Development of the next-generation atmosphere dynamics model in Russia

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Outline

- Motivation
- New dynamical core basic concepts
- Current state and results
- Semi-Lagrangian advection efficiency
- Conclusions

Current and perspective problems

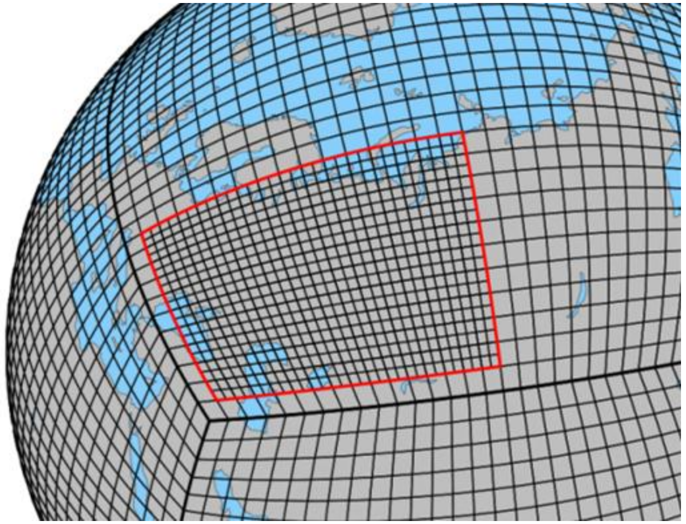
- Global numerical weather forecast
  - Refining resolution: 10 km(current) → 5-7 km → 3-5 km
  - Reproducing non-hydrostatic phenomena
- Climate modeling
  - Standard experiments at $\sim 1^0$ (next CMIP)
  - HighResMIP at $\sim 0.25^0$
  - Catching regional climate extremes
  - *Cloud-resolving modeling (a big milestone in future)*

What kind of software do we need to address these problems?

Next-generation atmospheric models

Numerics:

- Quasi-uniform spherical mesh
- Local resolution refinement

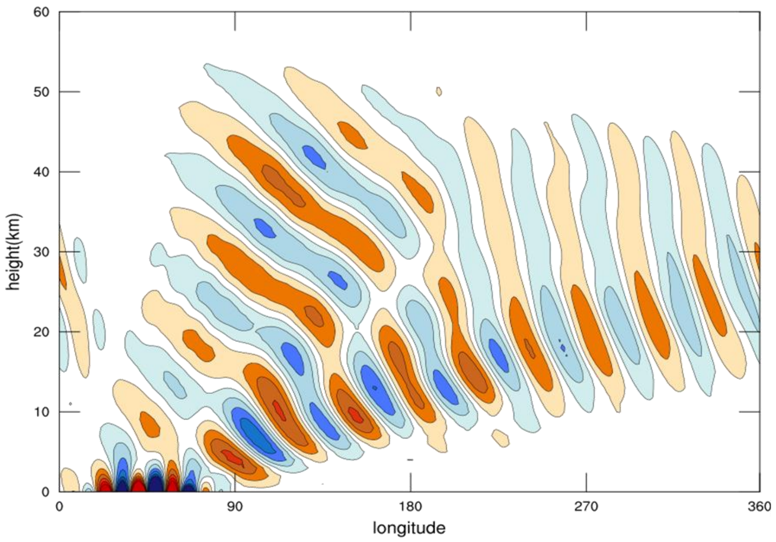


Meteorology:

- Non-hydrostatic equations

Computations:

- Efficiency with ~10^5 cores (CPU)
- Alternative computational architectures (GPUs, ARMs, …)



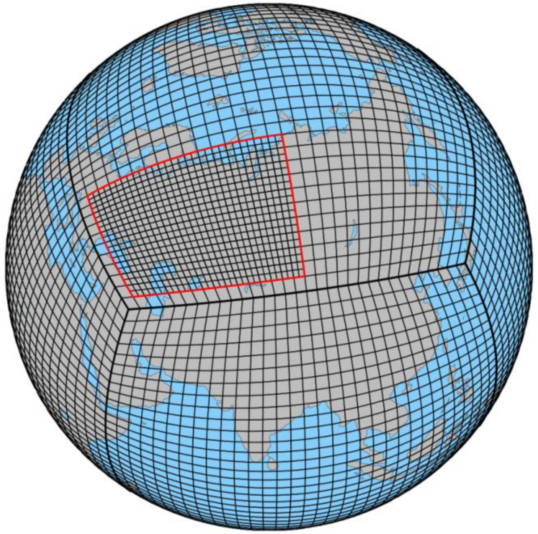
Kind of revolution in the development of dynamic-equations solvers

