SL-AV Model: Numerical Weather Prediction at Extra-Massively Parallel Supercomputer

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SL-AV global atmosphere model (1)

SL-AV: **S**emi-**L**agrangian, based on **A**bsolute **V**orticity equation

- **Finite-difference semi-implicit semi-Lagrangian** dynamical core of own development. Vorticity-divergence formulation, unstaggered grid (Z grid), 4^{th} order finite differences
- Possibility to use **reduced lat-lon grid** in dynamical core. (Tolstykh, Shashkin JCP 2012; Shashkin, Fadeev Tolstykh, JCP 2016;Tolstykh, Shashkin,Tolstykh et.al., Geosci.Mod.Dev., 2017).
- **Mass-conserving version** (Shashkin, Tolstykh GMD 2014)
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SL-AV global atmosphere model

- Many parameterizations algorithms for subgrid-scale processes developed by ALADIN/ALARO consortium.
- Parameterizations for shortwave and longwave radiation: CLIRAD SW + RRTMG LW.
- INM RAS- SRCC MSU multilayer soil model (Volodin, Lykossov, Izv. RAN 1998).
- Marine stratocumulus parameterization

Current applications of SL-AV model:

- Operational medium-range weather prediction up to 10 days; probabilistic seasonal forecast at Hydrometcentre of Russia.
- Weather prediction up to 3 days at Novosibirsk.
- 60 days weekly forecast (S2S Prediction project, WMO) – quite old SL-AV version ! Need of urgent update

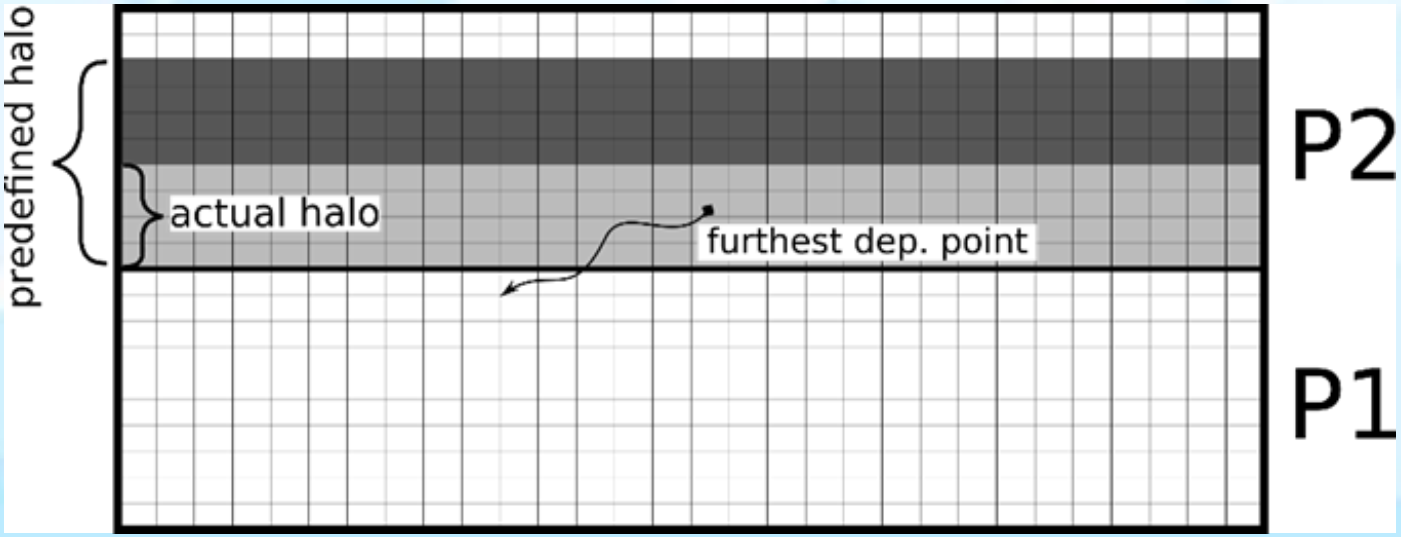
System setup

- All the experiments were carried out at the Cray XC40 system installed at Roshydromet
- 936 nodes with two Intel Xeon E2697v4 18-core CPUs and 128 GB RAM
- Nodes are connected with Cray ARIES interconnect.
- Peak performance –1.2 PFlops.

SL-advection optimization

- Algorithm requires halo exchanges of the predefined width determined by the max wind speed estimate

- New version of the algorithm uses information about position of the furthest departure points to define width of the halo exchanges needed for the interpolation part



MPI optimizations

- The parallel implementation of the elliptic problem solvers requires data transpositions, i.e. global redistribution of data between processes.
- Code modifications allowed to reduce number of transpositions from 4 to 2 per time step

OpenMP code optimizations (1)

- Some parts of the model code used OpenMP to parallelize loops along the same direction as MPI decomposition (latitudinal index)
- Available parallelism is exhausted when N_mpi*N_openMP=N_lat-1
- These parts of code were modified to use OpenMP parallelization along additional index (longitude/wavenumber/vertical)

