ с АНАЛИЗОМ



TREND in the development of modern operational NWP

- **ONLY supercomputers** are used for operational NWP: in the November 2025 TOP500 list of the fastest supercomputers **for NWP, 22 of the first 264 supercomputers are in use (more than 8%).**
- Conducting NWP (global and limited-area) using **coupled models** of the atmosphere, land and ocean.
- **Seamless** operation and, as a result, the use of a single operational atmospheric and environmental model for all forecast lead times and domains.
- Working with **big data** in NWP: if a forecaster spent just one second reviewing each value of a single temperature forecast field across all levels of the ICON-RU13/6N29 model, it would take them more than **4 years**!
- The use of **uniform grids** such as triangular or square ones based on regular polyhedrom inscribed in a sphere.
- **Open source code for NWP models** (ICON (30.01.2024), IFS, WRF and MPAS).

2. WEATHER and TURBULENCE

A.M. Obukhov. Turbulence and atmospheric dynamics // Leningrad: Gidrometeoizdat, 1988, 414 p

22. Weather and turbulence, 25.09.1967, c. 281 – 288)

“ Many of those present here are convinced that the concepts of 'weather' and turbulence are signify-cantly different, or at least not the same thing. (p. 281)

...Let us consider an idealized situation in which we are dealing with a very dense observation grid with distances between adjacent stations of the order of 1 mm, and the forecast lead time of interest is of the order of 1 s. In this case, there is no point in talking about turbulence, since the forecast can be made with a very high degree of accuracy using the Navier-Stokes equations. (p. 282)… “

3. WEATHER, TURBULENCE and CLIMATE

Wedi, N. P., et al. (2020). A baseline for global weather and climate simulations at 1 km resolution. *Journal of Advances in Modeling Earth Systems*, *12*, e2020MS002192. https://doi.org/10.029/2020MS002192

We present the world's first global simulation of an entire season of the Earth's atmosphere with 1.4 km average grid spacing and the top of the modeled atmosphere as high as 80 km.

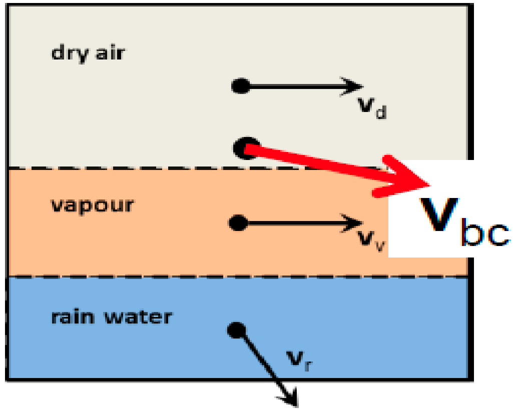
L. Ruby Leung[1], David C. Bader[2], Mark A. Taylor[3], and Renata B. McCoy[2] (2020). An introduction to the E3SM special collection: Goals, science drivers, development, and analysis. Journal of Advances in Modeling Earth Systems, 12, e2019MS001821. **https://doi.org/10.1029/2019MS001821**

[1] **Pacific Northwest National Laboratory, Richland, WA, USA,**
[2] **Lawrence Livermore National Laboratory, Livermore, CA, USA,**
[3] **Sandia National Laboratory, Albuquerque, NM, USA**

4. WEATHER, TURBULENCE, CLIMATE and ICON MODEL

- Equation set describes **mixture** of dry air and water (all 3 phases)
  - ρ is the total density (including water vapour and condensate)
  - velocity is defined as the barycentric velocity (Wacker et. al, 2003)

$$\boldsymbol{v}_{bc} = \frac{\sum_k \rho_k \boldsymbol{v}_k}{\sum_k \rho_k}$$



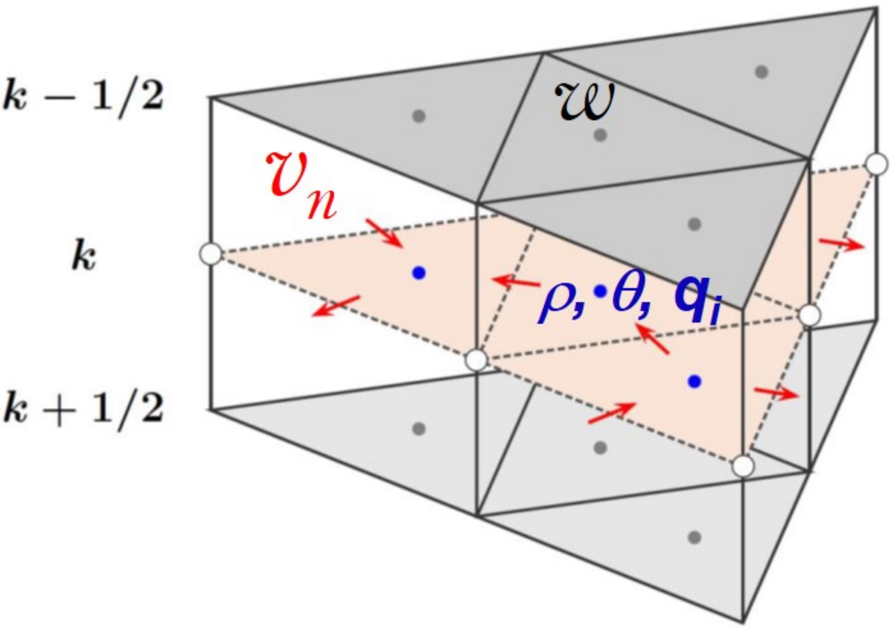
  - Current implementation contains approximations w.r.t. moisture effects

i.e. $w_{bc} = 0$ at the surface

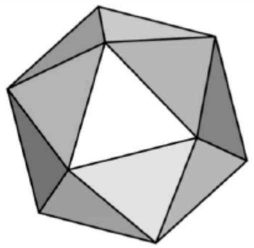
GRID

prognostic fields:

- v_n edge-normal vel. component
- w vertical velocity
- ρ density of moist air
- θ_v virtual potential temperature
- q_i mass fractions



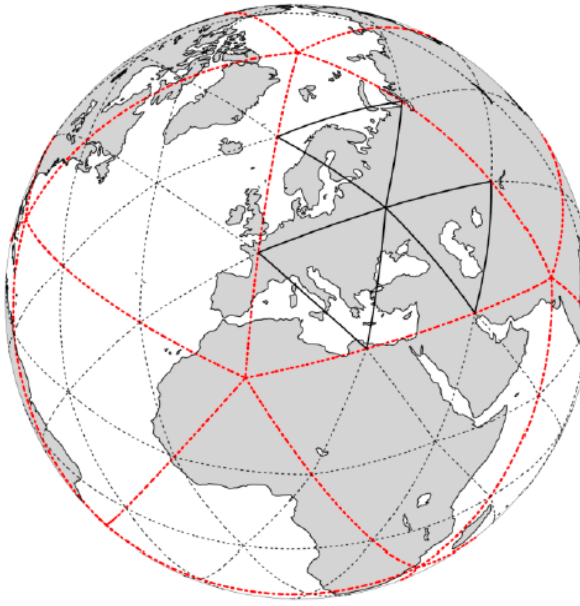
- grid generation is based on the Icosahedron



- By R*n*B*k* we denote a grid that originates from an icosahedron whose
  - edges have been initially divided into n parts,
  - followed by k subsequent edge bisections.

- The total number of grid cells in the ICON grid is given by

$$n_{cells} = 20n^2 4^k$$



R3B0 (black)

- Operationally used:

R3B7 ≈ 2.95 millions cells

h=13.2 km

The system of differential equations of the ICON model

Full set of governing equations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

DWD

- describes two-component system (dry air + water)
- fully compressible nonhydrostatic, shallow atmosphere approx.
- vector invariant form $(\boldsymbol{u}\cdot\nabla\boldsymbol{u} = \nabla K + \zeta \times \boldsymbol{u})$ for horizontal wind component

$$\frac{\partial \widehat{v_n}}{\partial t} + \frac{\partial \widehat{K}_h}{\partial n} + \boxed{(\widehat{\zeta} + f)\widehat{v_t}} + \widehat{w}\frac{\partial \widehat{v_n}}{\partial z} = \boxed{-c_{pd}\widehat{\theta}_v\frac{\partial \overline{\pi}}{\partial n}} - F(v_n)$$

$$\frac{\partial \widehat{w}}{\partial t} + \widehat{\boldsymbol{v}}_h \cdot \nabla \widehat{w} + \widehat{w}\frac{\partial \widehat{w}}{\partial z} = \boxed{-c_{pd}\widehat{\theta}_v\frac{\partial \overline{\pi}}{\partial z} - g}$$

momentum

$$\boxed{\theta_v = T\left(\frac{p_0}{p}\right)^{\frac{R}{C_p}}}$$

$$\frac{\partial \overline{\rho}\widehat{\theta}_v}{\partial t} + \nabla \cdot (\overline{\rho}\widehat{\boldsymbol{v}}\widehat{\theta}_v) = \overline{Q}$$

energy

$$\frac{\partial \overline{\rho}}{\partial t} + \nabla \cdot (\overline{\rho}\widehat{\boldsymbol{v}}) = 0$$

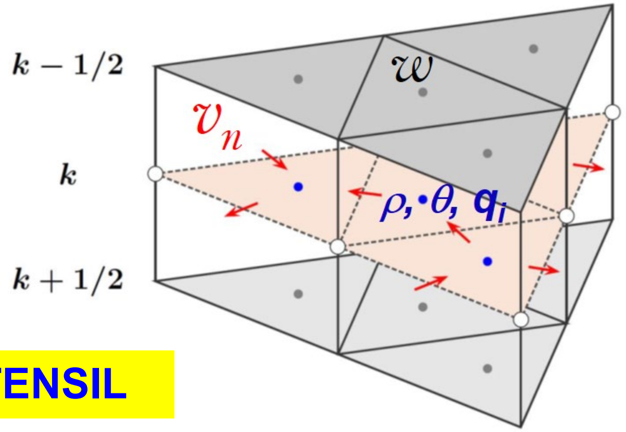
mass

$$\frac{\partial \overline{\rho}\widehat{q}_k}{\partial t} + \nabla \cdot (\overline{\rho}\widehat{q}_k\widehat{\boldsymbol{v}}) = -\nabla \cdot \left(\overline{\boldsymbol{J}}_k + \overline{\rho q_k'' \boldsymbol{v}''}\right)$$

partial mass

based on Gassmann and Herzog (2008)

ICON: METHOD of DIRECTIONAL SPLITTING



STENSIL

ρ, θ, q_i, v_n, w

Max-Planck-Institut für Meteorologie

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Tracer transport in ICON
General design and performance

Eruption of Eyjafjallajökull (NASA-MODIS)

Daniel Reinert
Deutscher Wetterdienst

5th ICON Training Course
April 2019, Langen, Germany

Directional splitting II

Two options are available in ICON

lstrang=.FALSE.	Namelist transport_nml	lstrang=.TRUE.