New INM RAS/Hydrometeorological center dynamical core

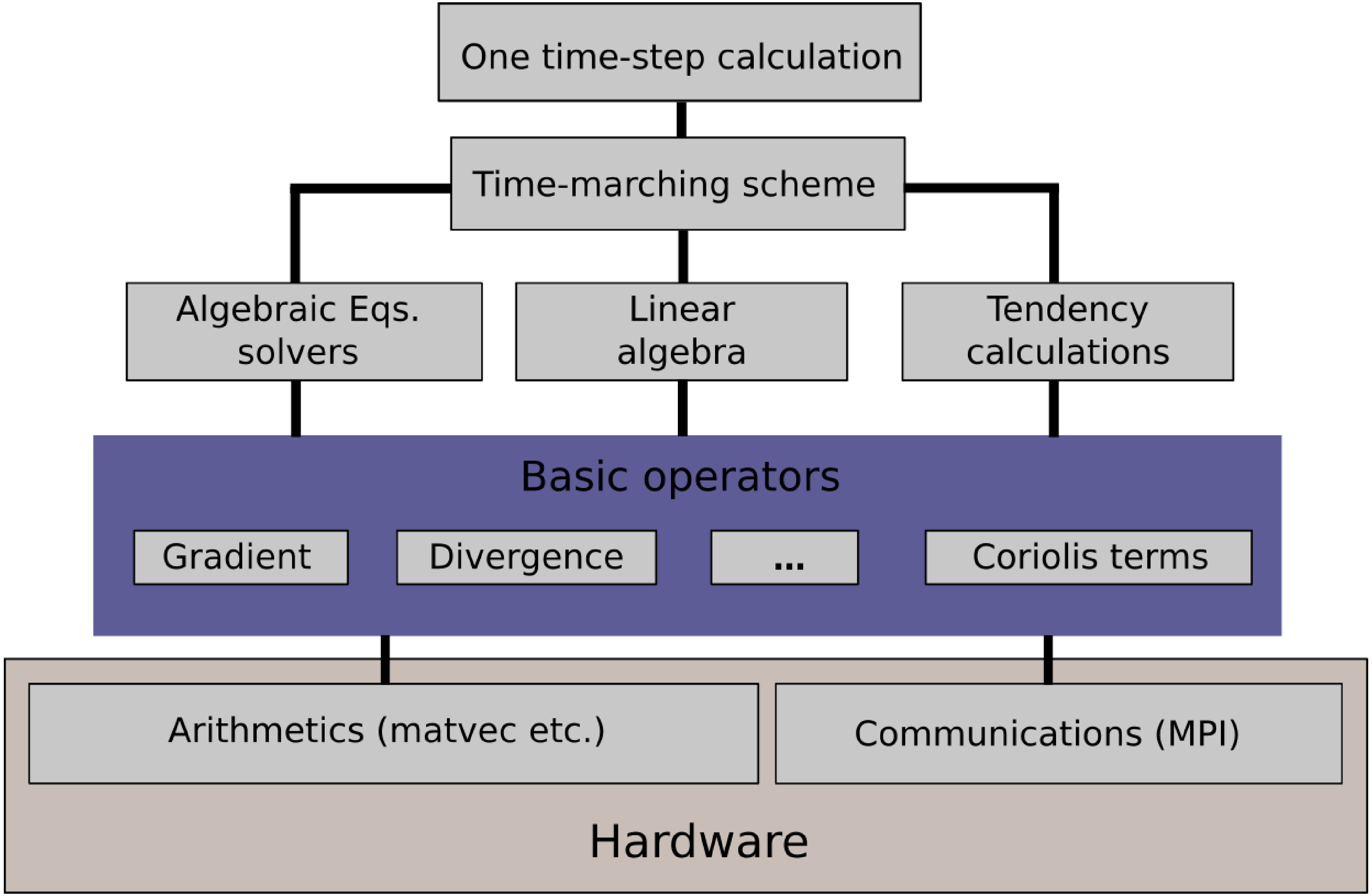
Principal goal: *Build a single hydrodynamics solver for a wide range of atmospheric models applications*

Main features:

- Cubed sphere mesh
- A collection of combinable numerical methods (time-integration schemes, spatial discretizations)
- Various system of equations
- Generic interface to subrid-scale physics packages
- Local mesh refinement
- Testing capabilities



Program complex structure



Current state and works

Non-hydrostatic and hydrostatic equations solver:

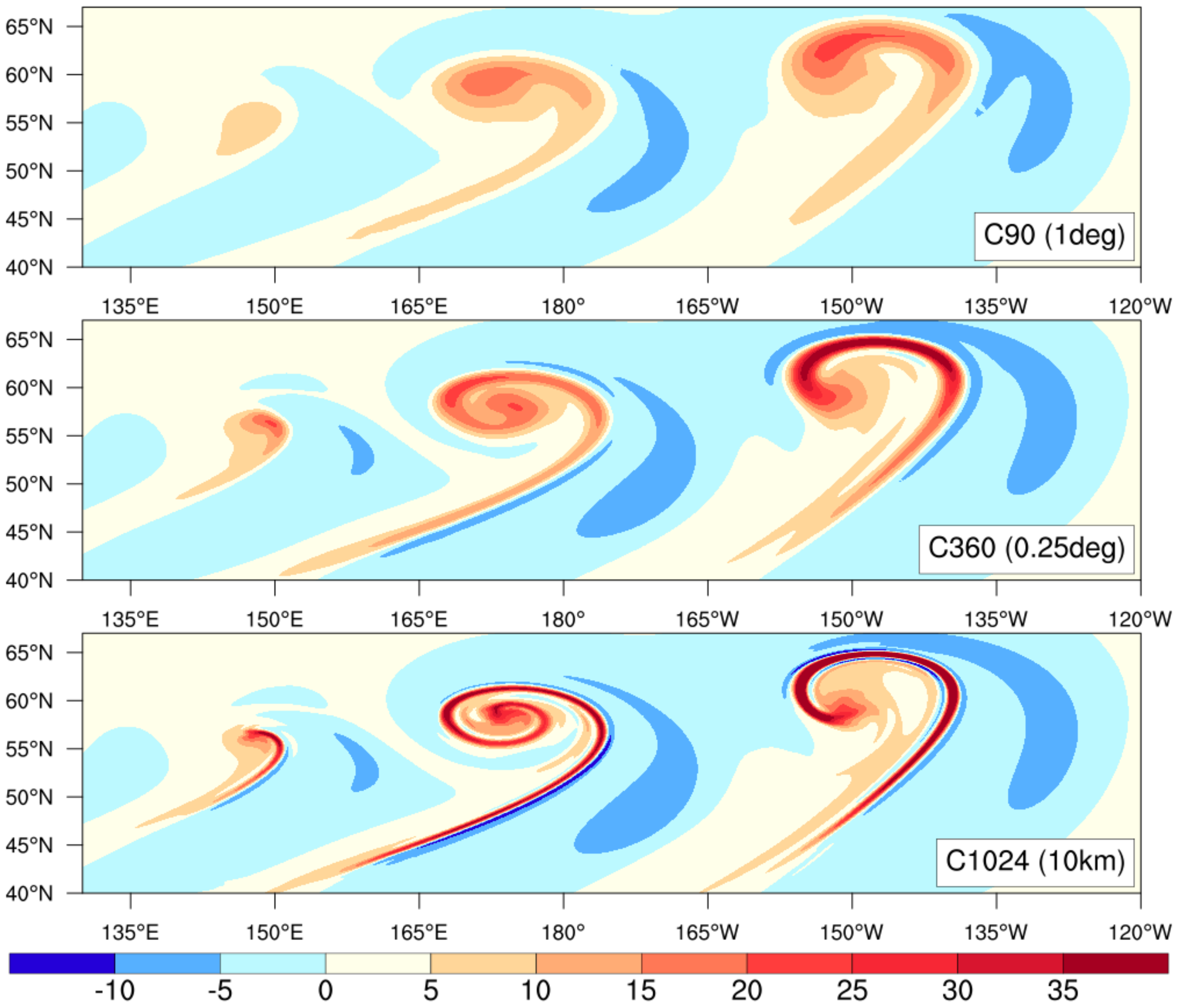
- Time-stepping: HEVI, Advection explicit, semi-Lagrangian
- Spatial approximation: SBP-FD, staggered and collocated grids
- Verification: idealized and simple-physics experiments

