Global multi-scale atmosphere model SL-AV

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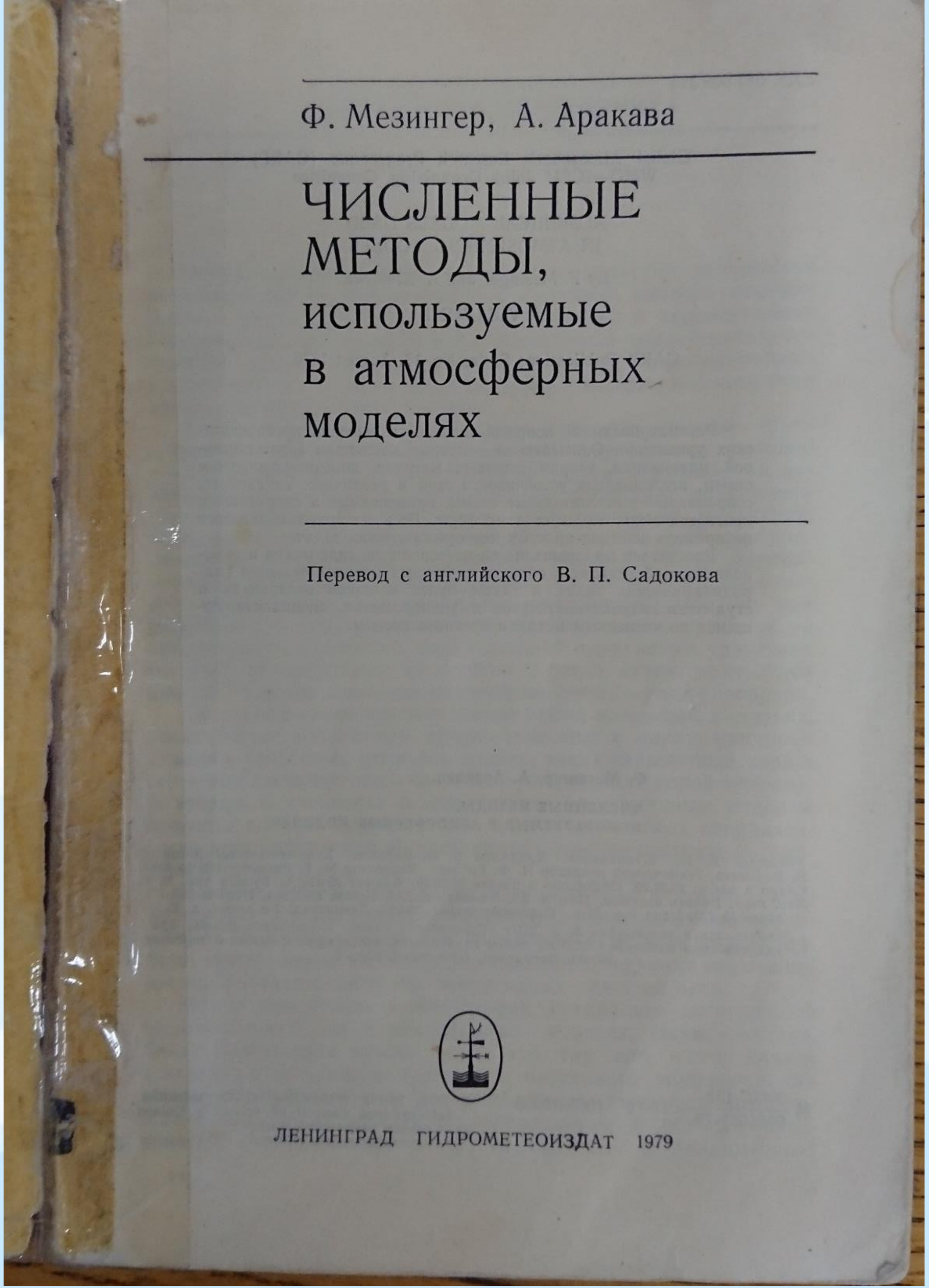
Russian translation of F.Mesinger and A.Arakawa 1976’ book (GARP publ.ser.), 1979