Marchuk splitting $\mathcal{O}(\Delta t)$

Odd time steps

$$\Psi^* = \Psi^n + \Delta t \mathcal{V}(\Psi^n)$$
$$\Psi^{n+1} = \Psi^* + \Delta t \mathcal{H}(\Psi^*)$$

Even time steps

$$\Psi^* = \Psi^n + \Delta t \mathcal{H}(\Psi^n)$$
$$\Psi^{n+1} = \Psi^* + \Delta t \mathcal{V}(\Psi^*)$$

Default

Strang splitting $\mathcal{O}(\Delta t^2)$

$$\Psi^* = \Psi^n + \frac{1}{2}\Delta t \mathcal{V}(\Psi^n)$$
$$\Psi^{**} = \Psi^* + \Delta t \mathcal{H}(\Psi^*)$$
$$\Psi^{n+1} = \Psi^{**} + \frac{1}{2}\Delta t \mathcal{V}(\Psi^{**})$$

Formally more accurate but more expensive

W. A. Mueller et al. ICON: Toward Vertically Integrated Model Configurations for Numerical Weather Prediction, Climate Prediction, and Projections// BAMS, v.106 (2025): Issue 6 (June 2025) DOI: https://doi.org/10.1175/BAMS-D-24-0147.1

2010 [1] First ICON hydrostatic atmospheric dynamical core on triangular grids
2015 [2] ICON modelling framework of DWD and MPI-M (Zängl et al., 2015)
2015 [3] ICON-NWP becomes operational
2015 [4] ICON-ART 1.0 (Rieger et al., 2015)
2012 [5] Regional ICON on the nested European domain becomes operational
2018 [6] ICON km-scale Limited Area Mode becomes operational

2017 [7] First ICON Ocean (Korn et al., 2017)
2018 [8] ICON-A, the atmosphere component of the ICON Earth system model (Giorgetta et al., 2018)
2022 [9] First ICON coupled Earth system model – ICON-ESM (Jungclaus et al., 2022)
2023 [10] First ICON Earth system at kilometer and subkilometer scales (Hohenegger et al., 2023)
2024 [11] ICON Open Source Release in 2024

Daniel Klocke, …, Bjorn Stevens. **Computing the Full Earth System at 1 km Resolution.** arXiv:2511.02021v2 [physics.ao-ph] 7 Nov 2025

We present the first-ever global simulation of the full Earth system at 1.25 km grid spacing, achieving highest time compression with an unseen number of degrees of freedom.

Our model captures the flow of energy, water, and carbon through key components of the Earth system: atmosphere, ocean, and land. To achieve this landmark simulation, we harness the power of 8192 GPUs on Alps and 20 480 GPUs on JUPITER, two of the world's largest GH200 superchip installations.

We show how separation of concerns can reduce the code complexity by half while increasing performance and portability. Our achieved time compression of 145.7 simulated days per day enables long studies including full interactions in the Earth system and even outperforms earlier atmosphere-only simulations at a similar resolution.

arXiv:2511.02021v2 [physics.ao-ph] 7 Nov 2025

Table 1: Overview of current state of the art km-scale climate simulations, their horizontal grid spacing, included Earth system components (A - Atmosphere, L - Land, V - Vegetation, O - Ocean, B - Biogeochemistry, C - Carbon), the system they ran on, the temporal compression τ (e.g., Simulated Days Per Day) and a rescaled value $\tau^*_{1.25}$ corresponding to the expected performance on the same resource but with $\Delta x = 1.25$ km.

Model	Δx / km	Components	Resource	τ	τ^*
SCREAM [33]	3.25/4.875	A L - - - -	≈87 % Frontier GPU	458	26
ICON	1.25	A L - O - -	≈95 % Lumi GPU	69	69
NICAM (H. Yashiro pers.)	3.5	A L - - - -	≈26 % Fugaku CPU	≈ 365	17
this work	**1.25**	**A L V O B C**	≈85 % JUPITER GPU	**145.7**	**145.7**

[33] **Mark Taylor**, **Peter M. Caldwell, Luca Bertagna, Conrad Clevenger, Aaron Donahue, et al.** **The simple cloud-resolving E3SM atmosphere model running on the FRONTIER exascale system.** In *Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis*, SC '23, New York, NY, USA, **2023**. Association for Computing Machinery. **ISBN 9798400701092. doi: 10.1145/3581784.3627044. URL https://doi.org/10.1145/3581784.3627044**.

5. WEATHER, TURBULENCE, CLIMATE, ICON MODEL and OPERATIONAL RUSSIAN CONFIGURATION ICON-Ru13/6N29 model ICON and CONFIGURATIONS under DEVELOPMENT (Ru - Russia)

(НИОКТР 125032004255-7)

Development of short-term NWP

Improvements to the COSMO and ICON models

1. Snow cover formation and evolution.
2. Solar radiation transport and aerosol pollutant accounting.
3. Urban parameterization.
4. Modeling and numerical forecasting of polar mesocyclones.
5. Creation and verification of ensemble forecasts for a limited area.
6. Perturbation generation for ensemble systems.
7. Development of an NWP system with a 1.1 km grid spacing for Sochi 2014 and a 1.0 km grid spacing for Moscow.
8. Development of verification methods and testing of 1 km configurations.
9. Finding optimal solutions for developing data assimilation systems, including radar systems.
10. Development of a turbulent mixing scheme in the surface layer.
11. Application of neural networks for postprocessing.
12. Development of a new dynamic block for the ICON model (?)
13. Development of an environmental model (?)
14. Development of an assimilation system (?)

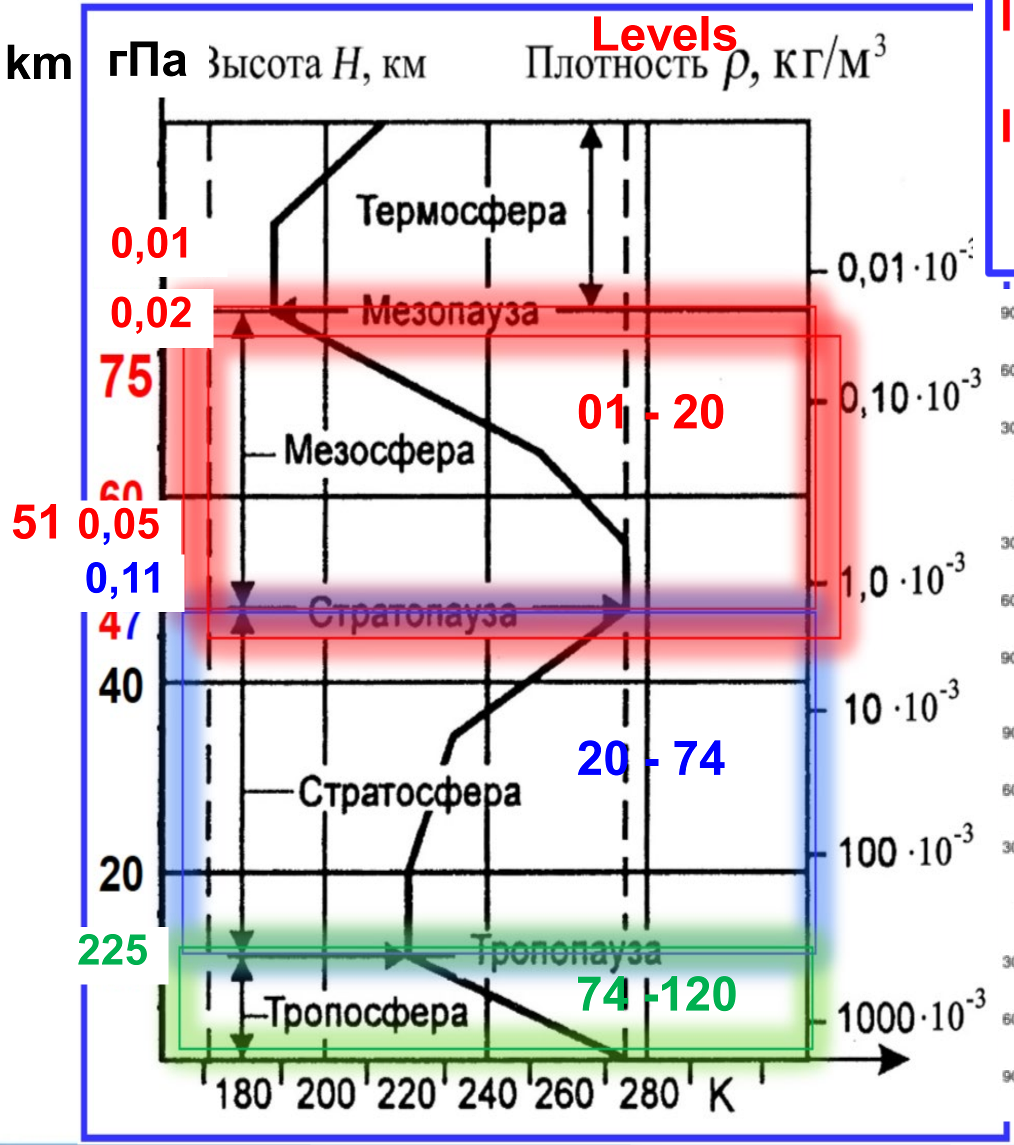
Dissertations defended

1. Dmitry Alferov 2011
2. Filip Bykov 2021
3. Ekaterina Kazakova
4. Alexander Kirsanov
5. Alexey Polyukhov
6. Anastasia Revokatova
7. Andrey Shishov 2025
8. Yulia Shuvalova
9. Evgeny Churyulin

Prepared

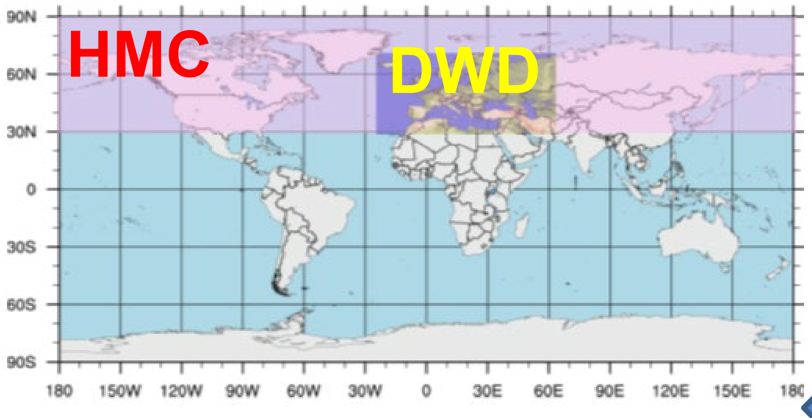
1. Denis Blinov
2. Mikhail Nikitin

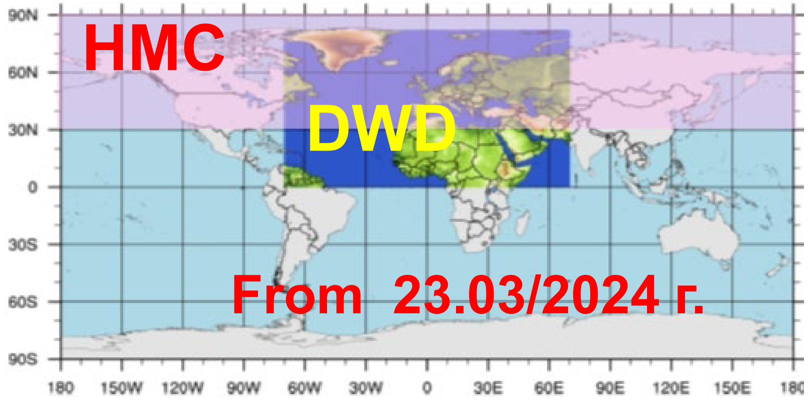
OPERATIVE RUSSIAN ICON-Ru13/6N29 and GERMAN CONFIGURATIONS ICON MODEL



ICON-Ru13: global, 120 levels up to 75 km, grid spacing 13,2 km, 5760 cores, 120 h NWP in ≈ 20 min.

ICON-Ru13/6N29: global, 120 levels up to 75 km, grid spacing 13,2 km and with a nested grid with a grid spacing of 6.6 km at 74 lower levels north of parallel 29.5^{0}N, 5760 cores, 120 h NWP in ≈ 55 min.