Work in progress:

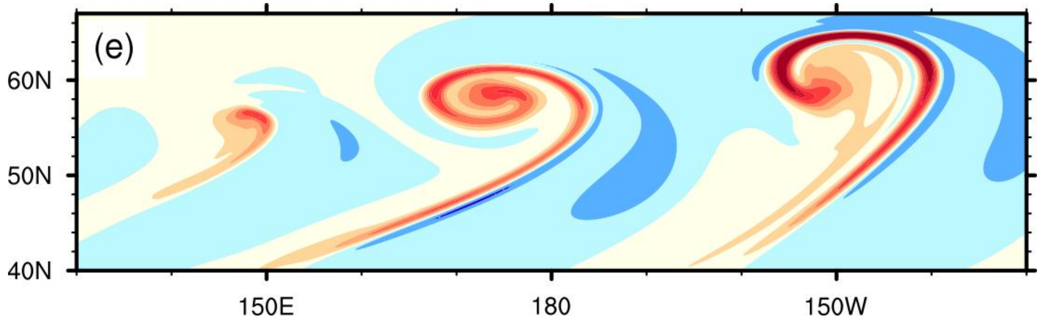
- Multiresolution – testing and debuging in 3D
- Linear solvers: fine-tunning
- Testing with real atmospheric data (incl. preprocessing etc.)
- Coupling with subgrid-scale physics
- Porting to GPU

Verification. Baroclinic instability test

850 hPa relative vorticity, day 9

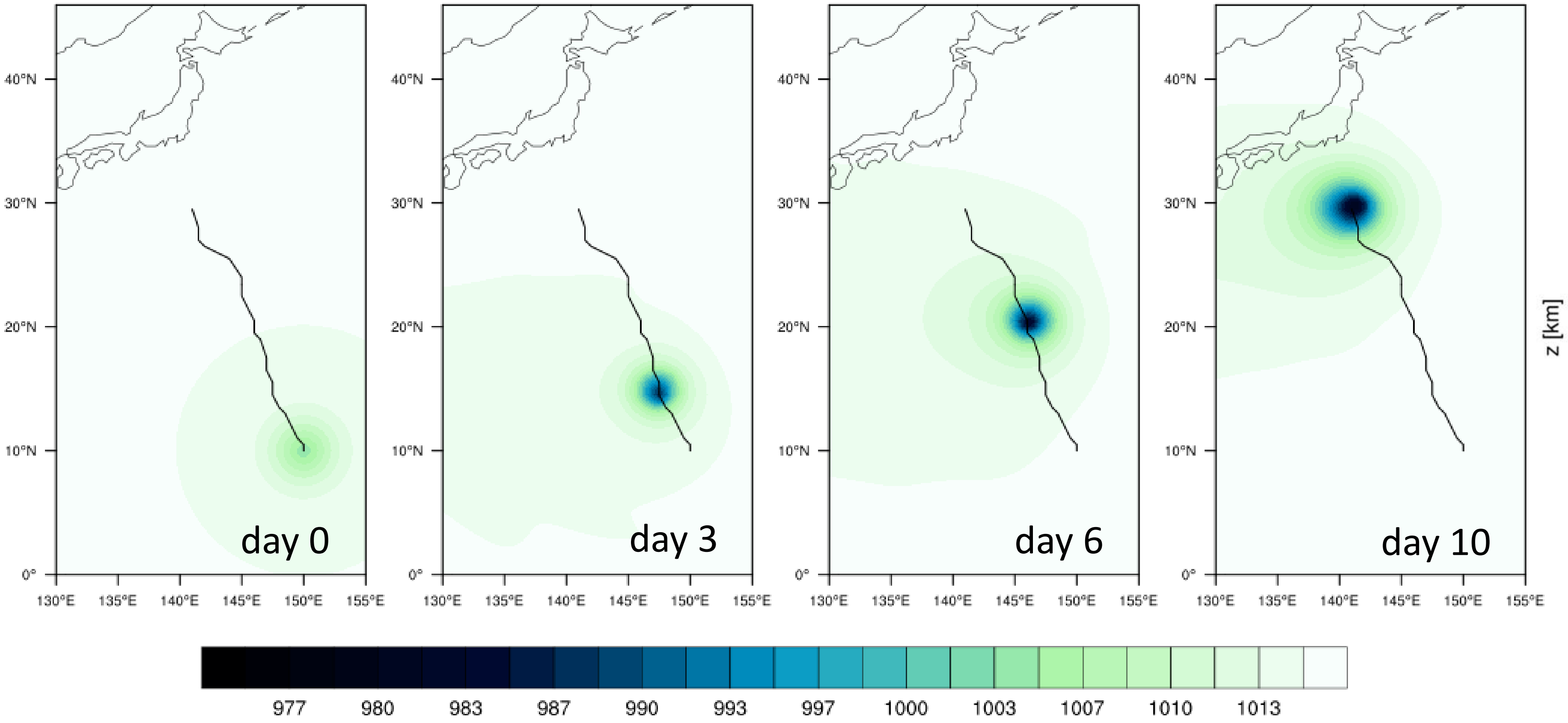


SL-AV20 model solution:

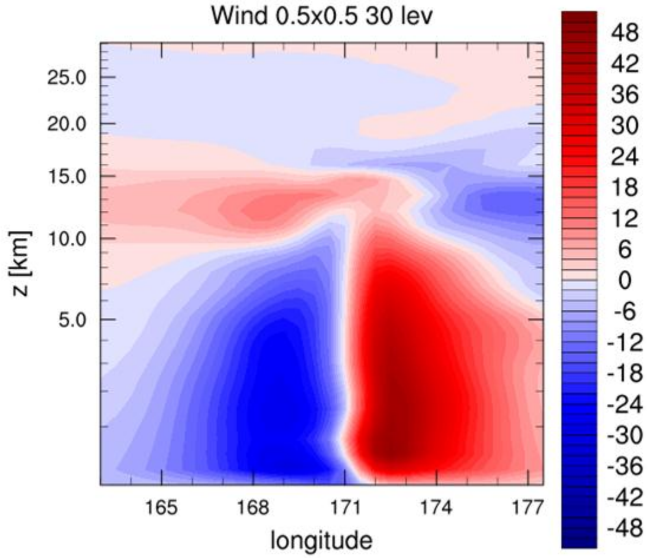


Verification. Idealized tropical cyclone

Simplified subgrid-scale physics:
Condensation, turbulent mixing, evaporation
Initial conditions: weak cyclonic perturbation