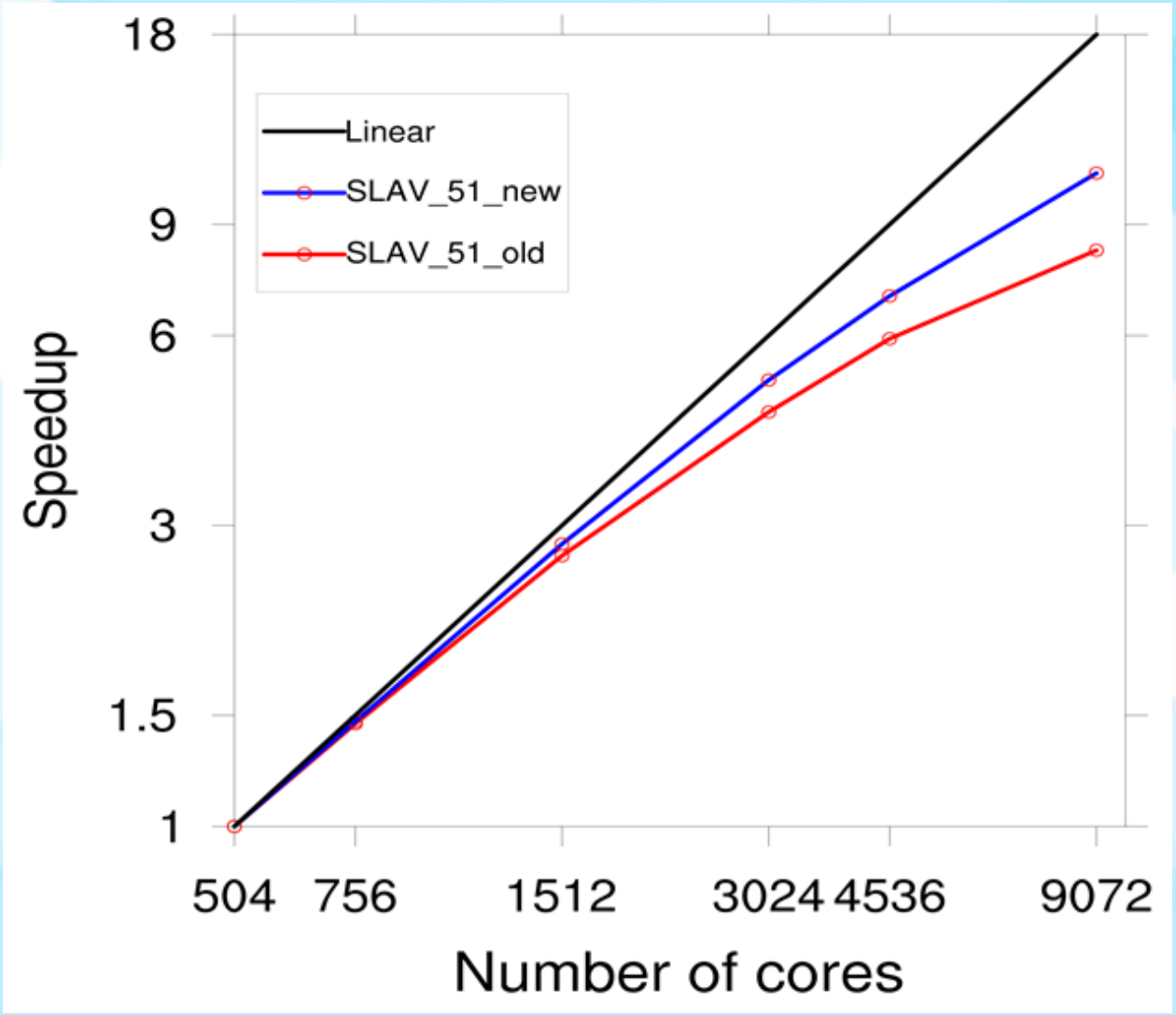
OpenMP code optimizations (2)

- Subgrid-scale parameterizations block is the most time-consuming part of the model.

- Computations in this block have only vertical index dependencies, so optimal arrays indices arrangement in terms of vectorization:

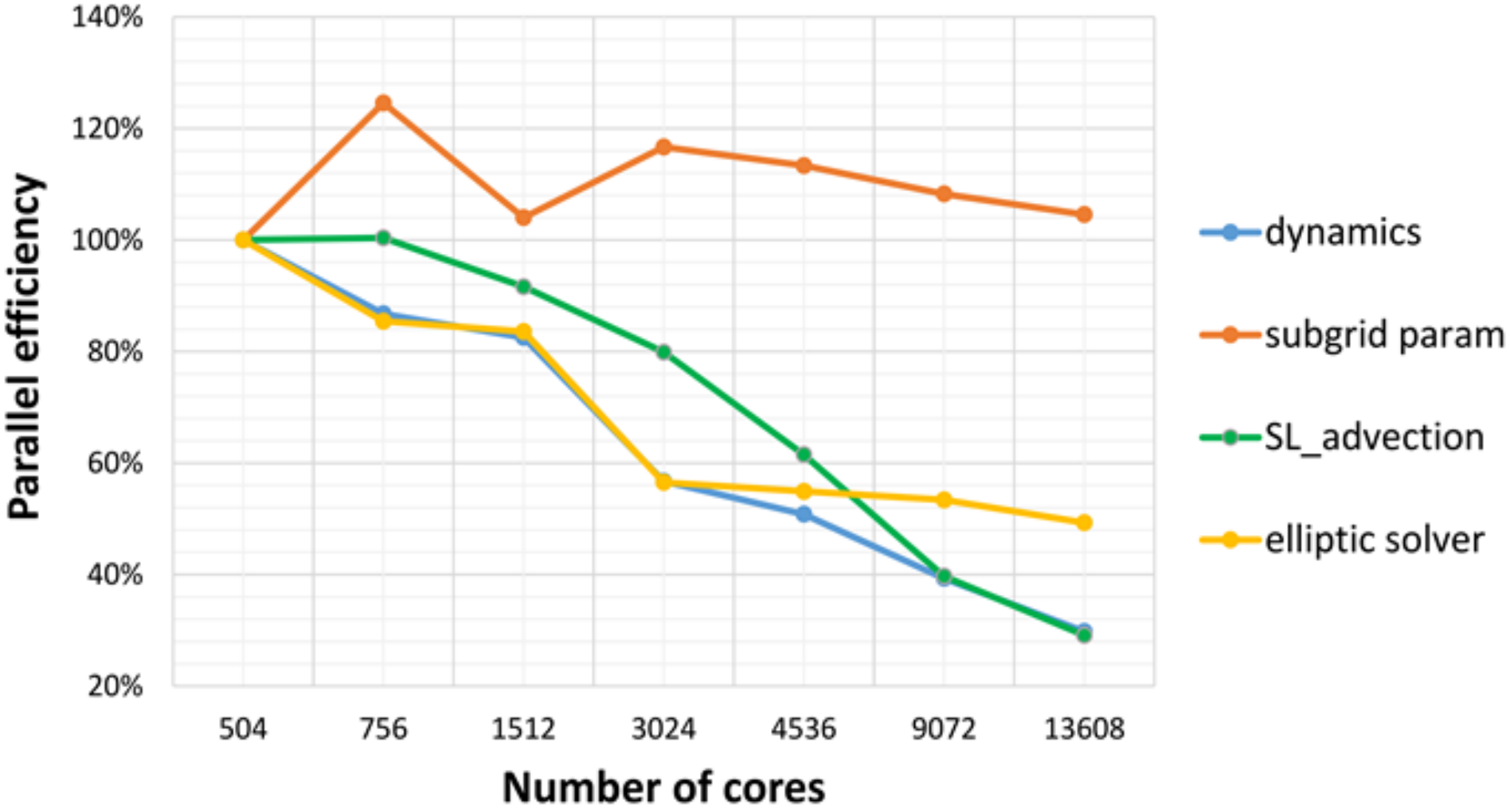
Array(horizontal dimension, vertical dimension)