MESOSCALE ENSEMBLE MODELLING
BASED ON ICON MODEL: ICON-Ru2-EPS

ICON-Ru2-EPS demonstrates high forecast quality

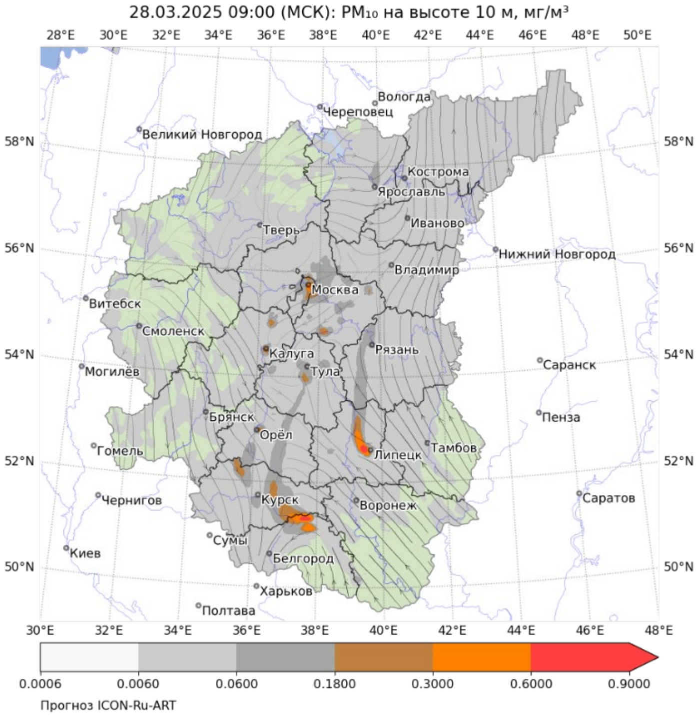
- **Domain: Central Federal District**
- **48-hour forecasts**
- **Horizontal grid spacing ~2.2 km, 65 vertical levels (up to ~22km)**
- **The ensemble size is 15**
- **Initial/boundary conditions from the global ICON-Ru13/6N29**
- **Perturbations of initial/boundary conditions downscaled from the global ensemble prediction system of the Hydrometcenter of Russia SLAV-EPS**
- **Verification using the METplus package**

E.D. Astakhova, A.Yu. Bundel, D.Yu. Alferov, I.A. Rozinkina, G.S. Rivin.
On the application of ensemble methods in short-range regional forecasting
// **Hydrometeorological research and forecasting. 2025. № 1 (395). pp. 6-36.**
DOI: https://doi.org/10.37162/2618-9631-2025-1-6-36 (in Russian)

THE COMPLEX OF RESEARCH AND DEVELOPMENT FOR THE IMPROVED COSMO-Ru SYSTEM

An hourly, **supershortrange (0:00 to 12:00) NWP** system has been developed, integrating data from the ground-based observation network, including radars, with output available every 10 minute, 1.5 hours after the observation time. The system has been shown to be highly effective compared to other methods in forecasting intense precipitation, particularly in the first six hours. **D.V. Blinov**

The ICON-ART-Ru chemical transport modeling system has been adapted to supercomputer «Roshydromet» and tested. It has been shown that ICON-ART-Ru6 modeling in passive mode for chemically inactive pollutants (e.g., CO, most NOx) is **more successful than COSMO-ART-Ru2** with a full chemical transformation system, enabling its use for real-time calculations of concentrations of these key pollutants. **A.A. Kirsanov**



CLOUD-RADIATION INTERACTION in ICON

(a joint work with Meteorology and Climatology department of the Faculty of Geography, MSU)

embedded version ⟪ ecRAD ⟫ stand alone version

❑ CRI in ecRAD is implemented in three solvers McICA, Tripleclouds, SPARTACUS with customizable functionality

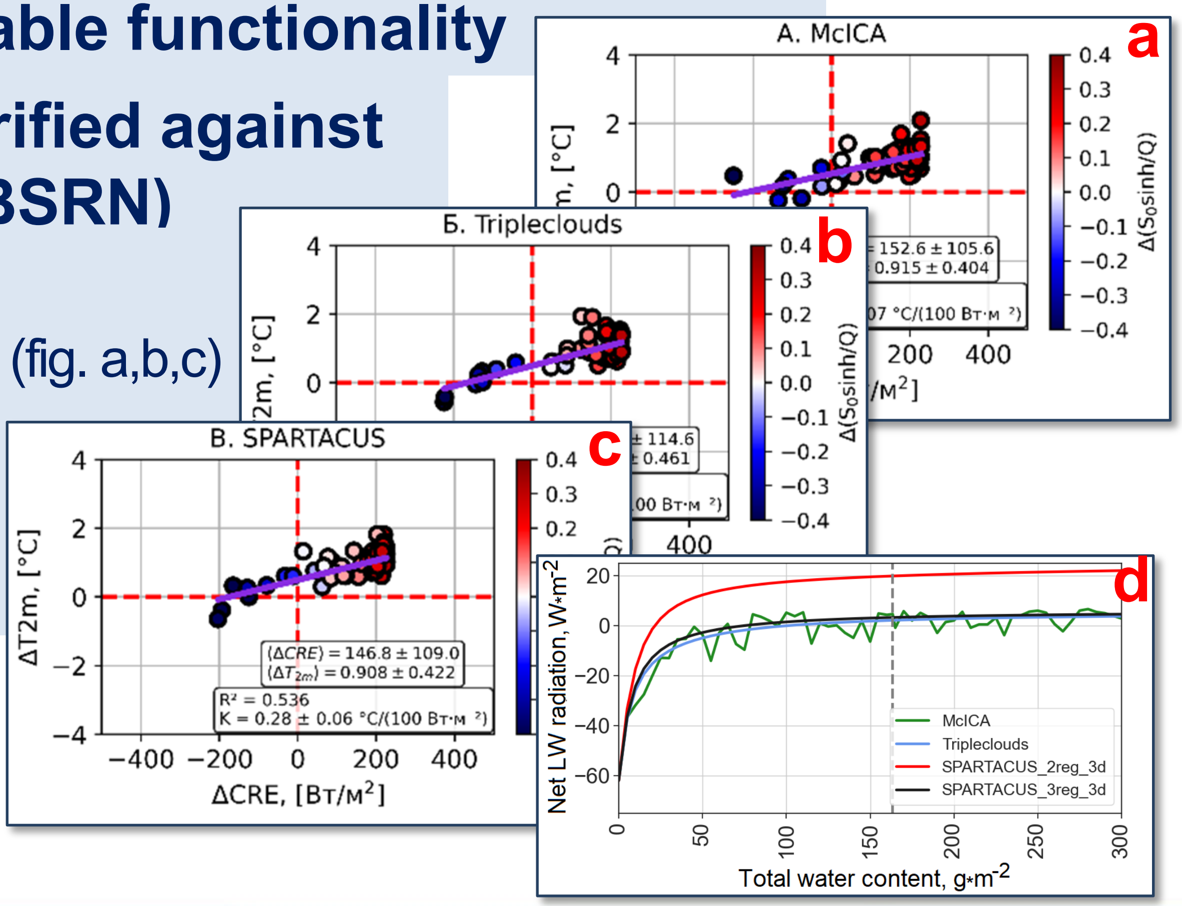
- Simulated radiative characteristics are verified against precise observational data of RAD-MSU (BSRN)
- Solvers validation

✓ joint verification of the radiation and T2m (fig. a,b,c)

✓ for different cloud conditions

✓ studying feedbacks on cloud parameters

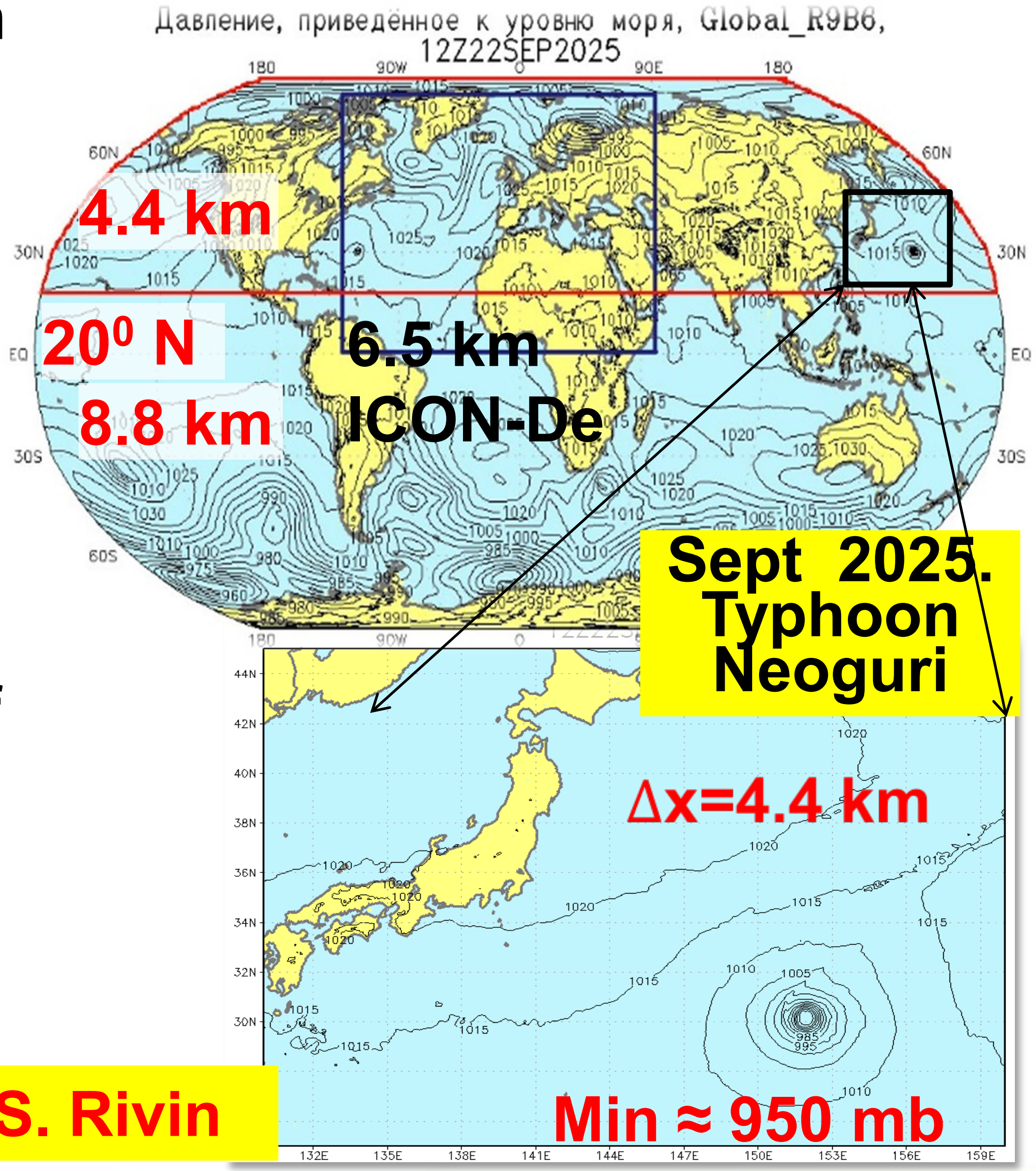
✓ studying LW scattering contribution (fig. d)



M. Shatunova, N. Chubarova,
D. Piskunova, N. Petrov, A. Golikov.

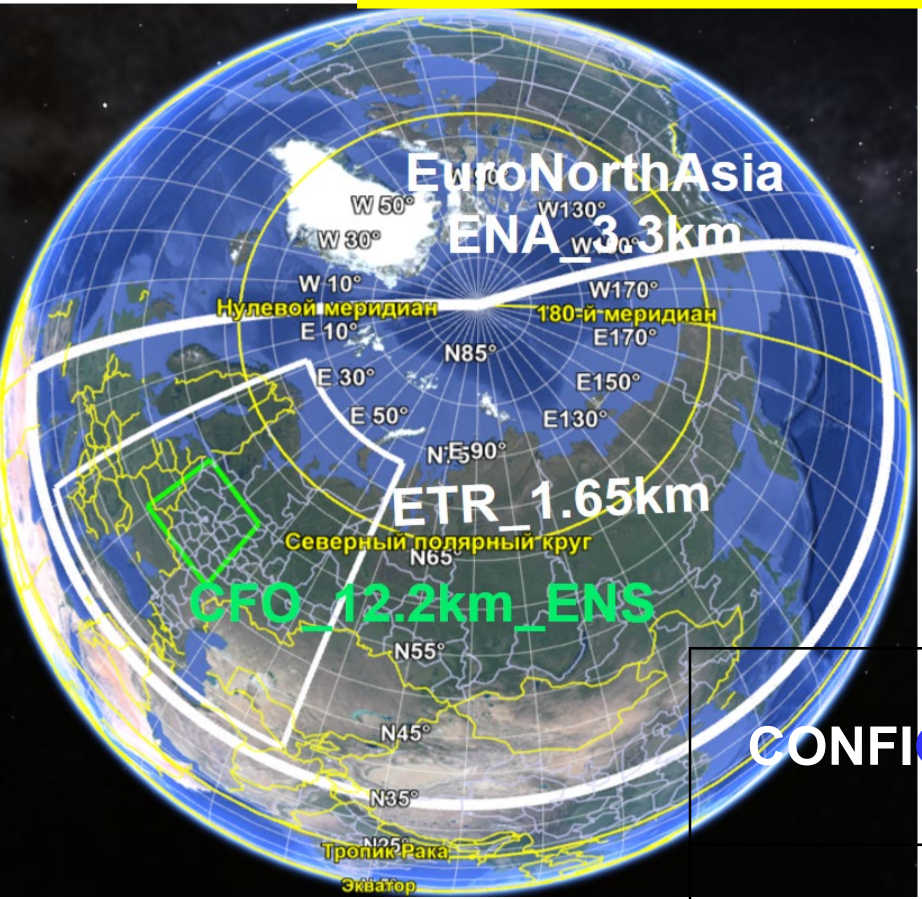
A prototype of the improved COSMO-Ru NWP system