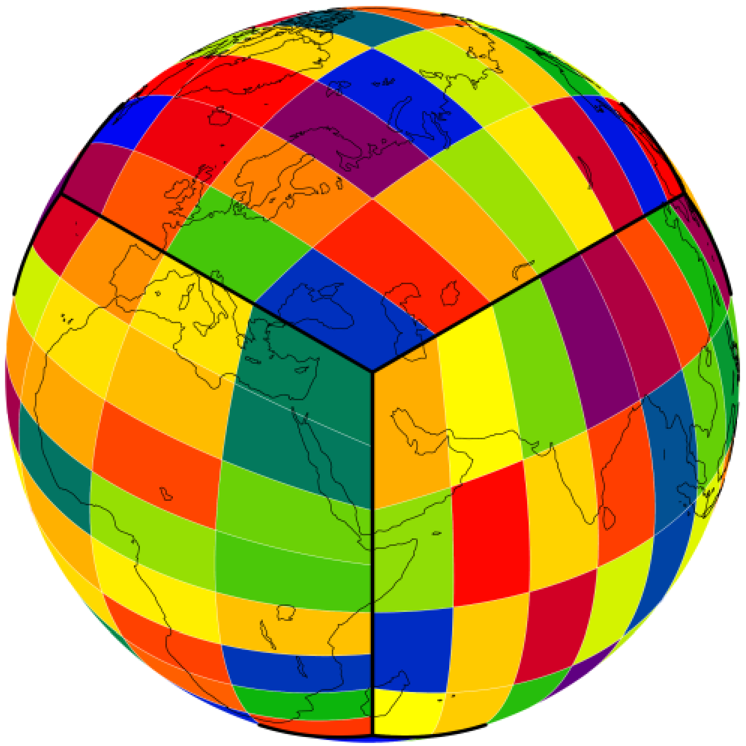
Sea level pressure (hPa), cyclone center trajectory



Wind field vertical cross-section, day 10

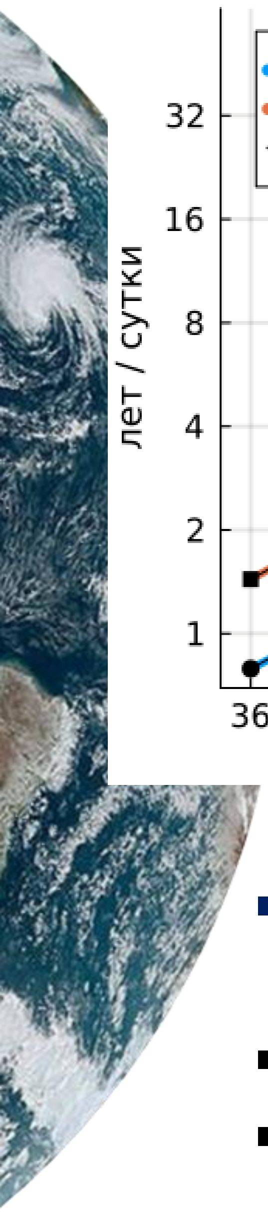
Parallel computations

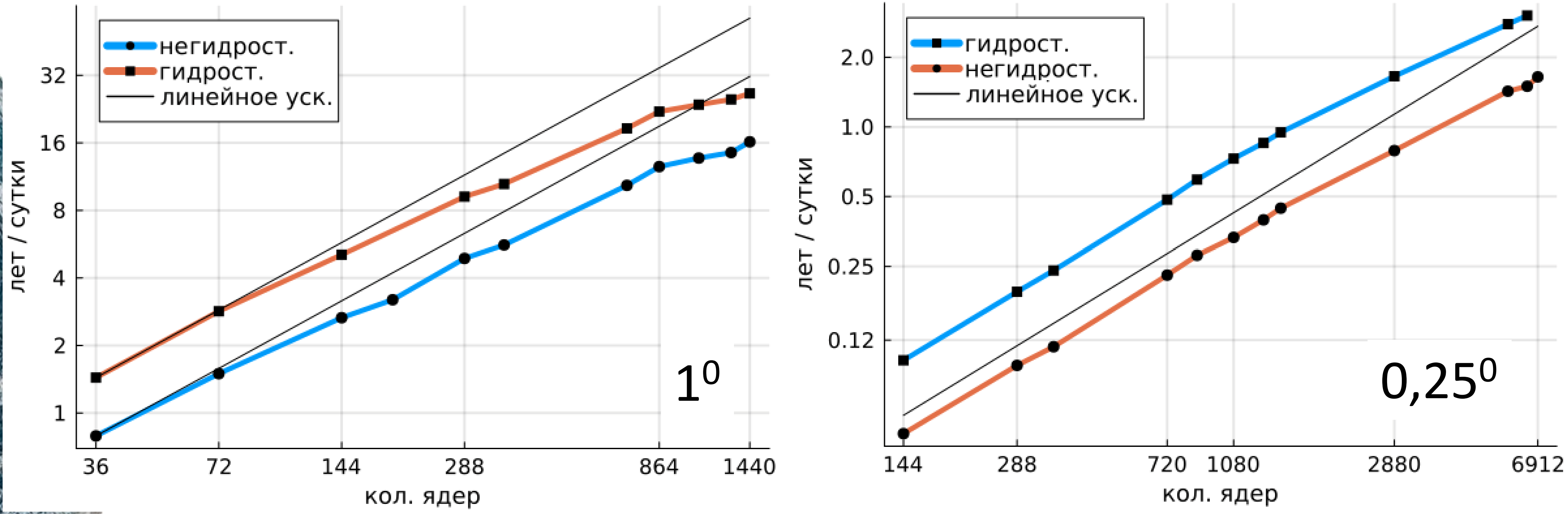
- 2D decomposition (n×m - points size tiles)
- MPI-based implementation
- One of more tile per MPI-process
- Any number of MPI-processes(more flexible than $6\times p\times q$ or $6\times p^2$)
- Possibility of OpenMP acceleration of tiles loop