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), 4th 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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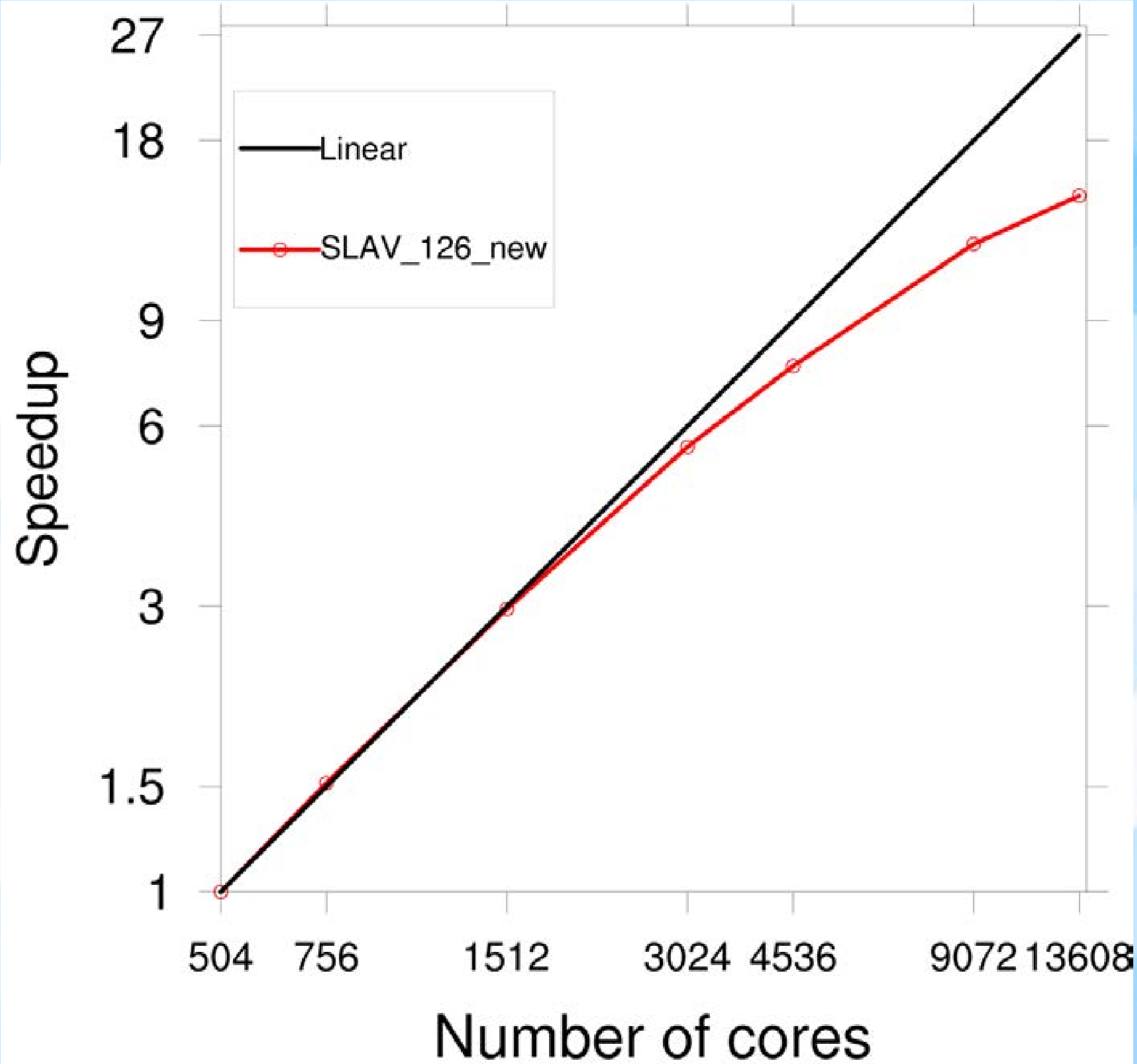
SL-AV global atmosphere model

- 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:

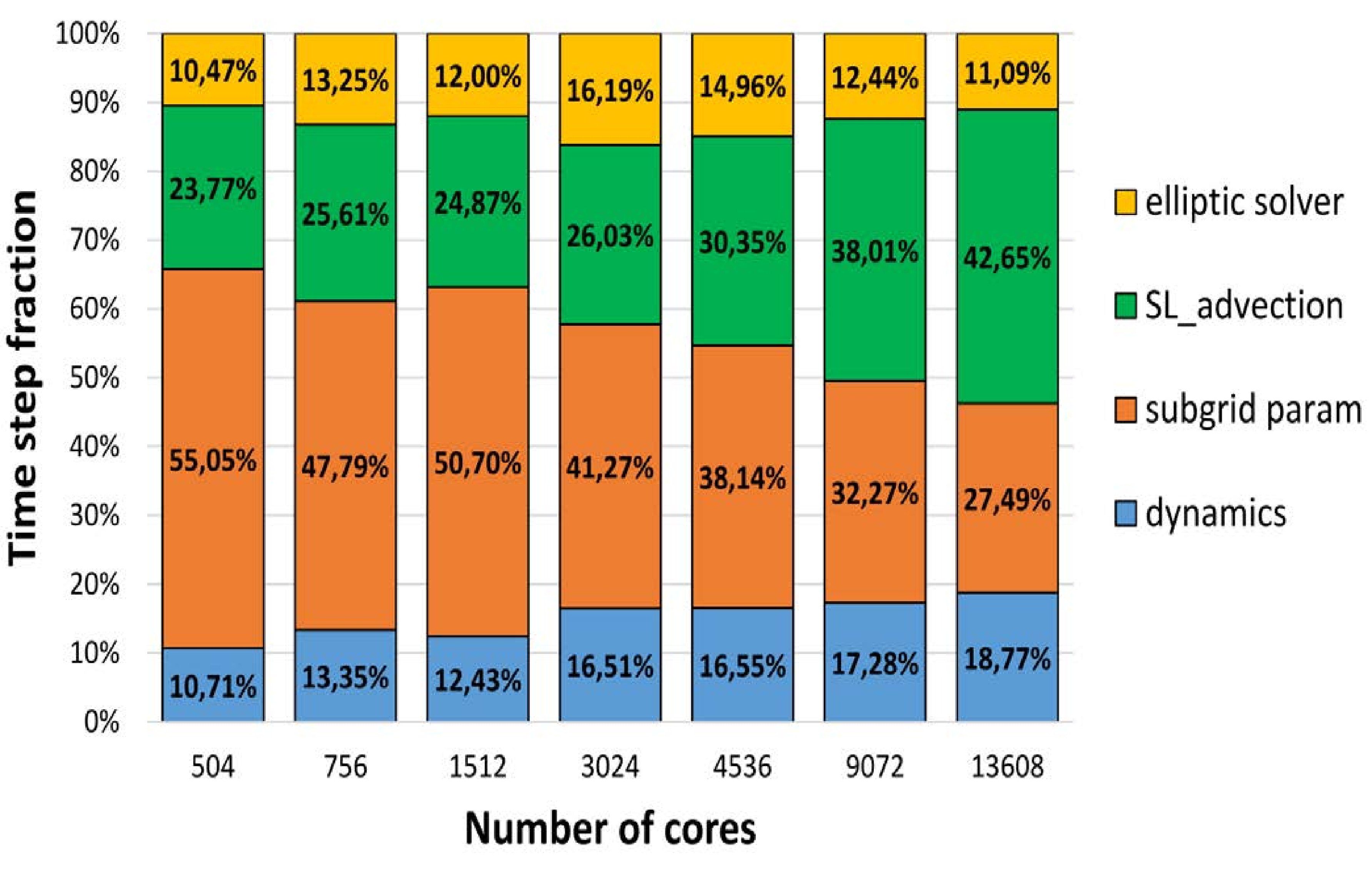
- Operational medium-range weather prediction up to 10 days; probabilistic seasonal forecast at Hydrometcentre of Russia.
- Weather prediction up to 3 days at Novosibirsk.
- 60 days weekly forecast (S2S Prediction project, WMO) – quite old SL-AV version ! Need of urgent update