1. The Russian ICON-Ru8.8/4.4N20 configuration has a non-uniform horizontal grid and 120 levels up to 75km
   - ✓ 4.4 km at the 74 lowest levels up to an altitude of 23 km north of the 20^0N parallel;
   - ✓ 8.8 km for the rest of the grid.
2. The grid spacing of 8.8 km is smaller (and 4.4 km !) than all operational global models in the world.
3. It will be significantly improve the reliability of numerical weather forecasts and the identification of hazardous event threats for many regions of Russia with complex geographic conditions, primarily Siberia, the Far East, and the Arctic zone.

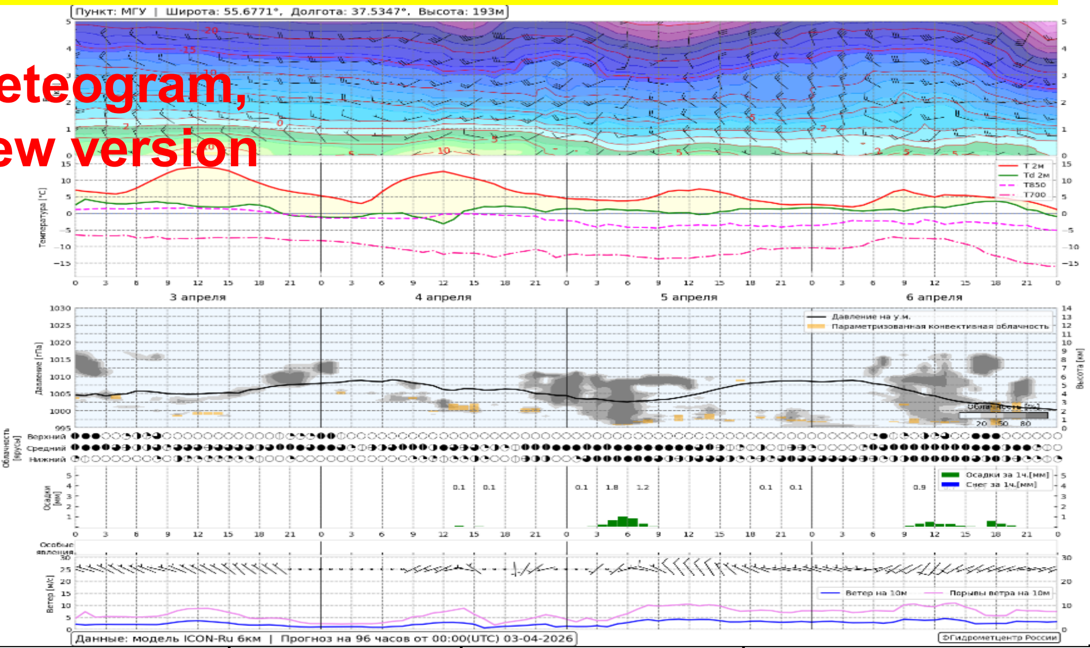


M.A Nikitin, G.S. Rivin

Global (24h, 120 h) and LAM (24h, 54 h) NWP



Meteogram,
new version

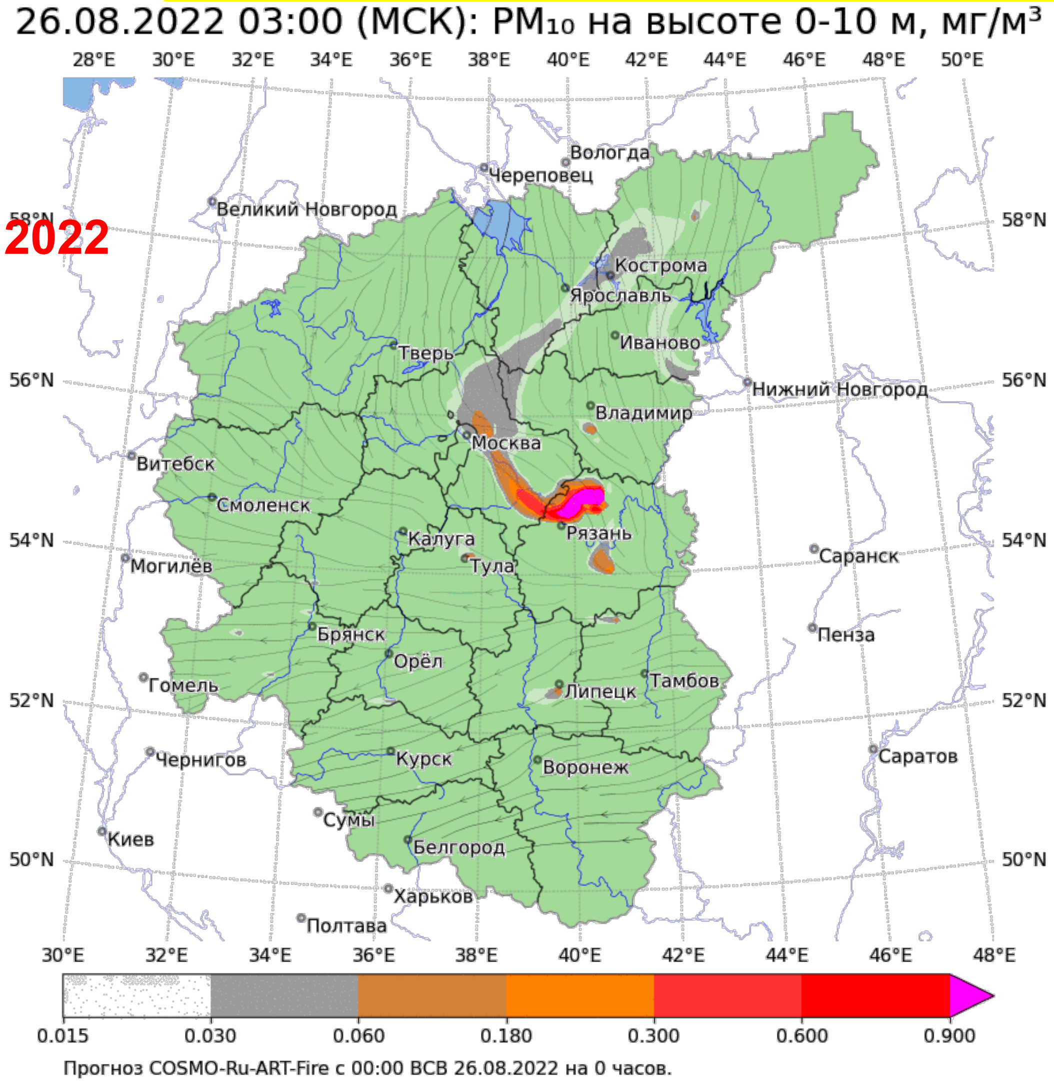


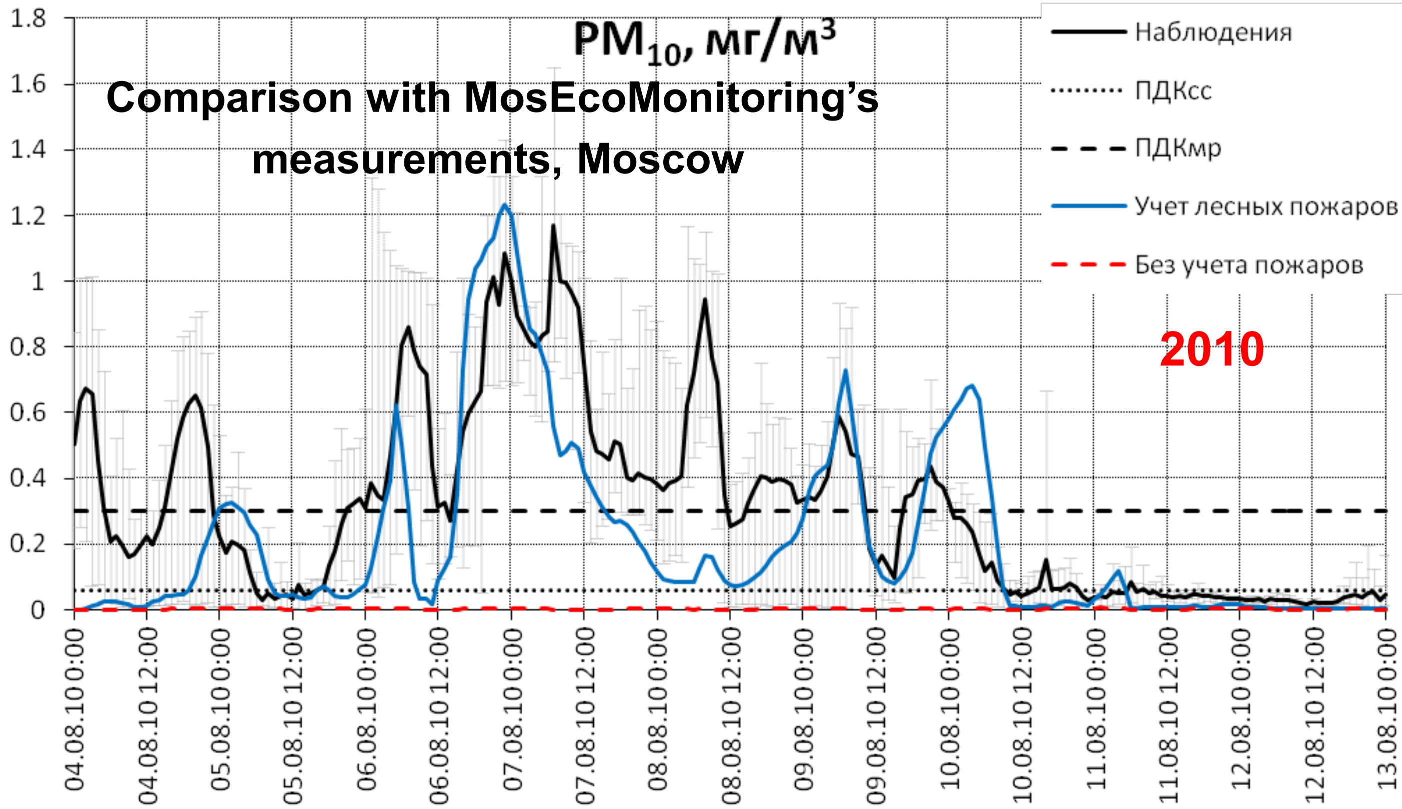
В сутки примерно подготавливается порядка 40 000 карт, метеограмм и аэрограмм

CONFIGURATION	Δt sec	L	CORES		
			5 120	10 240 maybe	15 360 maybe
GLOBAL, 120 h					
ICON-Ru13.2km	120	2 949 000	23min	13 min	8 min
ICON-Ru8.8km	80	6 636 000	77min	44 min	27 min
ILAM-Ru, 54 h					
EuNorthAsia_3.3km	30	5 571 000	63 min	33 min	22 min
ETR_1.65km	15	2 959 000	85 min	47 min	29 min

M. Nikitin, G. Rivin

Wildfires in the Central Federal District, smoke aerosol transport forecast





Effect on temperature (direct aerosol effect): during daytime hours at high aerosol concentrations, forecast success increases by more than 2°C (for the 2010 case)

A. A. Kirsanov, A. P. Revokatova, G. V. Surkova.

CONCLUSIONS

1. It is given the brief overview of the state of modern NWP.
2. G.I. Marchuk: "Weather forecasting is one of the central problems of science … ".
3. A.M.Obukhov: "Macroturbulence, turbulence, and the Navier-Stokes system of differential equations".
4. The results on global climate modeling with a 1.25 km grid spacing are given.
5. It is given information about Russian operational configuration ICON-Ru13/6N29 and configurations under development (Ru - Russia).