192 tiles cubed-sphere decomposition

Performance and scalability

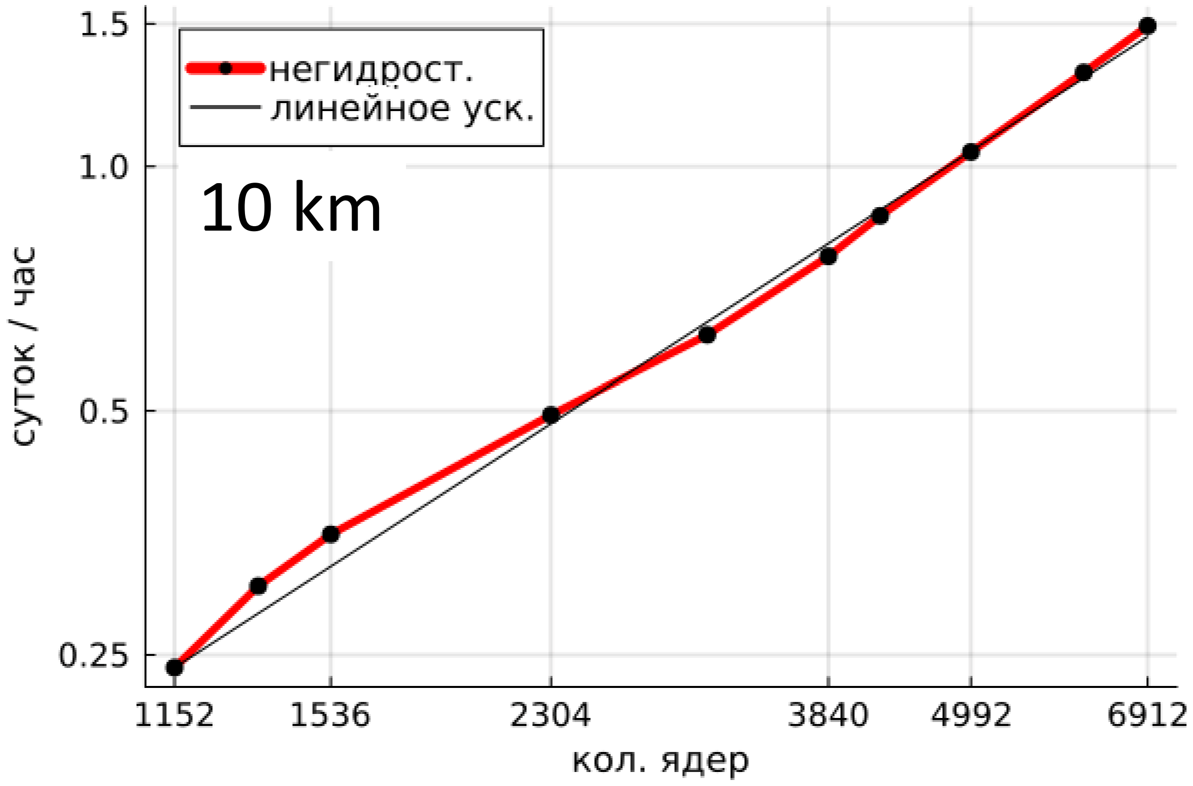




Dynamical core scalability

- Roshydromet CRAY XC-40, “climate modeling” configurations with 1^0 and $0,25^0$ horizontal resolution, 80 levels.
- Hydrostatic model is 1,5-1,7 times faster than non-hydrostatic
- 26 years/day at 1440 cores for 1^0 hydrostatic configuration (15×16 points in horizontal per core)

Performance and scalability



Dynamical core scalability

- Roshydromet CRAY XC-40, “medium-range forecast” configuration Δx=10 km.
- Super-linear acceleration (36×32 points in horizontal per core, not enough cores to challenge efficiency).