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

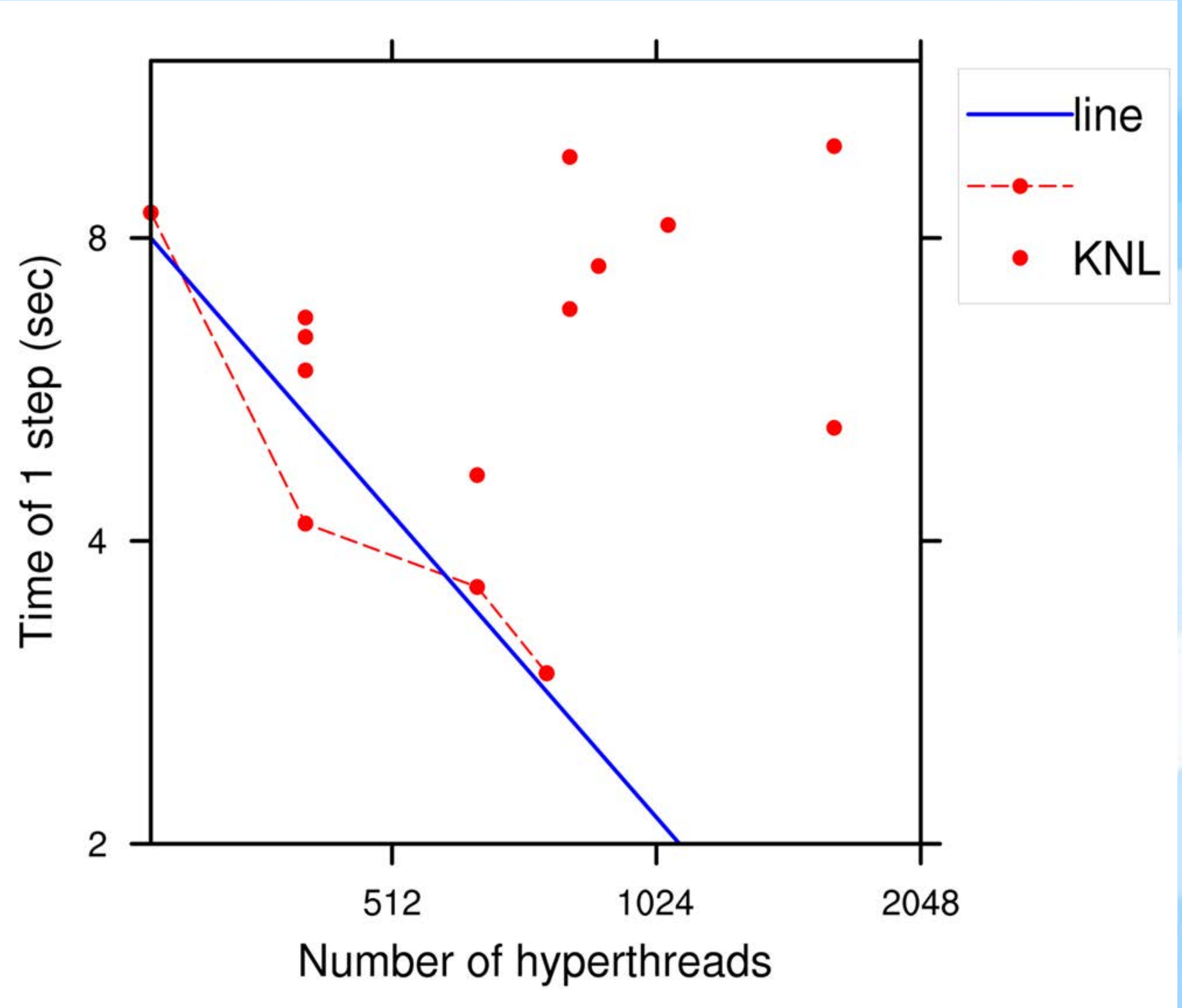


Horizontal grid of 3024x1513 points (~13 km). 126 vertical levels

Percentage of different dynamics part in elapsed time vs. processor number



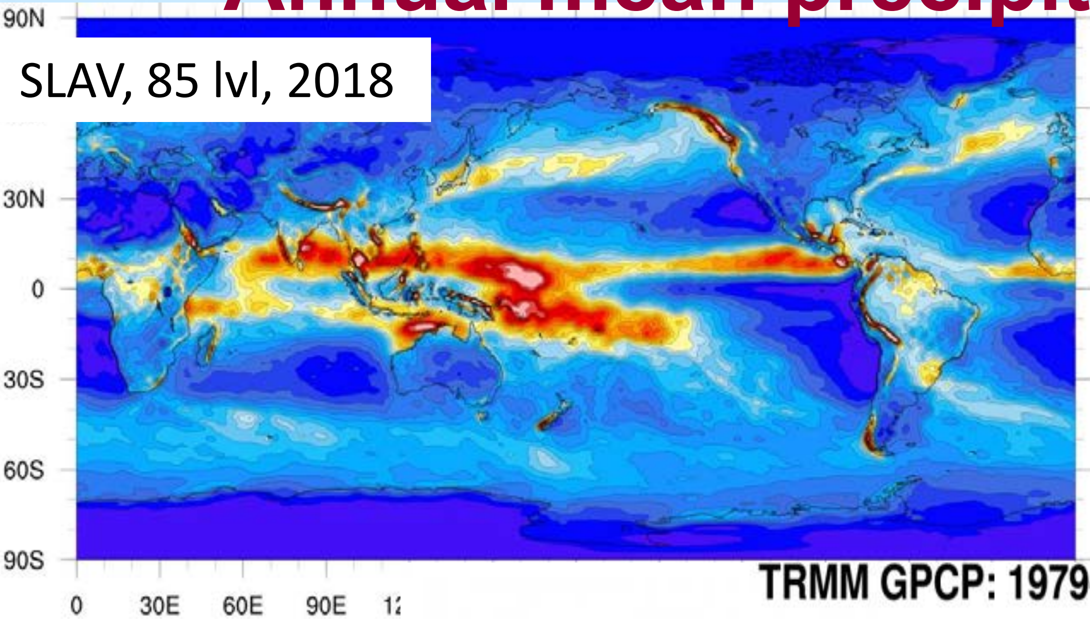
SL-AV code elapsed time at Intel Xeon7290 (KNL) w.r.t to 288 hypertheads

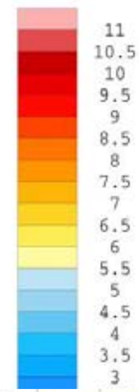


Horizontal grid of 1600x865 points (~22 km). 51 vertical levels

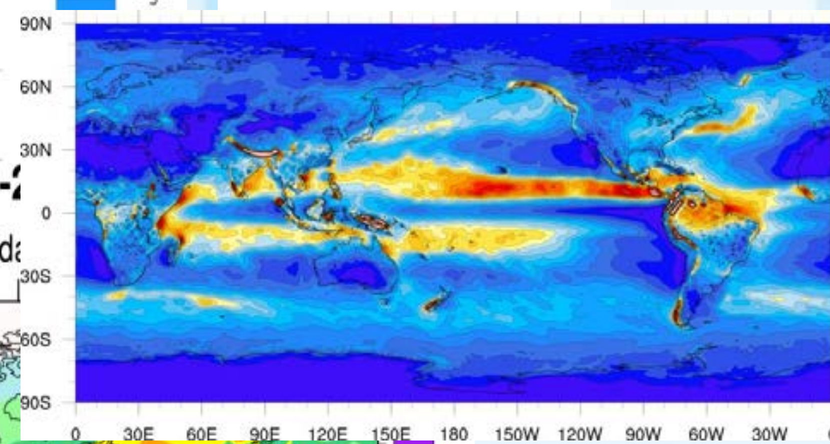
Annual mean precipitation (mm/day)