6. We thank the Main Computer Center of Roshydromet for the excellent working conditions on its computing system.

NUMERICAL WEATHER PREDICTION
and related problems of TURBULENCE AND CLIMATE MODELING: current state and further development

G.S. Rivin, I.A. Rozinkina and staff members

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Тема НИОКТР 125032004255-7

Hydrometcenter of Russia
Lomonosov's MSU

THANK YOU FOR YOUR ATTENTION !

L. Ruby Leung[1] , David C. Bader[2] , Mark A. Taylor[3] , and Renata B. McCoy[2] (**2020**). **An introduction to the E3SM special collection: Goals, science drivers, development, and analysis. Journal of Advances in Modeling Earth Systems**, 12, e2019MS001821. **https://doi.org/10.1029/2019MS001821**

[1] **Pacific Northwest National Laboratory, Richland, WA, USA,**
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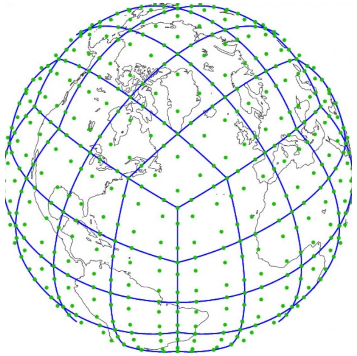


Earth system models are important tools for predicting future changes in the Earth system. … the Energy Exascale Earth System Model (E3SM) project aims to improve predictions of Earth system variability and change. The latter has a particular focus on predicting changes in the water cycle that influences precipitation and storms, biogeochemistry that influences greenhouse gases and future warming, and cryosphere systems that influence sea-level rise that threatens coastal communities. **This paper serves as an introduction to the E3SM special collection, which includes 50 papers published in several AGU journals.** It provides an overview of the E3SM project, including its goals and science drivers. It also provides a brief history of the development of E3SM version 1 and highlights some key findings from papers included in the special collection.

The operational numerical weather prediction (NWP) many years is an example of a digital technology

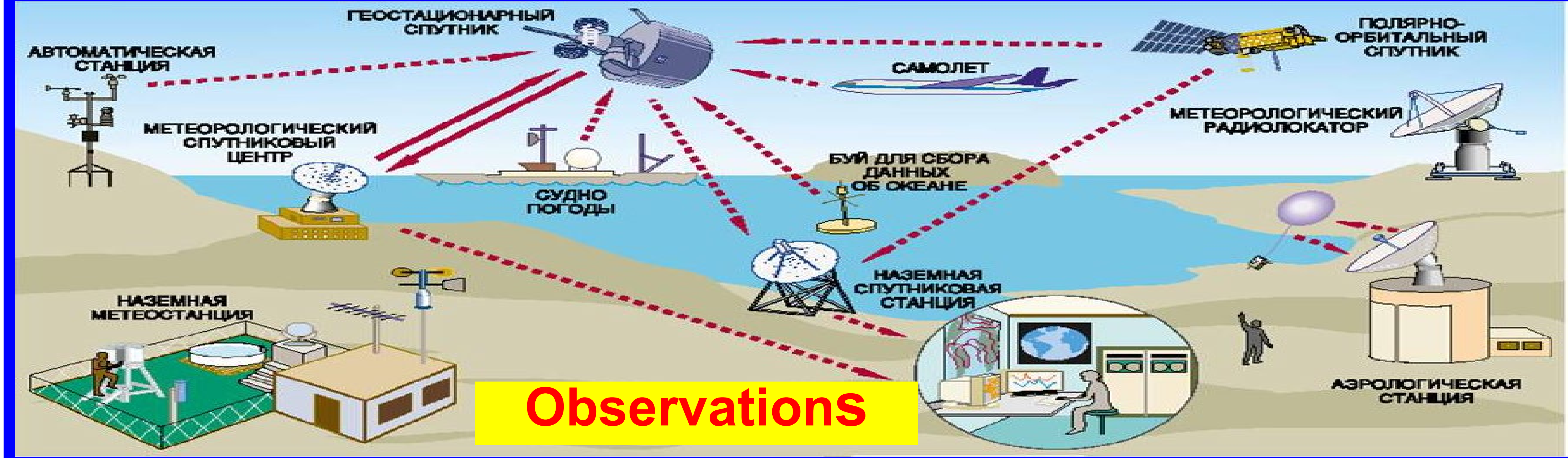
NWP system

Data assimilation

Preprocessing: initional fields, initialization

Model

Postprocessing
correction, visualization, distribution, archiving, verification



Observations

ВМО: ОЦЕНКИ Psea для 2012-2026 севернее 20^0N

ПРОГНОЗ на 72 час.

https://wmolcdnv.ecmwf.int/

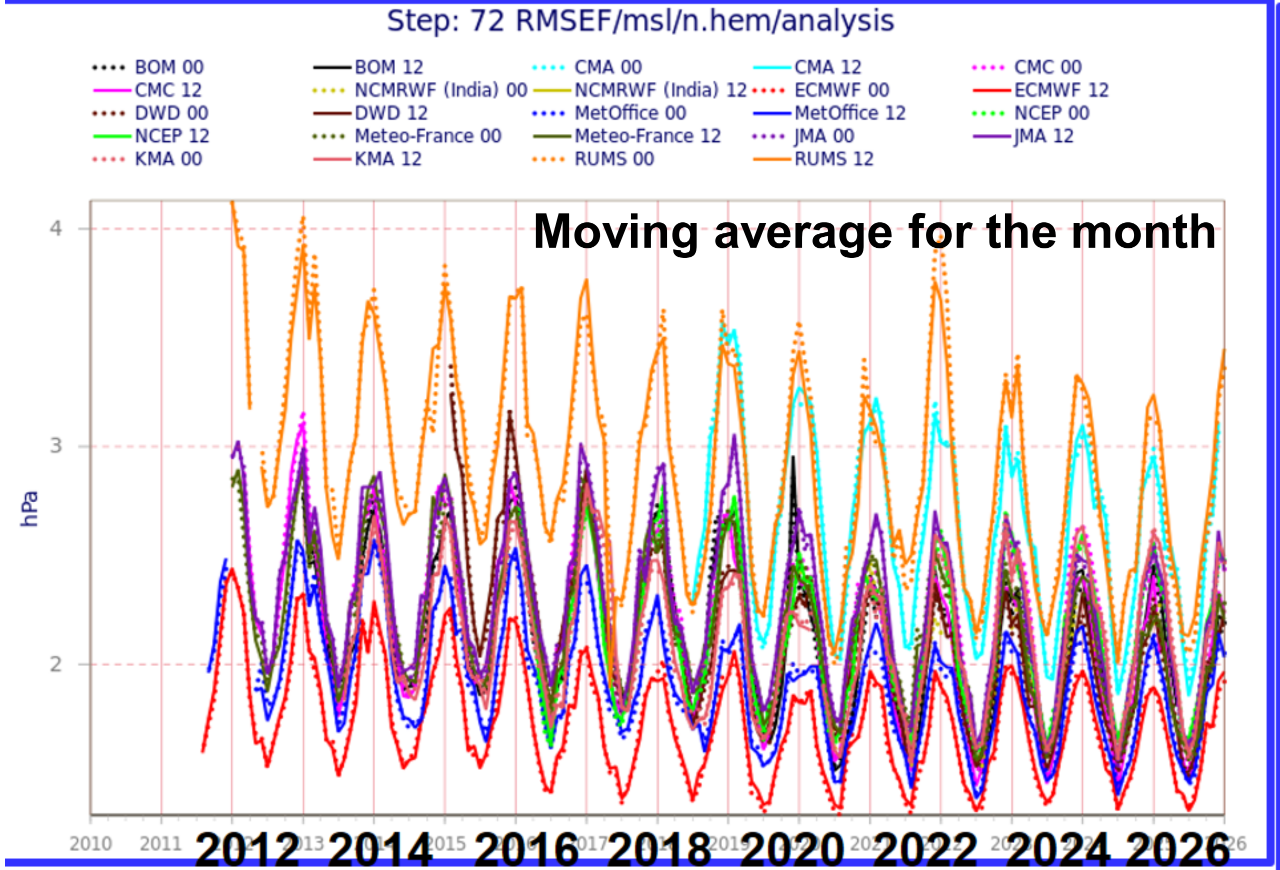
СРАВНЕНИЕ с АНАЛИЗОМ

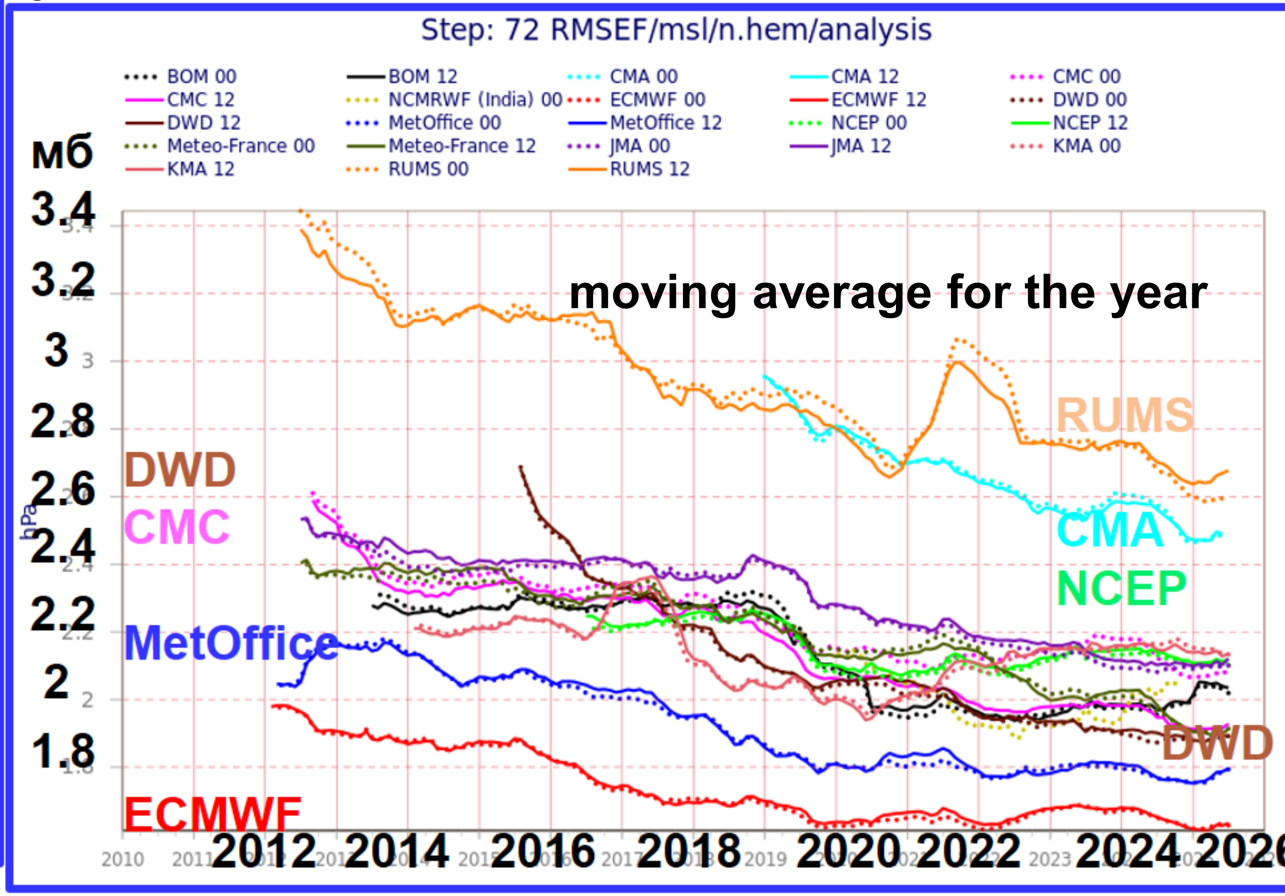
СРЕДНЕКВАДРАТИЧЕСКОЕ отклонение

Среднеквадратичное отклонение, скользящее среднее за месяц

RMSE, 72 h, > 20^0N

Среднеквадратичное отклонение, скользящее среднее за 12 месяцев





Current operational NWP (mainly as of January 1, 2024)