Results of optimizations: parallel speedup w.r.t. 504 cores at Cray XC40

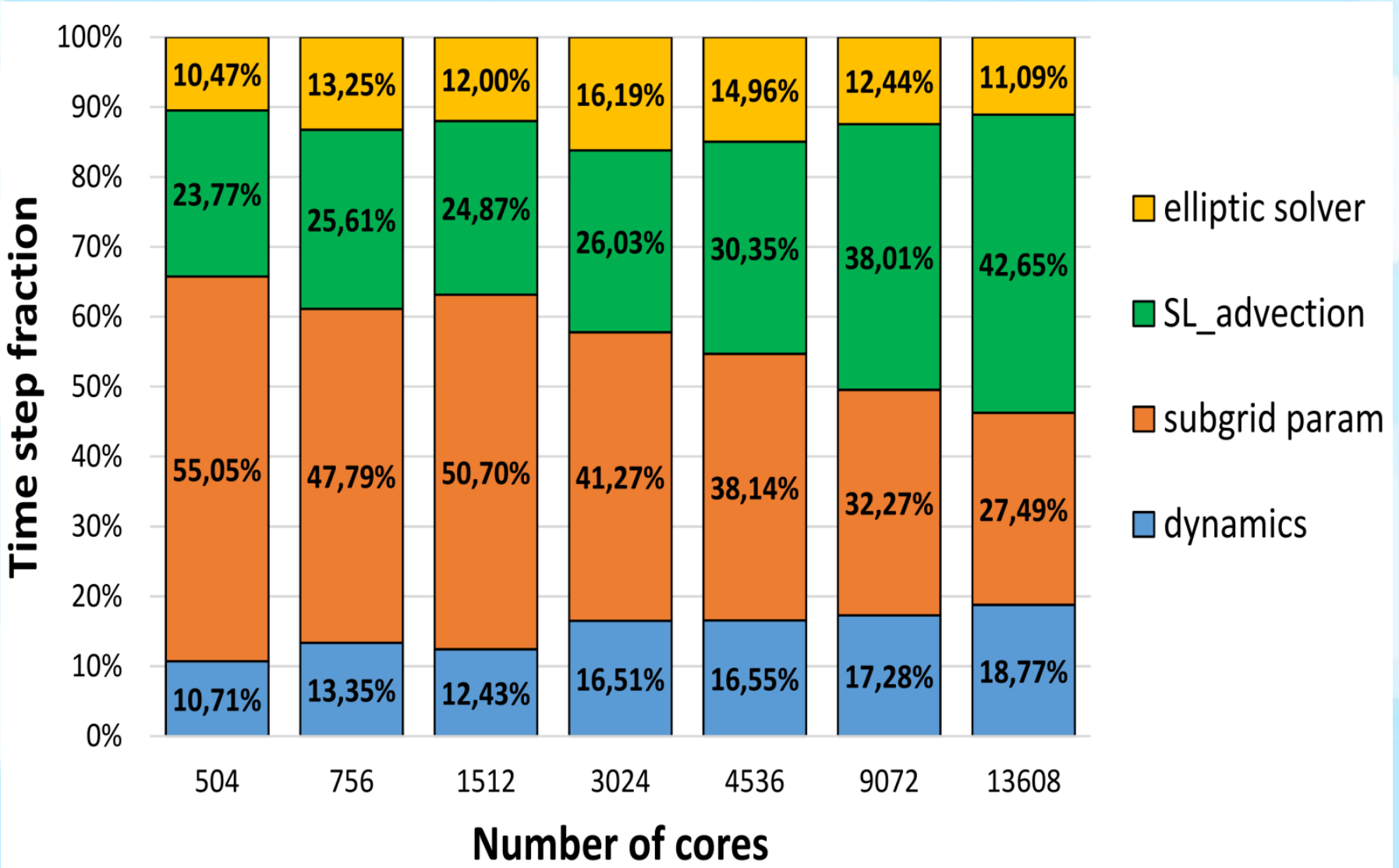


Grid: 3024x1513x51 (~10^8)