SLAV, 85 lvl, 2018





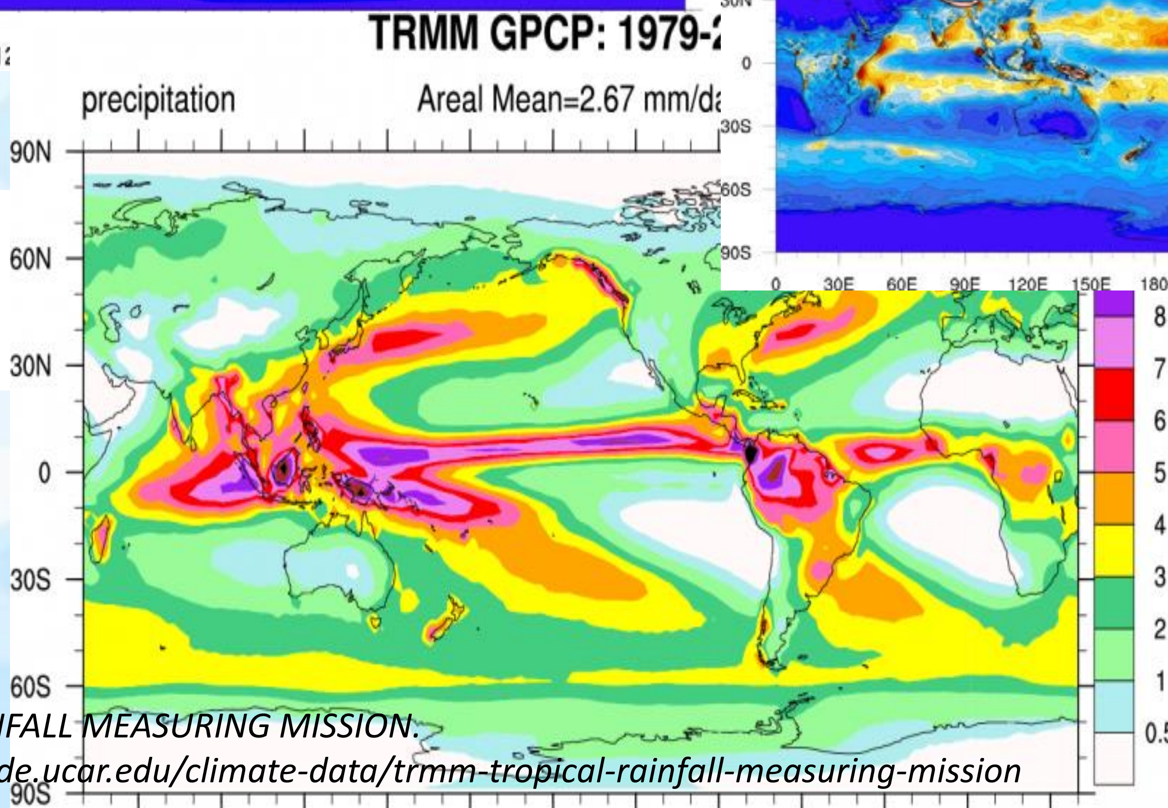
SLAV, 28 lvl, 2016



Obs GPCP

TRMM

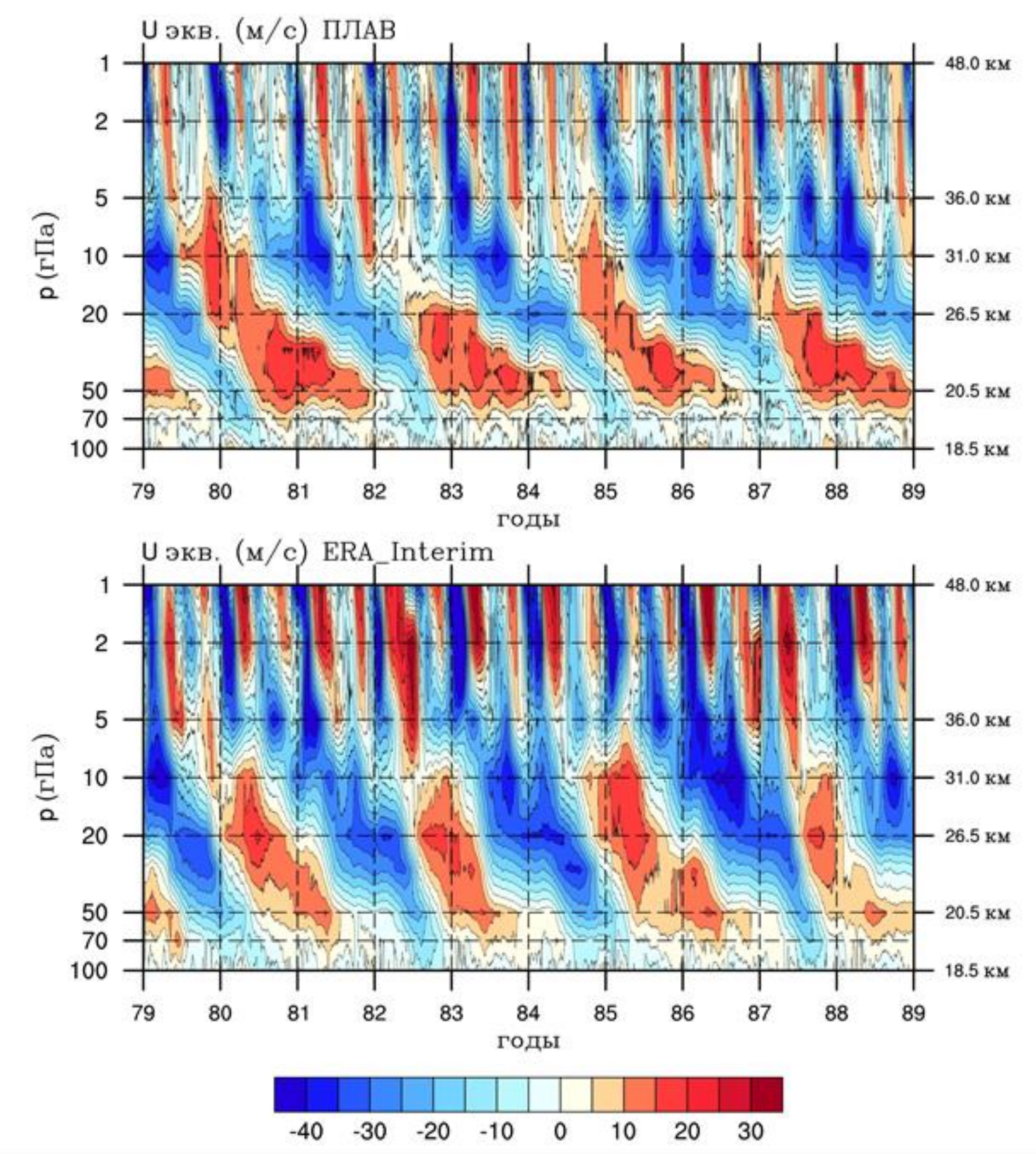
(1979-2010)