Semi-Lagrangian advection block test

- White III & Dongarra (2011) algorithm:

```
1) For each departure position (DP):
determine tile its falls in

2) Send DP-coordinates to tile it falls in
(send interpolation request)

3) Interpolate field values to the requested
DPs

4) Send interpolated values back

5) Receive field values
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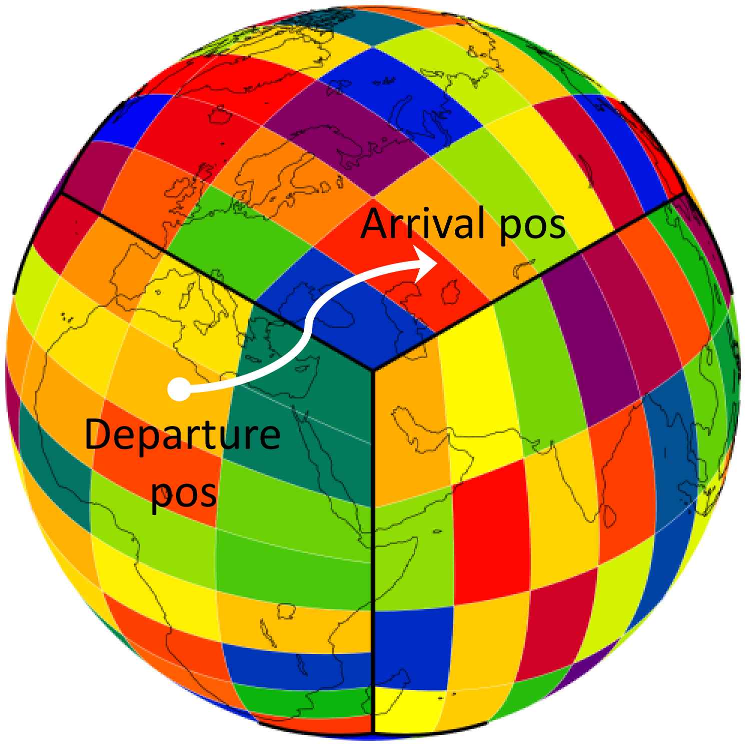
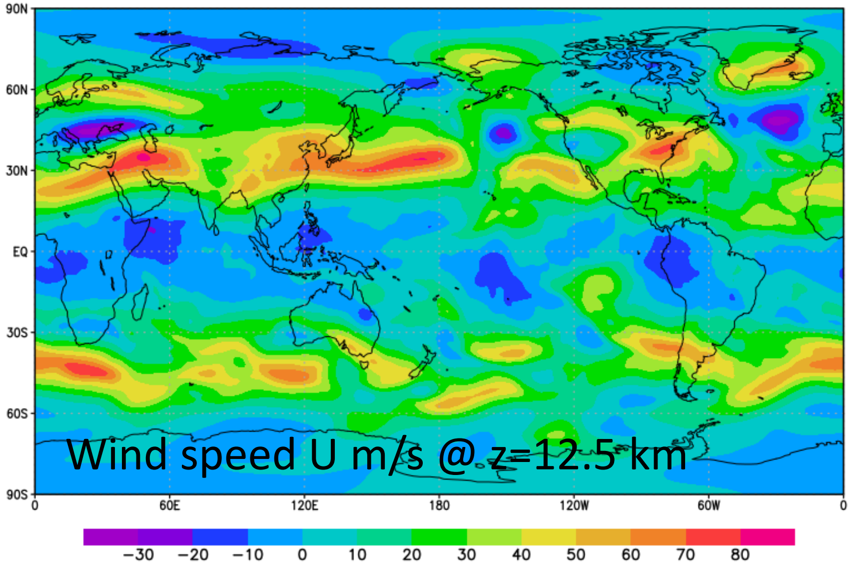


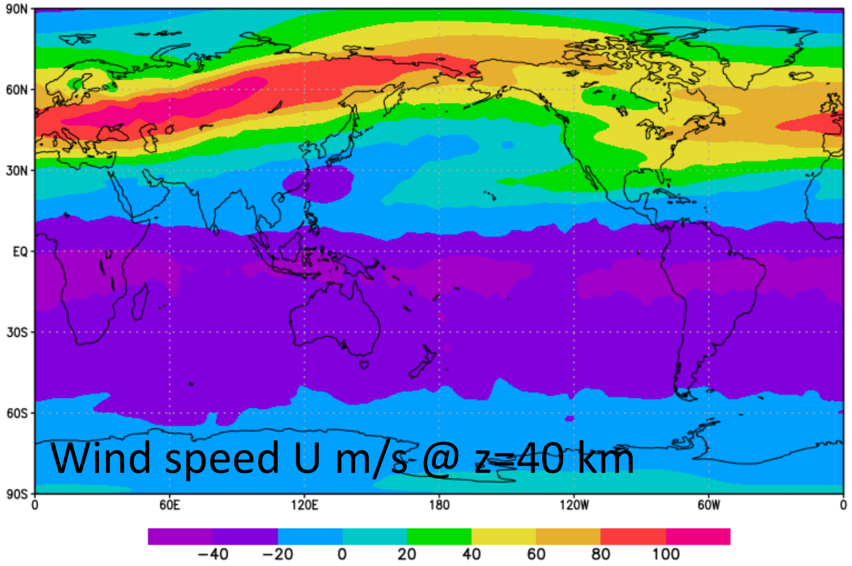
- Assumed to be scalable and efficient SL implementation for high CFL-s
- Never tested with real data