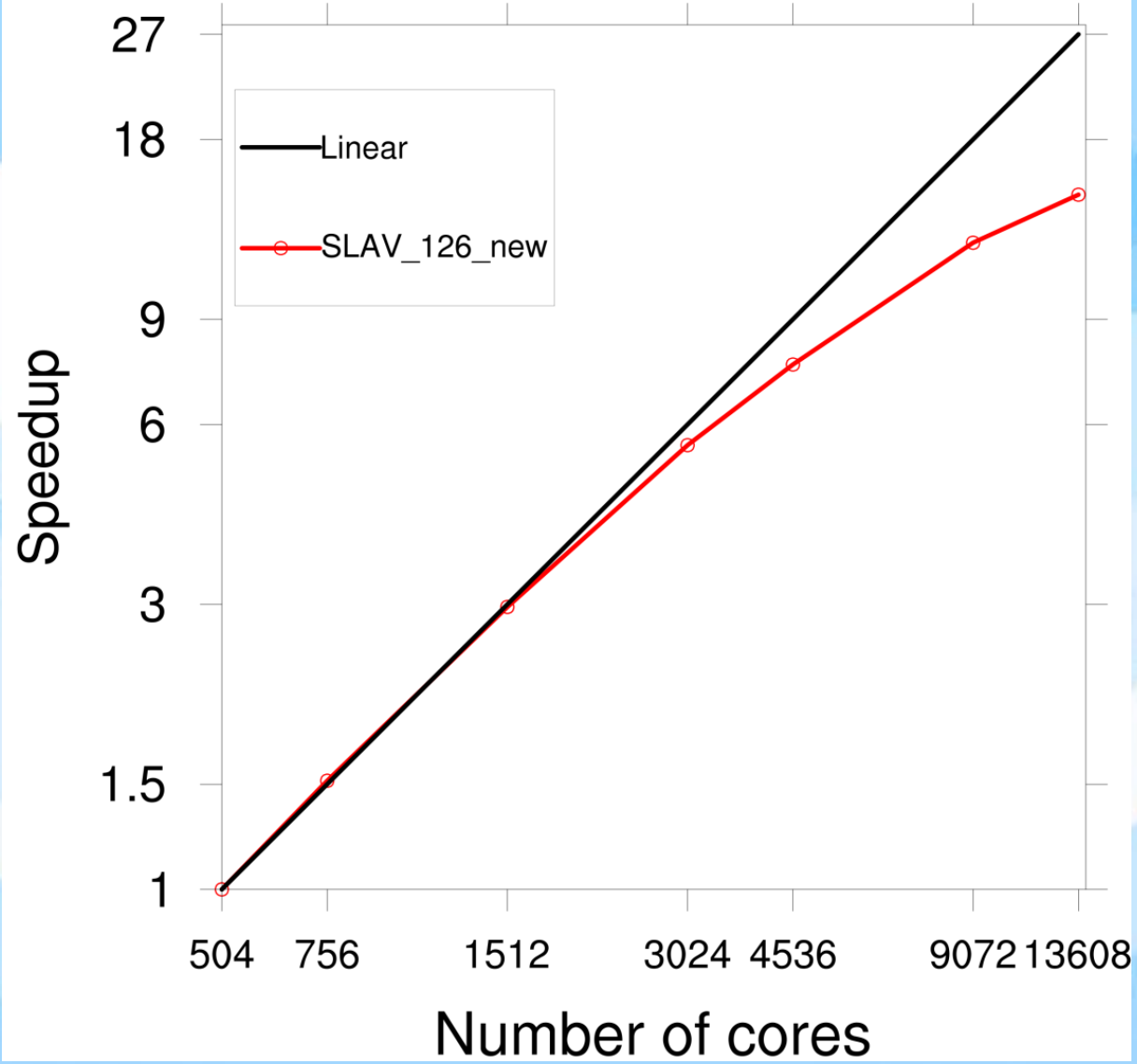
Parallel efficiency of different parts of the model code



Percentage of different dynamics part in elapsed time vs. # of cores

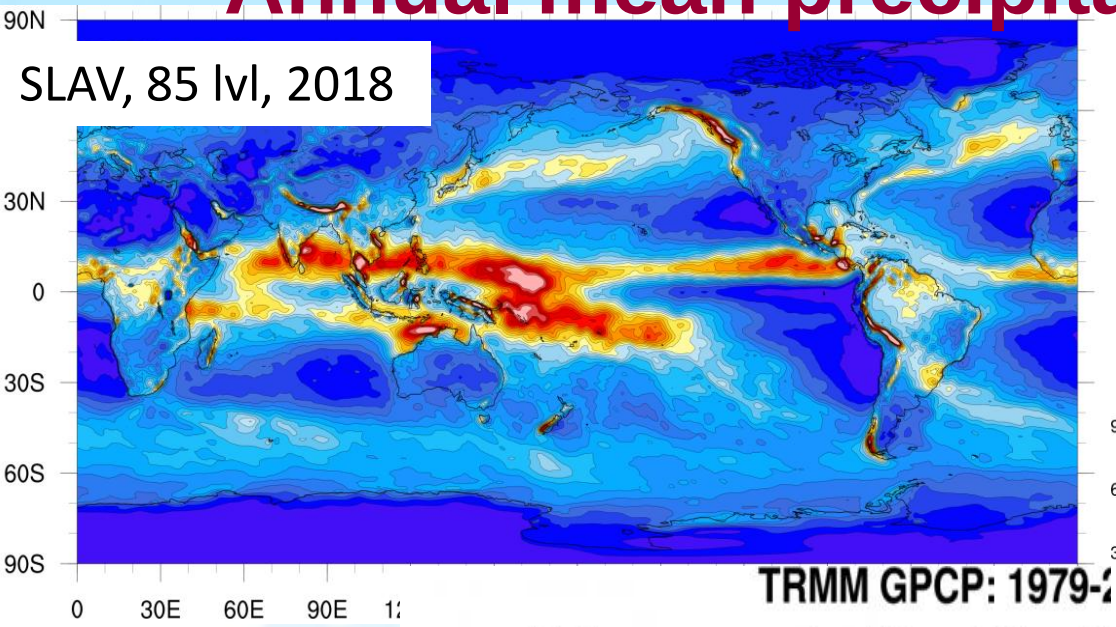


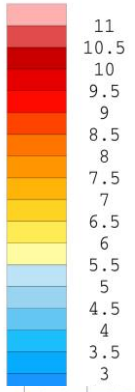
SL-AV code parallel speedup at Cray XC40 w.r.t to 504 cores