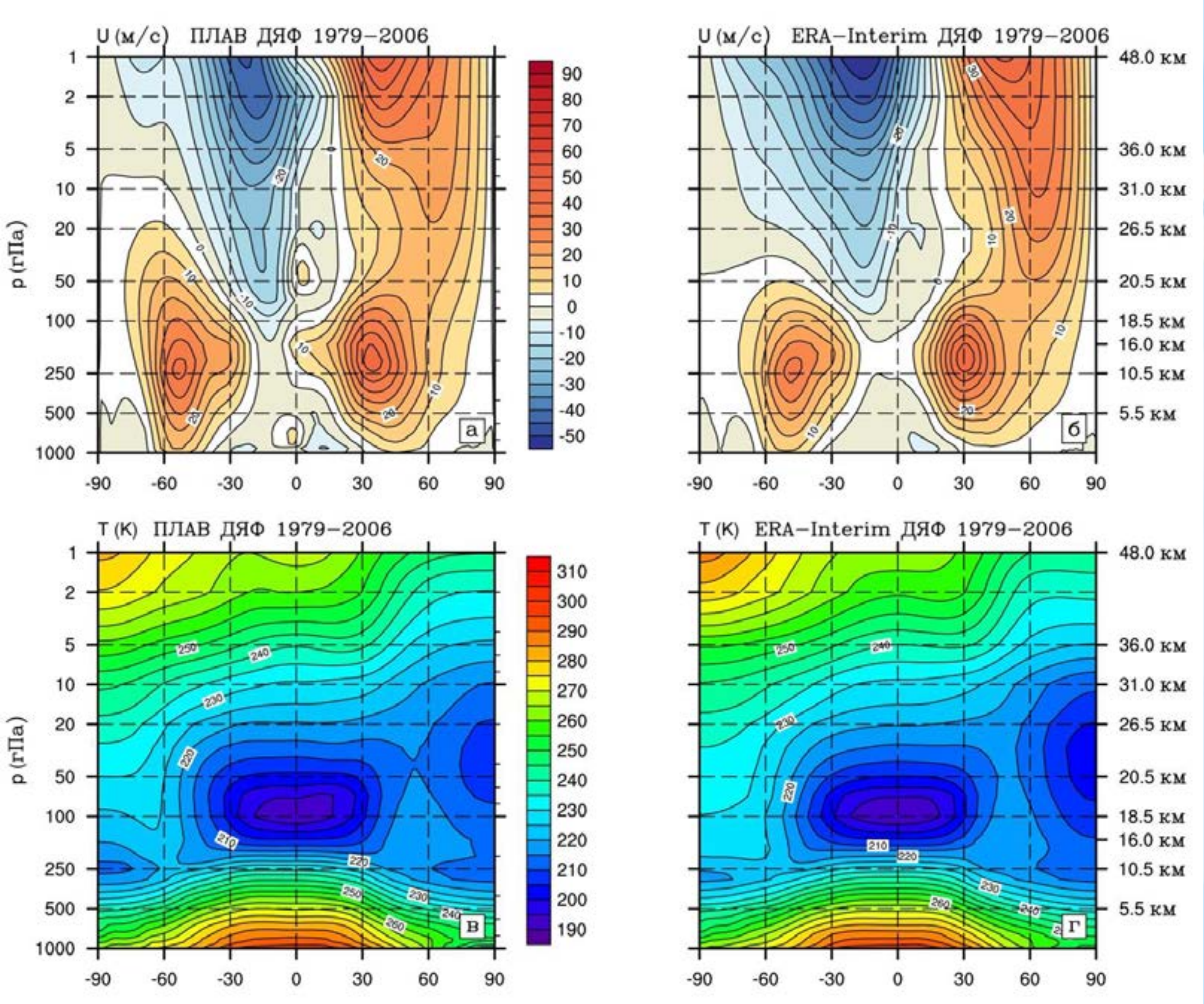
TRMM: TROPICAL RAINFALL MEASURING MISSION.