Semi-Lagrangian advection block test

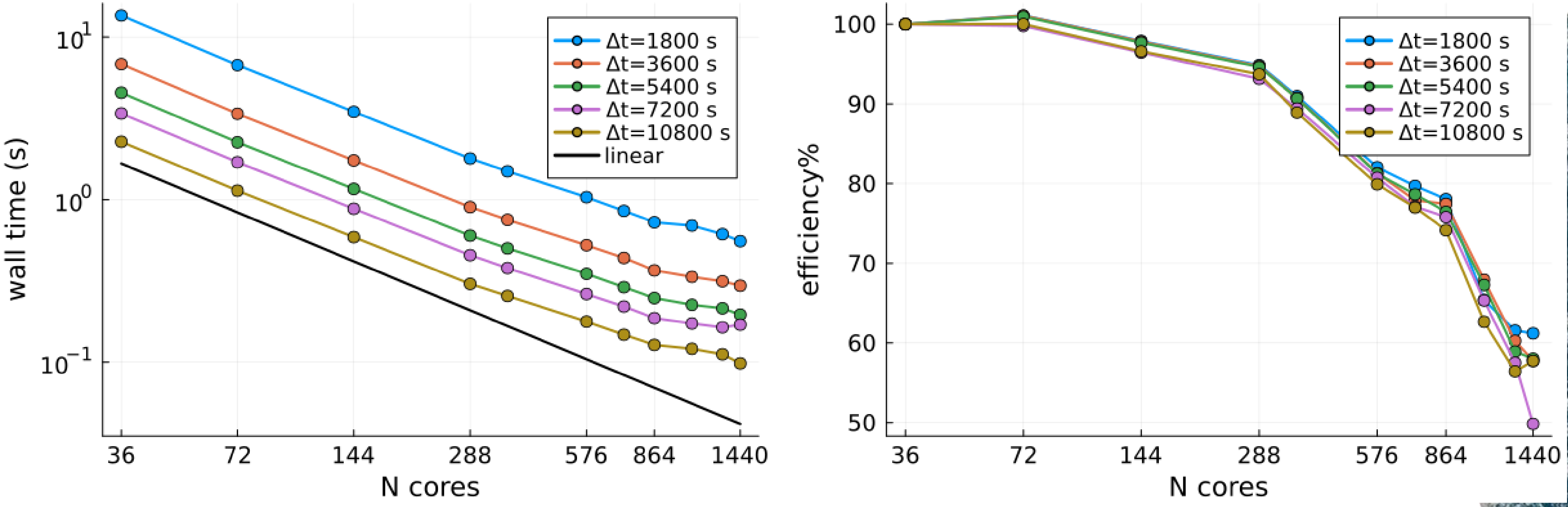
Test setup:

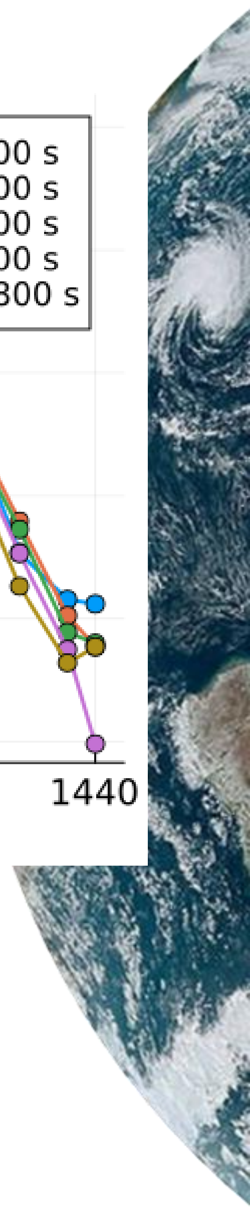
- 6×96×96 grid with 60 levels in vertical
- Upper lid height 45 km
- Real initial data from 01 January 2017 (max wind speed: 100 m/s)
- Evolution by HEVI dynamical core, Δt=120 s
- 20 tracers, two types of interpolation to departure points





Semi-Lagrangian advection block test

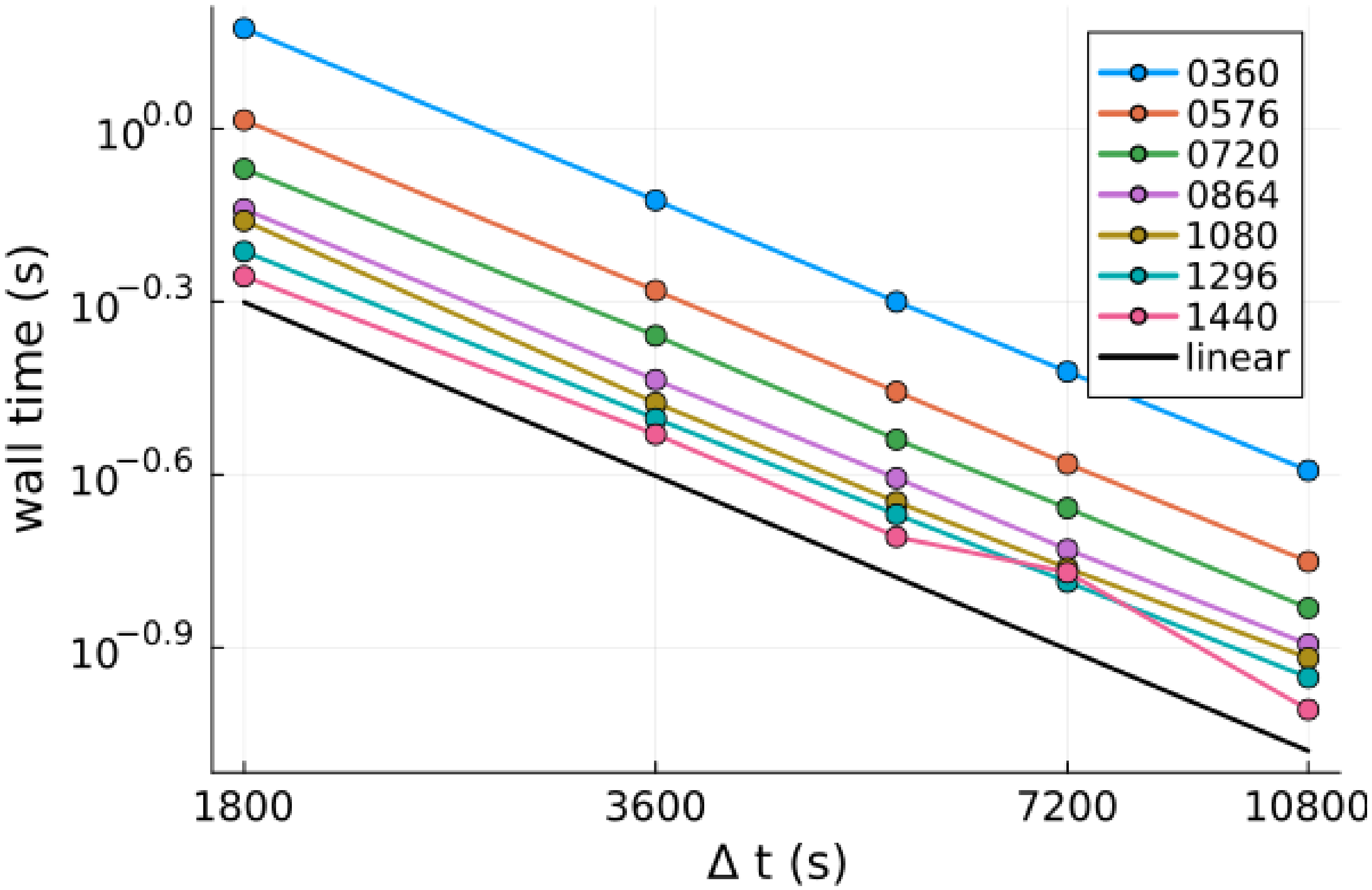




Strong scaling of SL-advection block at various Δt.

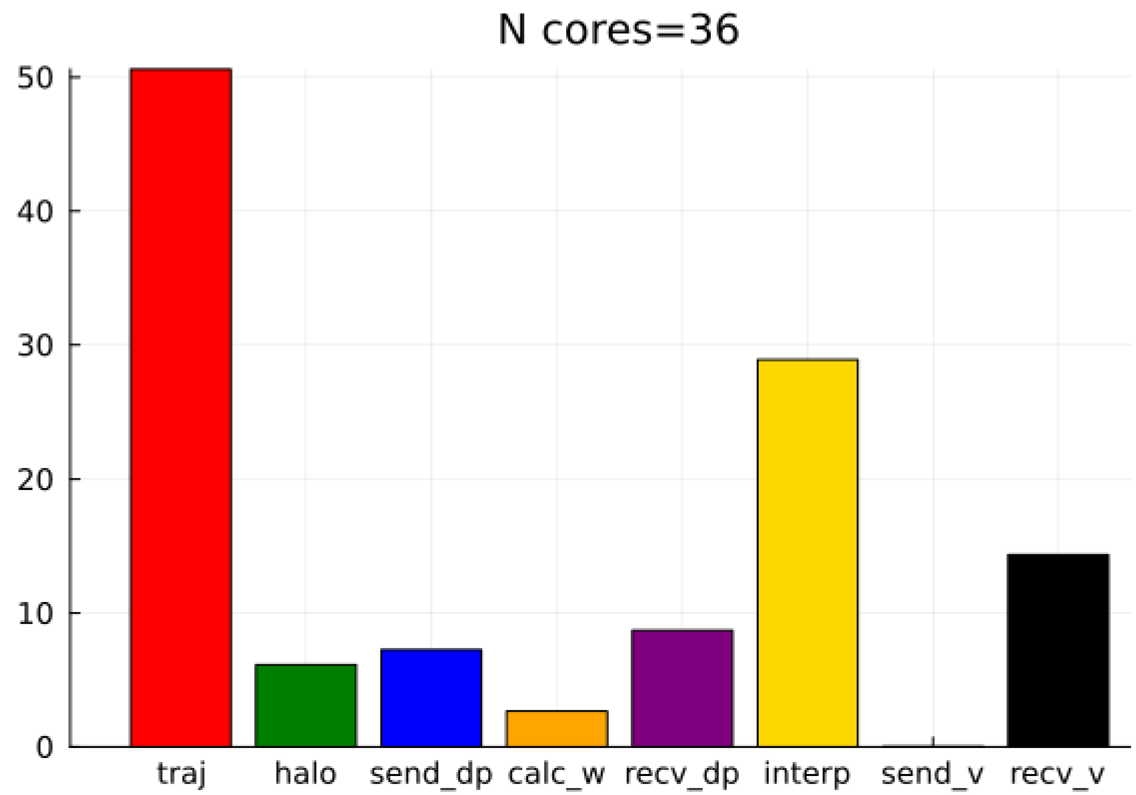
Left – wall time, right – acceleration efficiency.