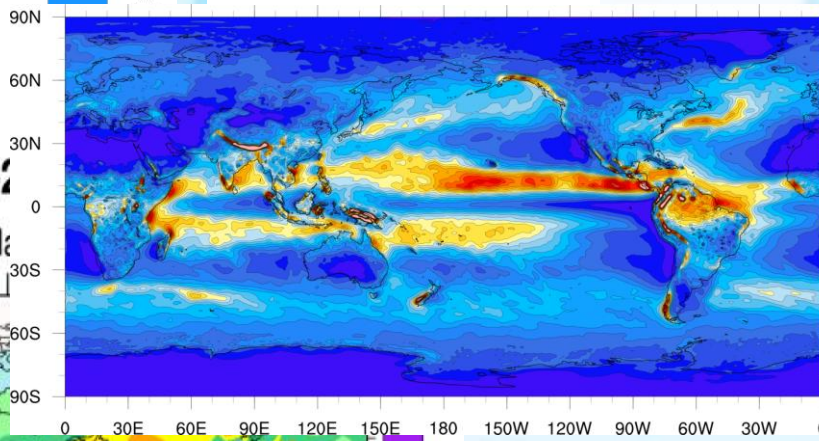


Horizontal grid of 3024x1513 points (~13 km). 126 vertical levels

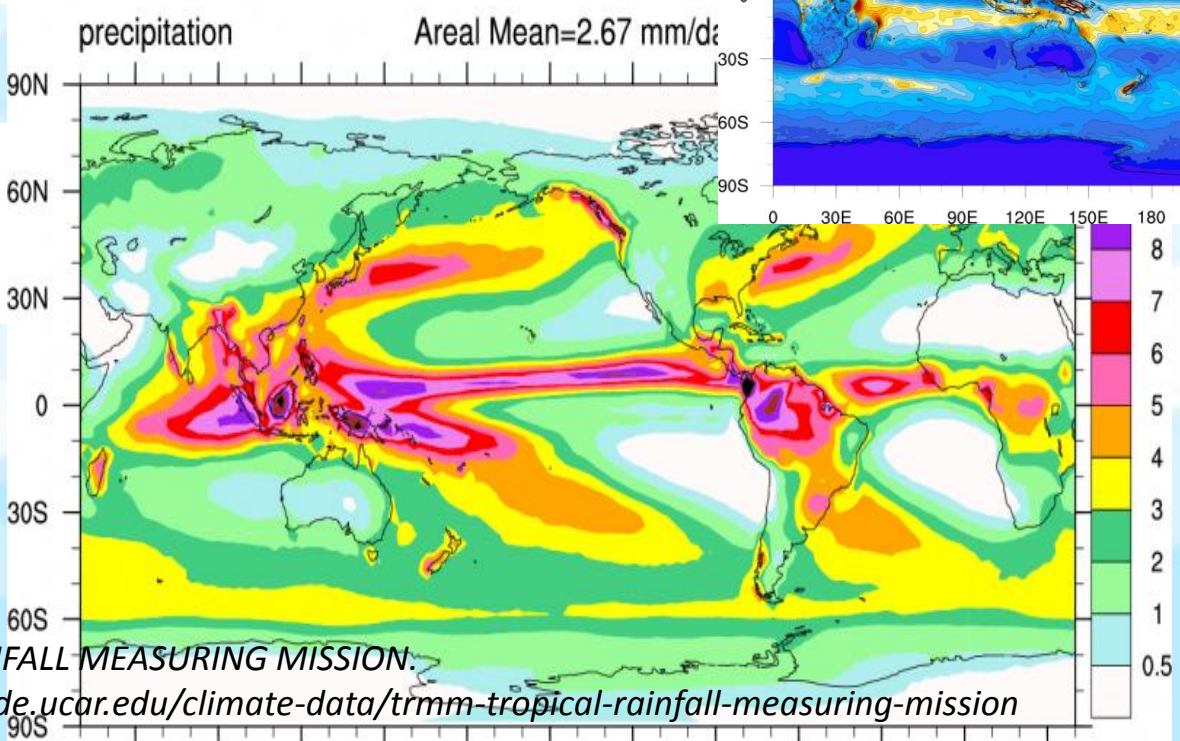
Annual mean precipitation (mm/day)