https://www.wcrp-esmo.org/working-groups/wgne/wgne-nwp-systems

01.01.2024	Global, grid spasing, levels	Limited Area Model (LAM) NWP
ECMWF	IFS: ~ 9 km; TCo1279 L137 +ocean0.25° 0.5° - 55 км	
MetOffice Великобритания	UM: 10 km, 70 lev., + ocean 0.25°, конечно-разностная 0.5° - 55 км	UM: 1.5 km, 950×1025×70,
DWD Germany	ICON: 6.5 km Europe, 13 km out; 120 ур. 13 км	ICON: 6.5 km Europe × **74**, ICON-De: 2.1 km, Germany×65,
CMC, Canada	GEM: 15 km; 84 levels, grid Yin-Yang	GEM: 10 km, 1108×1082×84 + oocean 0.09° GEM: 2.5 km, 2582×1332×84
CMA, China	GRAPES-GFS: 12.5 km, 90 levels	GRAPES-MESO: 3 km, 2251×1501×70
Rohydromet of Russia	SLAV: (0.08-0.14)° × 0.11°), 104 levels **(10.2023).** ICON-Ru: 6.6 km if > 29.5°N, 13.2 km out; 120 levels **(11.2024)**.	ICON-Ru: 6.6 km if > 29.5°N × **74**, COSMO-Ru: 2.2 km, 1200×1400×50, Moscow -1 km, Sochi -1.1 km 200×200×50
NCEP, USA	GFS_fv3: 13 km 127 levels 0.25 - 27 км	12 км, 935× 835×60; 3 km, 1827×1467×60, 1189×1249×60, 373×561×60,401×325×60; 1.5 km, 333× 333×60.
Meteo France	TL1798c2.2: 5 – 24 km (WestEu-out WestEu), 105 lev.	ALARO: 1.3 km, 1536×1440×90;
JMA, Japan	GSM; 13 km, TG959, 128 levels (up to 0.01 гПа) **(from 03.2023)**	MSM: 5 km, 817×661×76 up to 22 km; LSM: 2 km, 1581×1301×76 up to 20 km.
KIM, S. Korea	KIM (Korean Integrated Model) + UM: 8 km, 91 lev.	1.5 km, 1188×1148×70

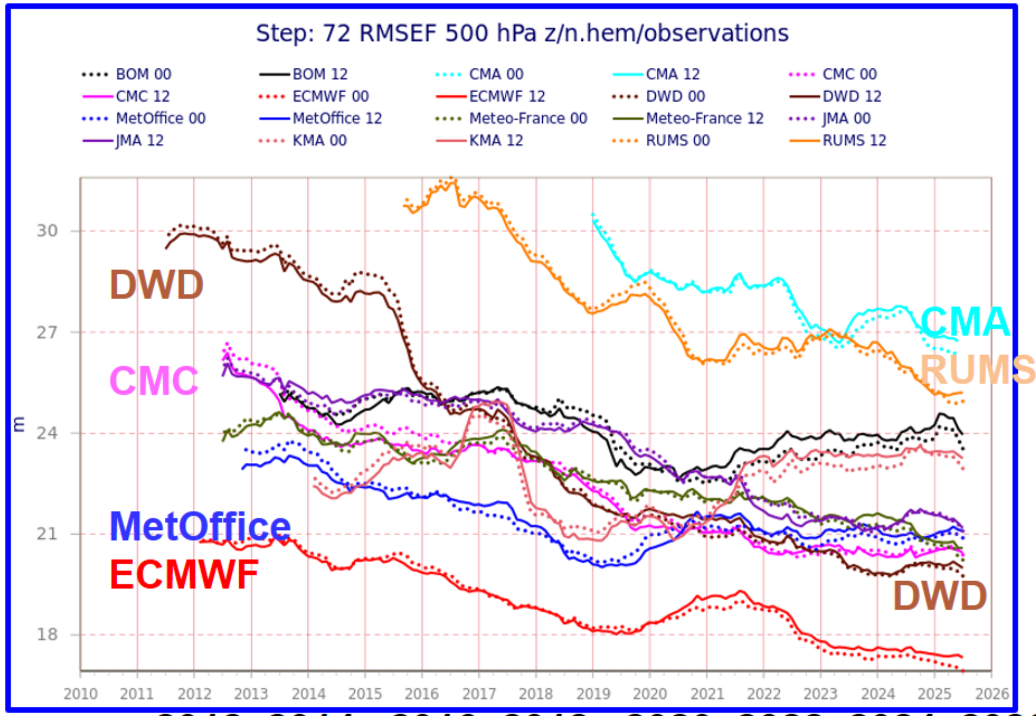
ВМО: ОЦЕНКИ (ско) Н500 для 2012-2026,Севернее 20^0N

ПРОГНОЗ на 72 час.

https://wmolcdnv.ecmwf.int/

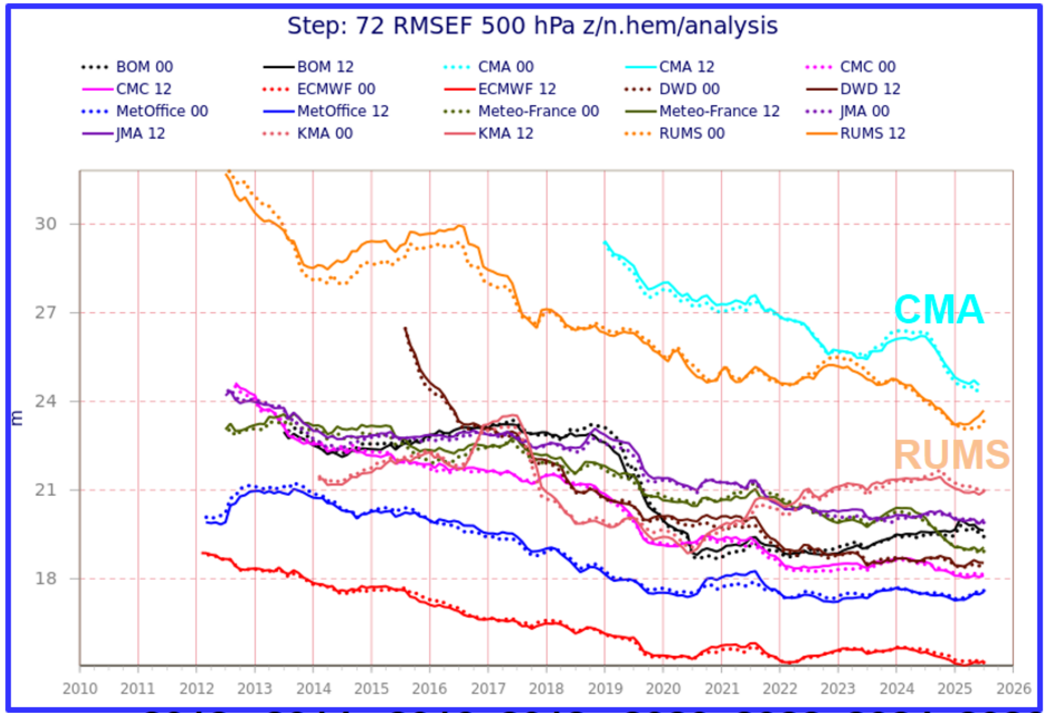
СРЕДНЕКВАДРАТИЧЕСКОЕ отклонение

СРАВНЕНИЕ с НАБЛЮДЕНИЯМИ



2012 2014 2016 2018 2020 2022 2024 2026

СРАВНЕНИЕ с АНАЛИЗОМ



2012 2014 2016 2018 2020 2022 2024 2026

https://wmolcdnv.ecmwf.int/

ВМО: ОЦЕНКИ (ско) V250 для 2012-2026,Севернее 20^0N

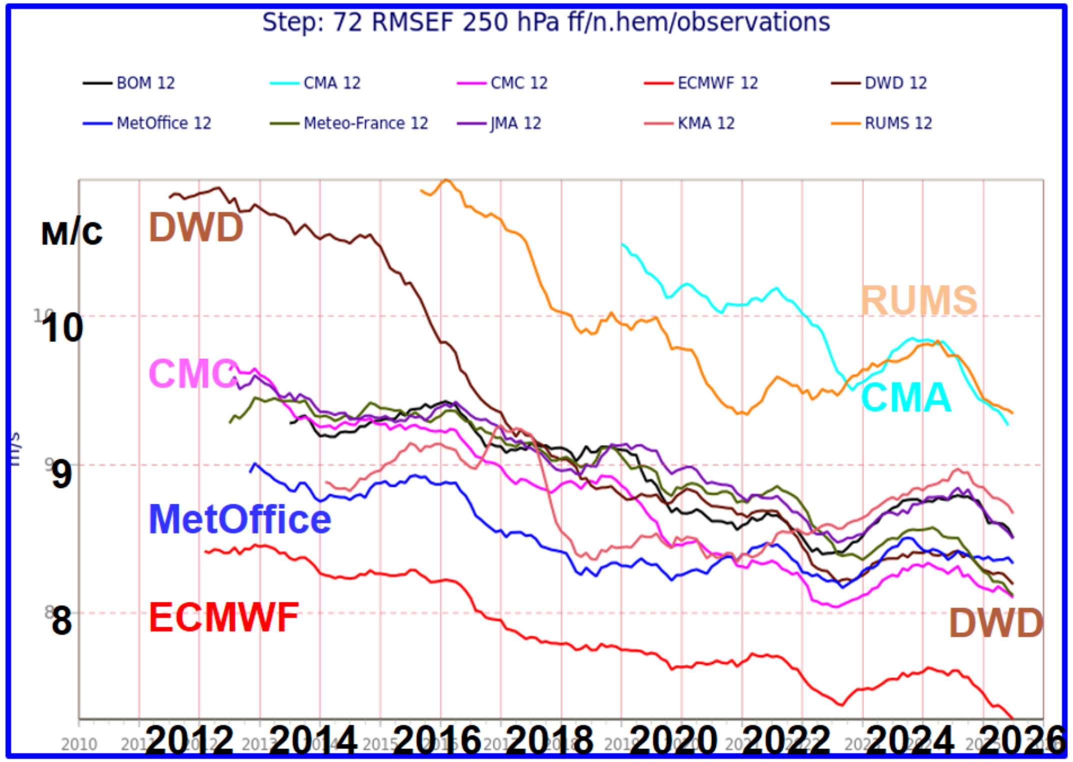
ПРОГНОЗ на 72 час.