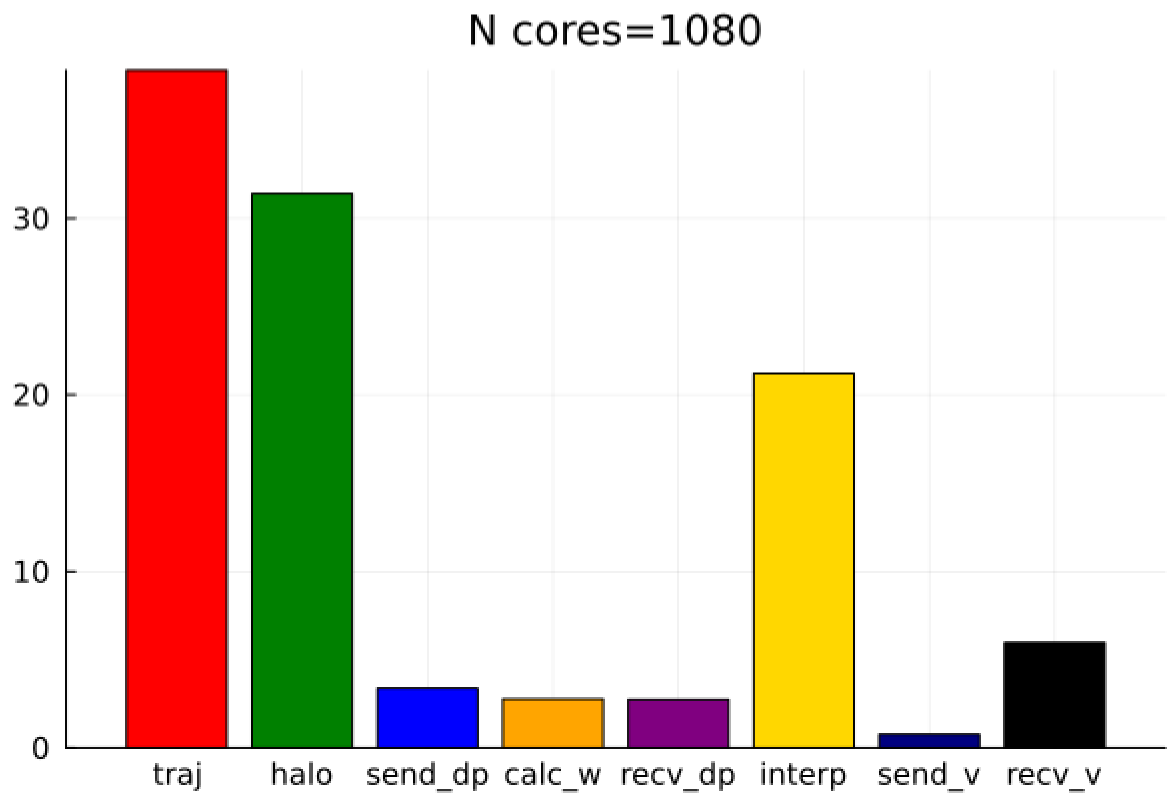
Semi-Lagrangian advection block test



SL-advection block acceleration with increasing Δt.

Semi-Lagrangian advection block test

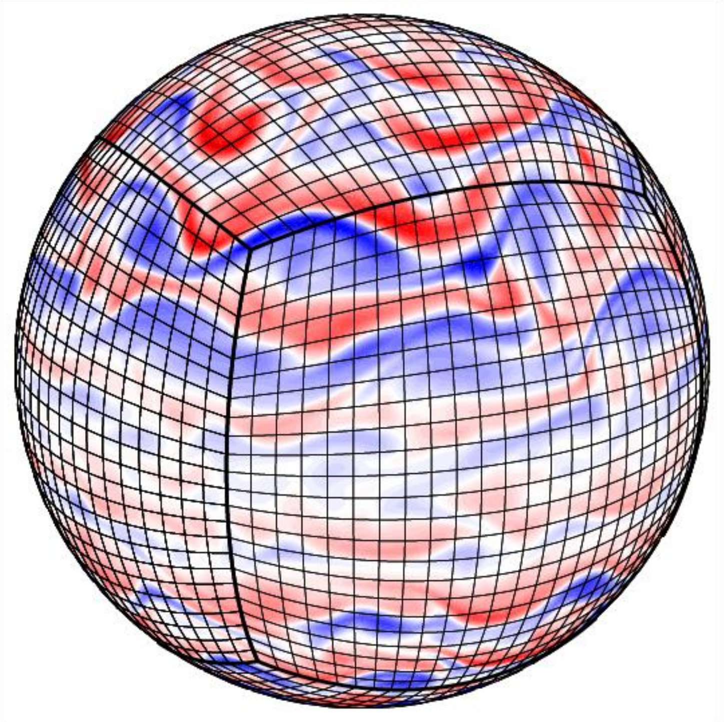




Wall time fraction (%) spent in each part of the algorithm with Δt=3600 s (the picture is nearly similar for all Δt).

Conclusions

- We are on the way to make highly scalable and efficient dynamical core
- Still much work to be done



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Thank you for attention!

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https://gitlab.inm.ras.ru/vshashkin/ParCS