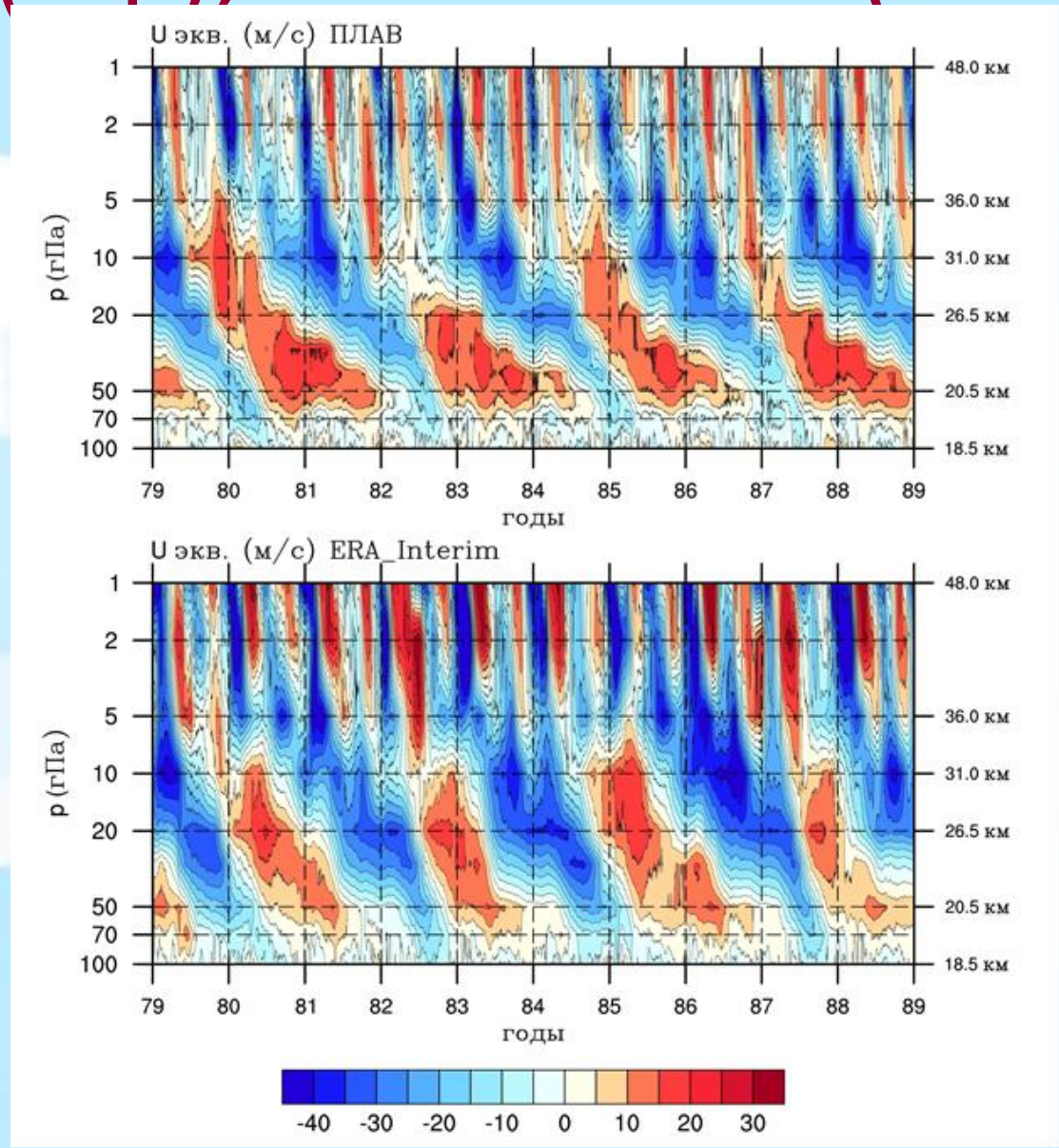


Obs GPCP
TRMM
(1979-2010)