https://wmolcdnv.ecmwf.int/

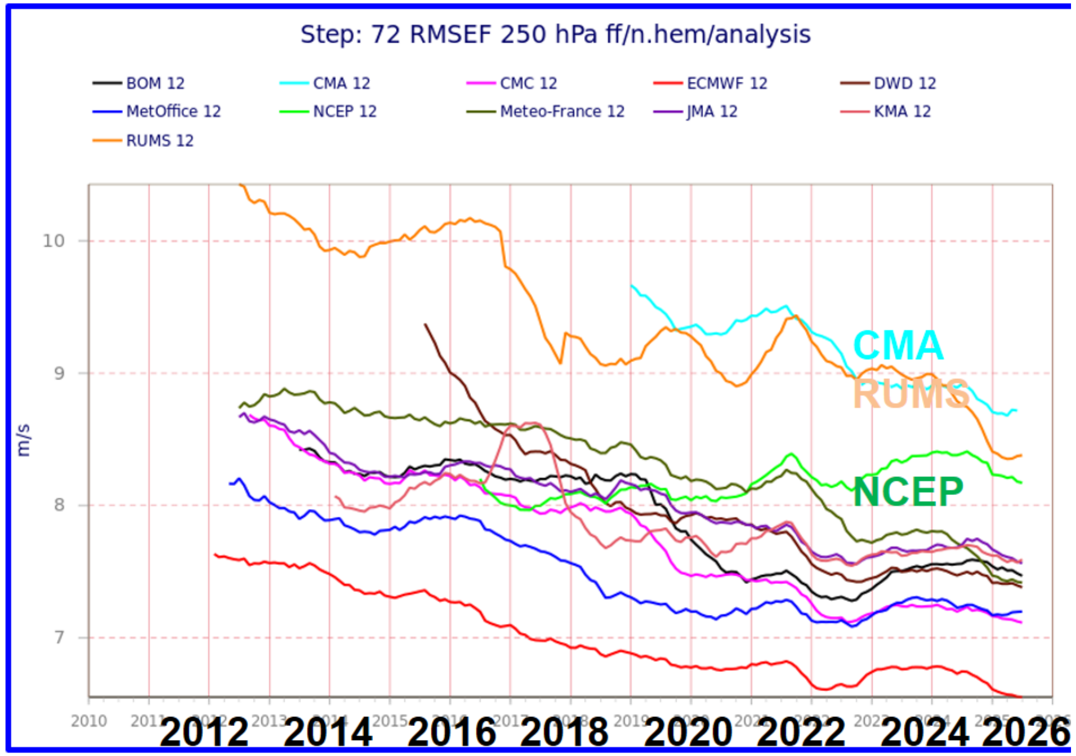
СРЕДНЕКВАДРАТИЧЕСКОЕ отклонение

RMSE, 72 h, > 20^0N

СРАВНЕНИЕ с НАБЛЮДЕНИЯМИ



СРАВНЕНИЕ с АНАЛИЗОМ



Переход к конфигурациям ICON-Ru модели ICON

Модель ICON по сообщениям немецких коллег, статьям, презентациям и на основании оценок ЕЦСПП прочно вошла в тройку лучших оперативных атмосферных моделей мира, причем по некоторым позициям является лучшей в мире.

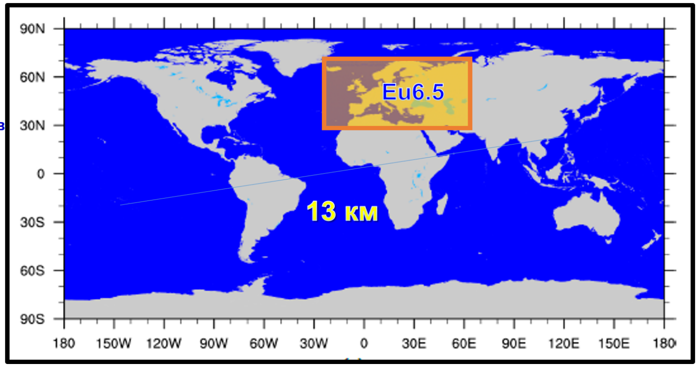
1. Использование модели в Немецкой службе погоды
2. Использование модели в странах консорциума COSMO
3. Опыт применения модели в Росгидромете.

Research and Development at DWD

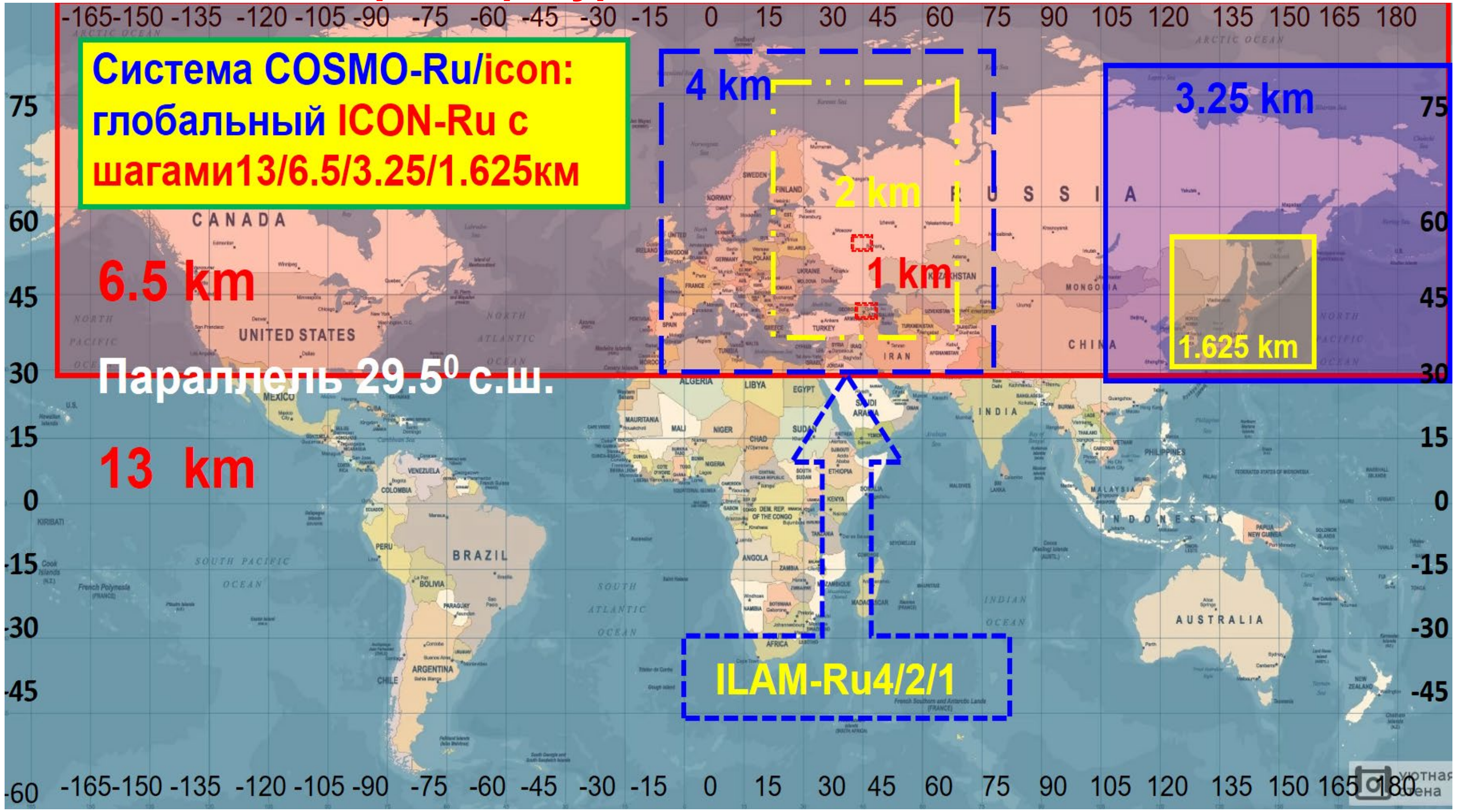
Database Reference Manual for ICON and ICON-EPS

Version 1.2.11

D. Reinert, F. Prill, H. Frank, M. Denhard, and G. Zängl

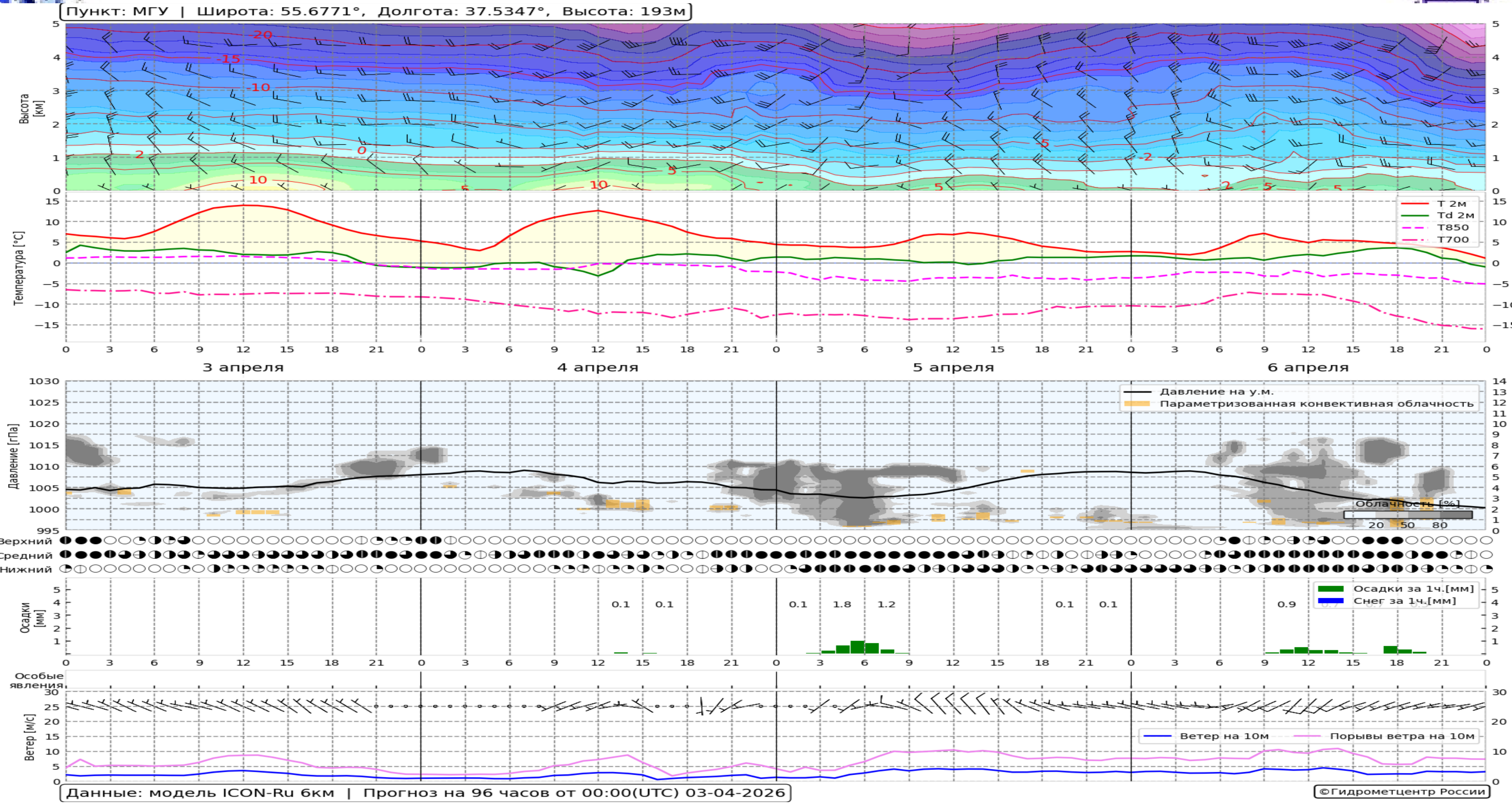


Выбор конфигураций ICON-Ru модели ICON



Оценка объемов передач в течении одних суток необходимых начальных данных и боковых ТРЕХЧАСОВЫХ граничных условий для COSMO-Ru6ENA – 60 Гб, необходимых начальных данных для ICON-Ru13/6N29 – 20 Гб, т.е в 3 раза меньше!

Время передачи данных для одного срока для COSMO-Ru6ENA равно 60 мин, а начальных ГЛОБАЛЬНЫХ данных для ICON-Ru13N29 5 мин, т.е в 12 раз меньше.