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)

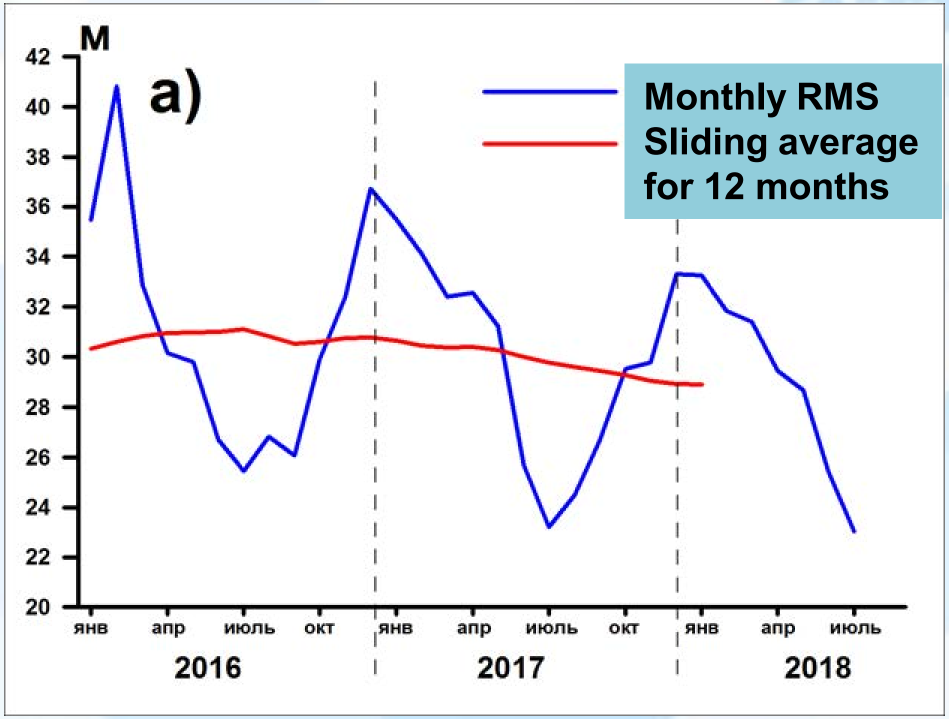


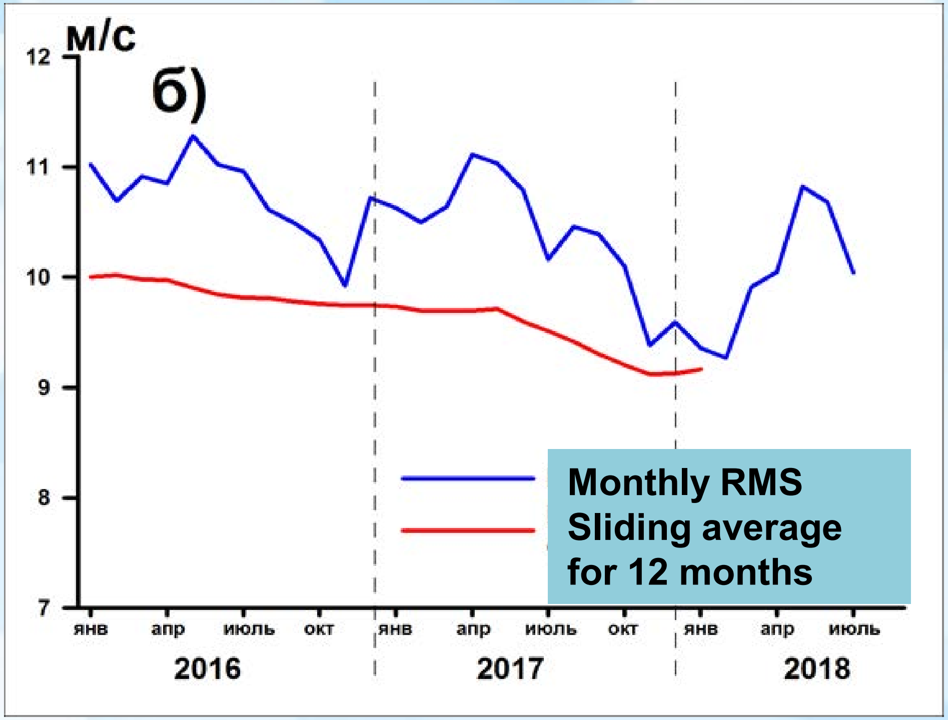
These improvements in model climate produced a reduction of operational medium range forecasts errors

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)