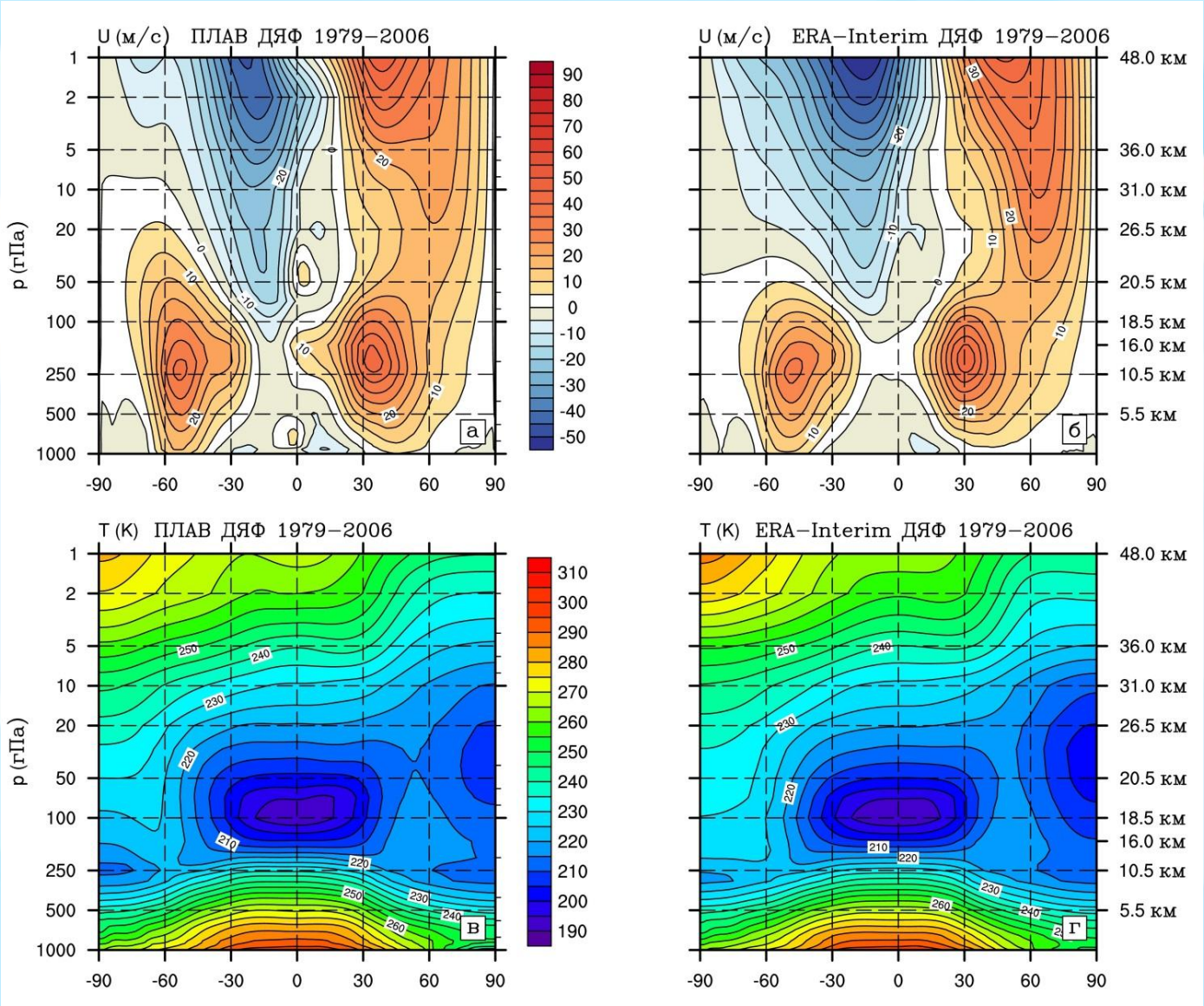


TRMM: TROPICAL RAINFALL MEASURING MISSION.
https://climatedataguide.ucar.edu/climate-data/trmm-tropical-rainfall-measuring-mission

QBO. U at equator, 1979-1989: SL-AV model (top), ERA Interim (bottom)



Zonal mean U and T (DJF, 1979-2006), SL-AV (left), ERA-Interim (right)

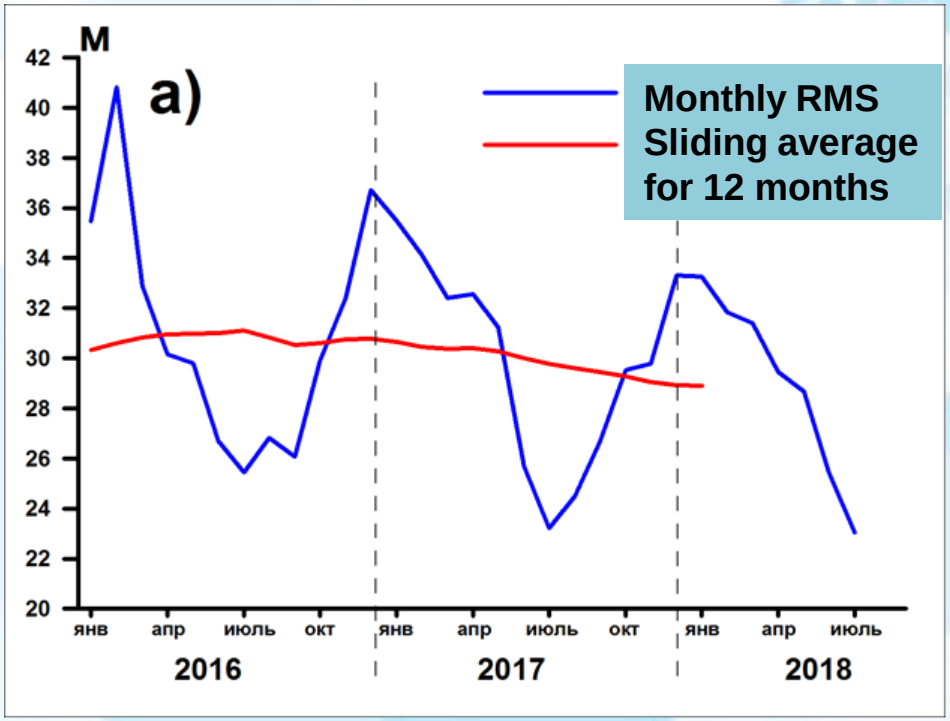


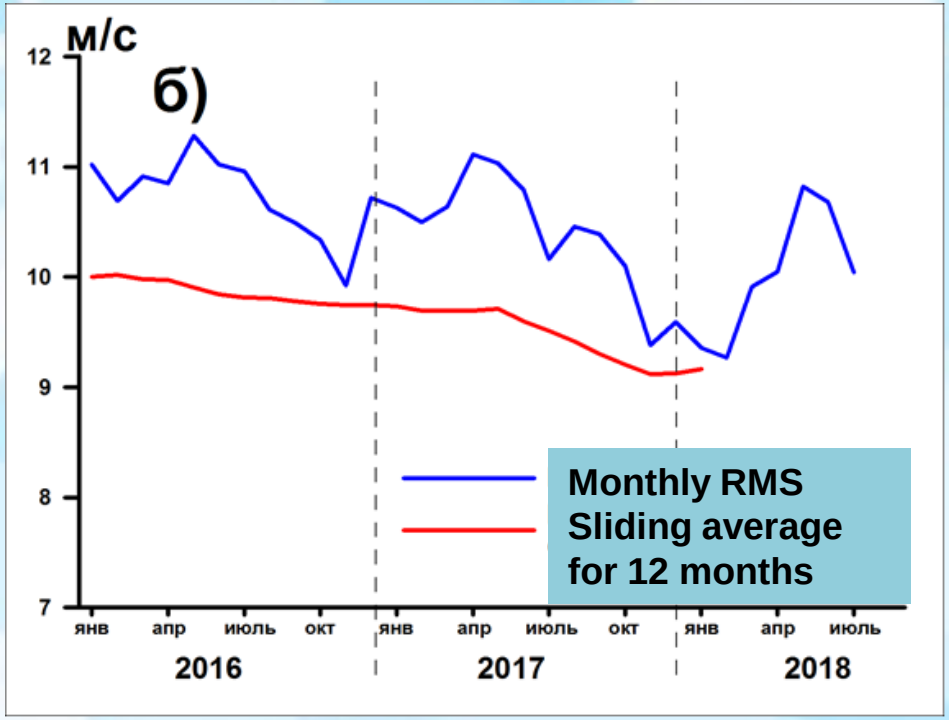
These improvements in model climate produced a reduction of operational medium range forecasts errors