Пункт: МГУ | Широта: 55.6771°, Долгота: 37.5347°, Высота: 193м
Высота [км]
Температура [°C]
T 2м
Td 2м
T850
T700
3 апреля
4 апреля
5 апреля
6 апреля
Давление на у.м.
Параметризованная конвективная облачность
Давление [гПа]
Высота [км]
Облачность [%]
Облачность [ярусы]
Верхний
Средний
Нижний
Осадки [мм]
Осадки за 1ч.[мм]
Снег за 1ч.[мм]
Особые явления
Ветер [м/с]
Ветер на 10м
Порывы ветра на 10м
Данные: модель ICON-Ru 6км | Прогноз на 96 часов от 00:00(UTC) 03-04-2026
©Гидрометцентр России

Будущее

Проекты, в которых участвует Институт Макса Планка-Меллона, такие как WarmWorld и European Eddy-Rich Earth System Models (EERIE), уже работают над дальнейшим развитием и улучшением моделей километрового масштаба и подготовкой их для самых быстрых суперкомпьютеров Европы. Европейская инициатива Destination Earth , которая разрабатывает цифровые двойники земной системы, в значительной степени опирается на разработки nextGEMS. А на европейском суперкомпьютере JUPITER модель ICON, позволяющая выявлять штормы, уже работает с разрешением всего в один километр в течение целого года, включая полный углеродный цикл — достижение, которое недавно было отмечено премией Гордона Белла за климатическое моделирование и премией HPCwire Readers' Choice Award .

Но выгоду от разработок и результатов nextGEMS получают не только исследователи. С самого начала целью было предоставить данные в руки людей и инструменты для их использования, чего удалось достичь, вовлекая потенциальных пользователей во весь процесс. В будущем в этом может сыграть важную роль искусственный интеллект. Эта идея лежит в основе инициативы Earth Virtualization Engines (EVE), предложенной Институтом Макса Планка-Меллона: предоставление легкодоступной климатической информации всем, кто в ней нуждается. «Мы взяли нечто, что казалось технологичным и эксклюзивным — эту огромную вычислительную мощность, эту огромную мощность обработки данных — и сделали это интуитивно понятным, доступным и демократичным», — говорит Стивенс.

После четырех лет работы nextGEMS сообщество ученых, техников и пользователей находится не в конце пути, а в его начале, заключает Стивенс : «Мы разработали новый тип модели, новые типы анализа, мы сформировали сообщество — мы объединили многое, что знаменует начало новой эры в исследованиях климата».

Дополнительная информация

Веб-сайт проекта NextGEMShttps://mpimet.mpg.de/en/communication/focus

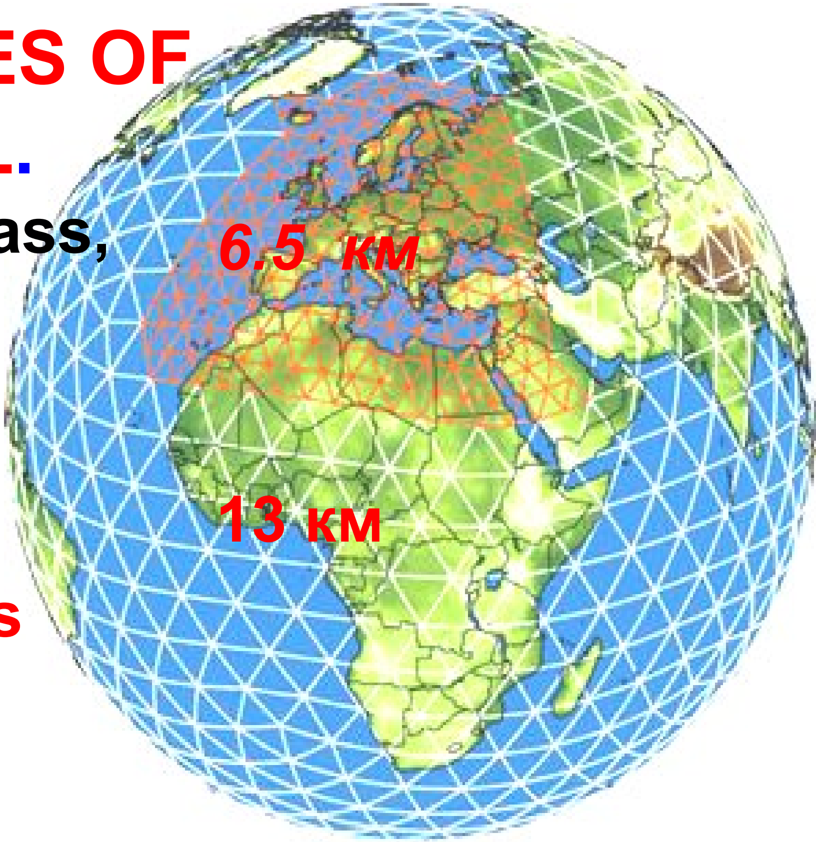
Контакт

Профессор Бьорн Стивенс,
Институт метеорологии им. Макса Планка ,
bjorn.stevens@mpimet.mpg.de

GRID

- ❑ Based on the Icosahedron (a convex, regular 20-sided polyhedron).
- ❑ Ability to calculate on a global grid with increased resolution in any region (non-uniform grids)
- ❑ Ability to enable/disable nested domains during calculations
- ❑ Ability to nest grids one- or two-wayNested grids vertically

PROPERTIES AND CAPABILITIES OF THE GLOBAL ICON MODEL.



- ❑ Conservation laws, including local conservation of mass, are satisfied.
- ❑ Applicability over a wide range of scales, from ~100 km to ~100 m.
- ❑ Possibility of horizontal and vertical grid nesting.
- ❑ Scalability and efficiency across a range of computers with both standard and GPU processors.
- ❑ Quasi-monotonic tracer transfer.

С мая 2025 года исследователи впервые начали моделировать климат Земли с шагом сетки 1 км в течение целого года, учитывая все важные компоненты климатической системы Земли.

Помимо атмосферы, океана, суши и морского льда, это также включает в себя моделирование всего углеродного цикла, включая перенос углекислого газа. «Это большой шаг для нас, и до сих пор это было невозможно», — говорит Дэниел Клоке.

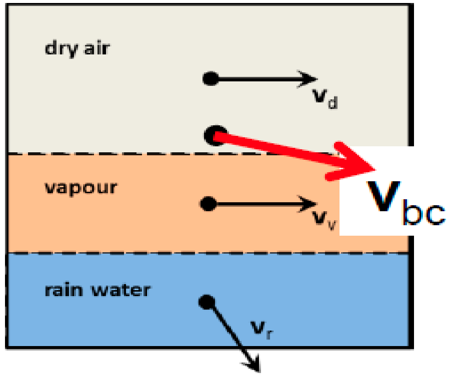
С более чем одним квинтиллионом – т.е. 1 000 000 000 000 000 000 – операций с плавающей точкой в секунду (FLOPS), высокопроизводительный компьютер **JUPITER**, установленный в исследовательском центре Юлих, **стал первым так называемым exascale-компьютером на европейском континенте**.

… Даже **финский суперкомпьютер LUMI** – на котором **MPI-M и его партнеры** по проекту «Destination Earth» выполняют сложные вычисления с моделями высокого разрешения – достигает «всего» 380 PFLOPS – добрая треть того, чего можно ожидать от JUPITER.

The system of differential equations of the ICON model

- Equation set describes **mixture** of dry air and water (all 3 phases)
  - ρ is the total density (including water vapour and condensate)
  - velocity is defined as the barycentric velocity (Wacker et. al, 2003)

$$\boldsymbol{v}_{bc} = \frac{\sum_k \rho_k \boldsymbol{v}_k}{\sum_k \rho_k}$$



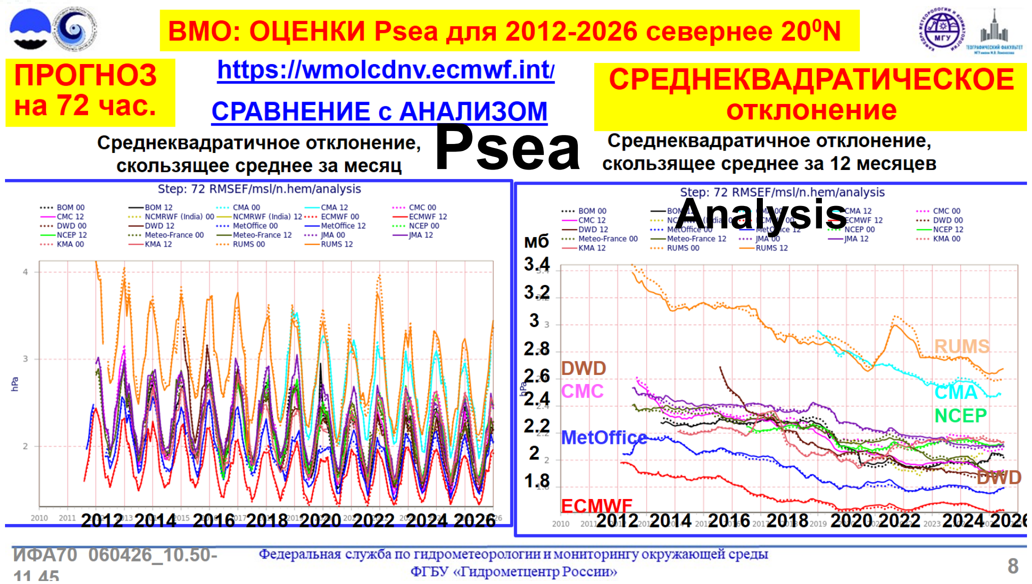
  - Current implementation contains approximations w.r.t. moisture effects

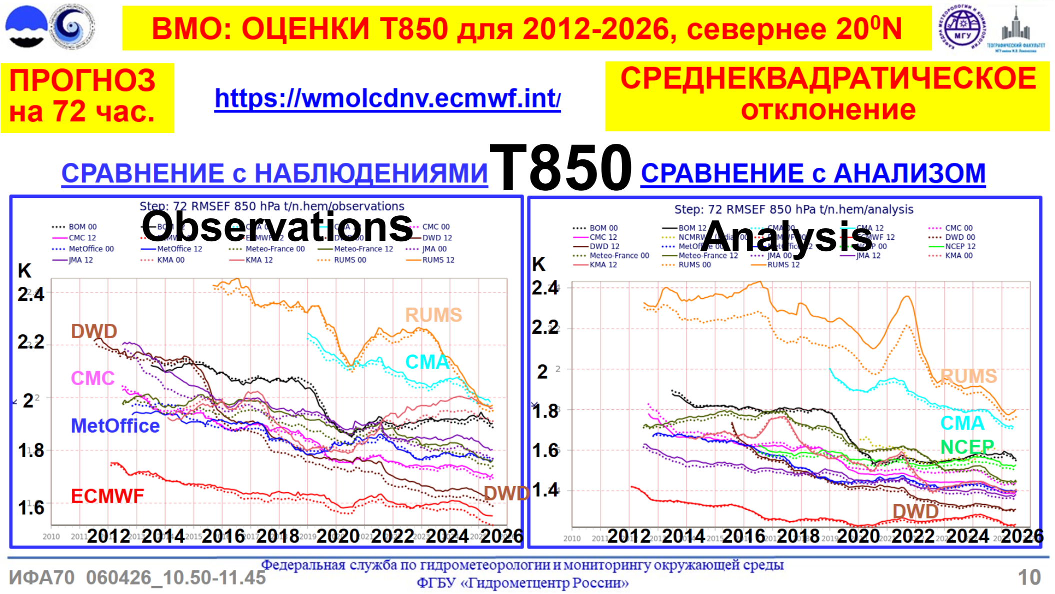
    i.e. $w_{bc} = 0$ at the surface

- flux form for ρ and q_k → inherently **mass conserving**
- Prognostic equation for θ_v actually re-formulated into equation for Exner pressure π

https://wmolcdnv.ecmwf.int/

WMO: 2012-2026; > 20^0N





RMSE

72 h

> 20^0N