Operational version of the model: resolution in longitude 0,225°, in latitude from 0,16° in NH to 0,245° in SH, 51 vertical levels

https://apps.ecmwf.int/wmolcdnv/

Reduction of SL-AV RMS forecast error (01.2016-07.2018). H500 at 72 hrs (left), W250 at 72 hrs (right)

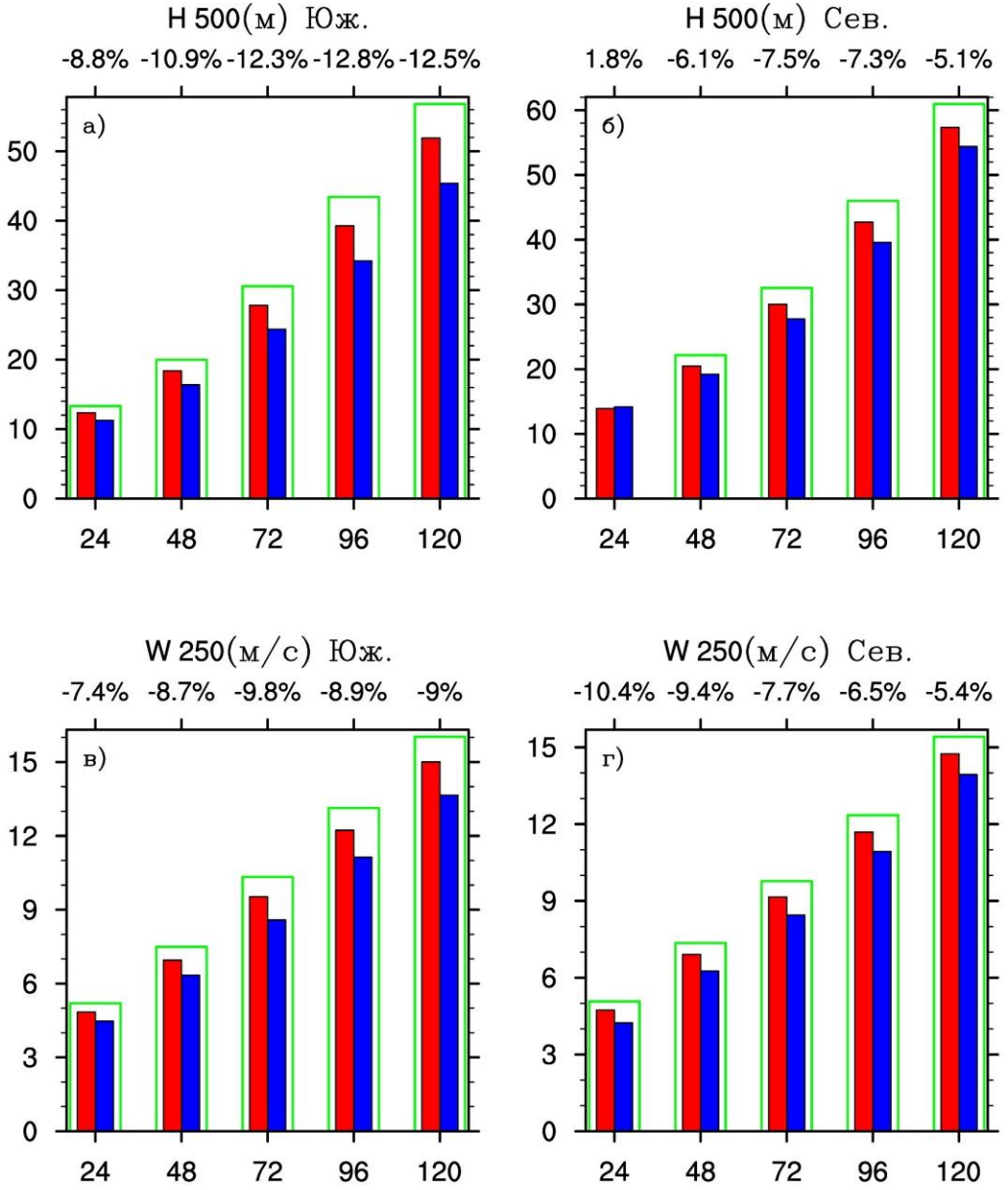




Reduction in H500 RMS eror: ~2,3 m (24hrs), 2,5m (72hrs), W250 RMS error: ~0,6 m/s (24hrs), 0.8 m/s (72 hrs). Lag between SL-AV and main group: ~1.2 m/s in W250 at 72 hrs, ~4,5 m in H500 at 72hrs

Improvements in RMS forecast error while using ECMWF upper-air initial data

Jan 2018.
Southern extratropics - left, Northern ones – right; top - H500 , bottom- W250



Reduction in 72 hrs forecast error: geopotential – 2-4 m, wind ~ 0.8 m/s.

Conclusions

- Achieved scalability allows to run future version with ~10km resolution operationally
- New version of SL-AV model with 100 vertical levels reproduces main characteristics of modern climate, including stratosphere oscillations.

- Improvements in model climate helped to reduce medium-range forecasts errors.

Thank you for attention!

http://nwplab.inm.ras.ru