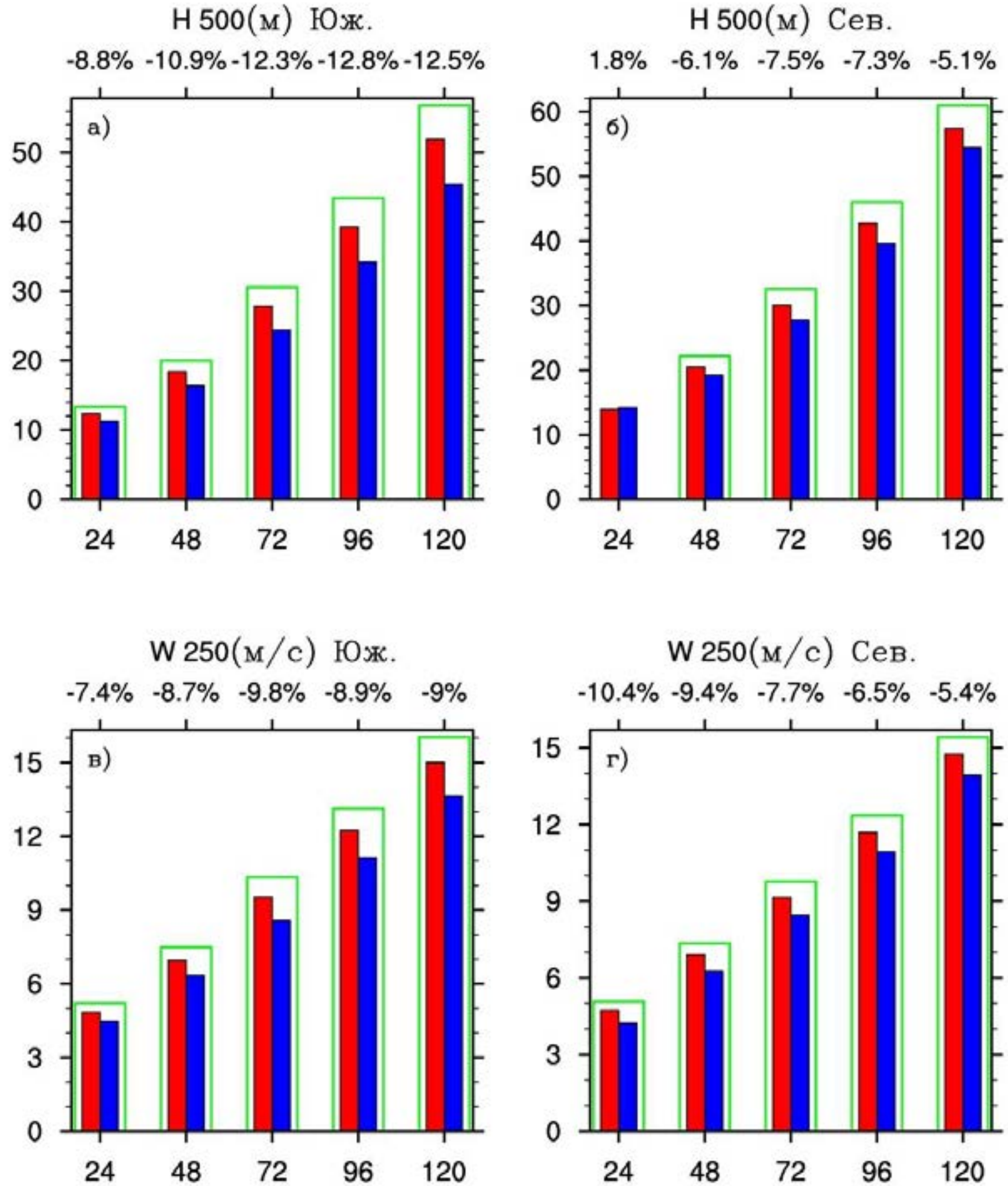




Reduction in H500 RMS eror: ~2,3 m (24hrs), 2,5m (72hrs), W250 RMS error: ~0,6 m/s (24hrs), 0.8 m/s (72 hrs). Lag between SL-AV and main group: ~1.2 m/s in W250 at 72 hrs, ~4,5 m in H500 at 72hrs

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

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



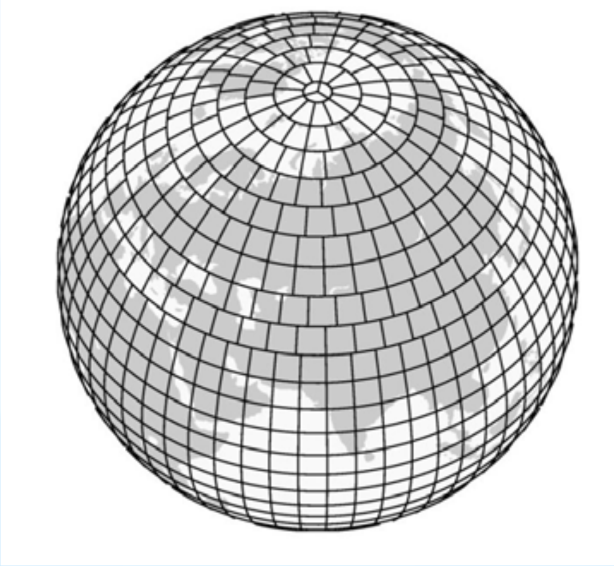
Reduction in 72 hrs forecast error: geopotential – 2-4 m, wind ~ 0.8 m/s.

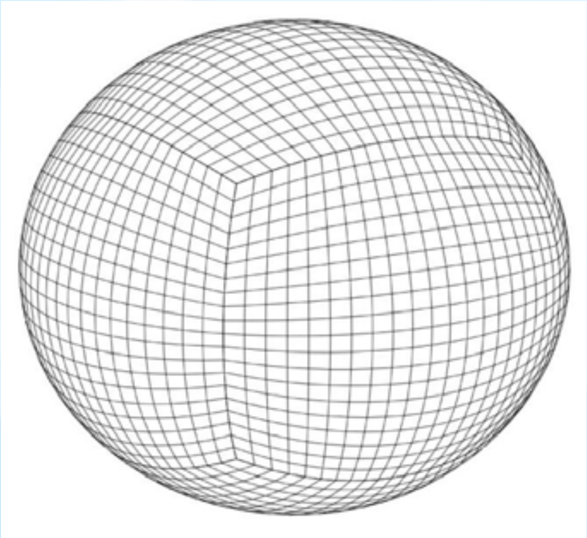
Future development of SL-AV dynamical core

- Target horizontal resolution of about 5km (we hope closer to 1 km).

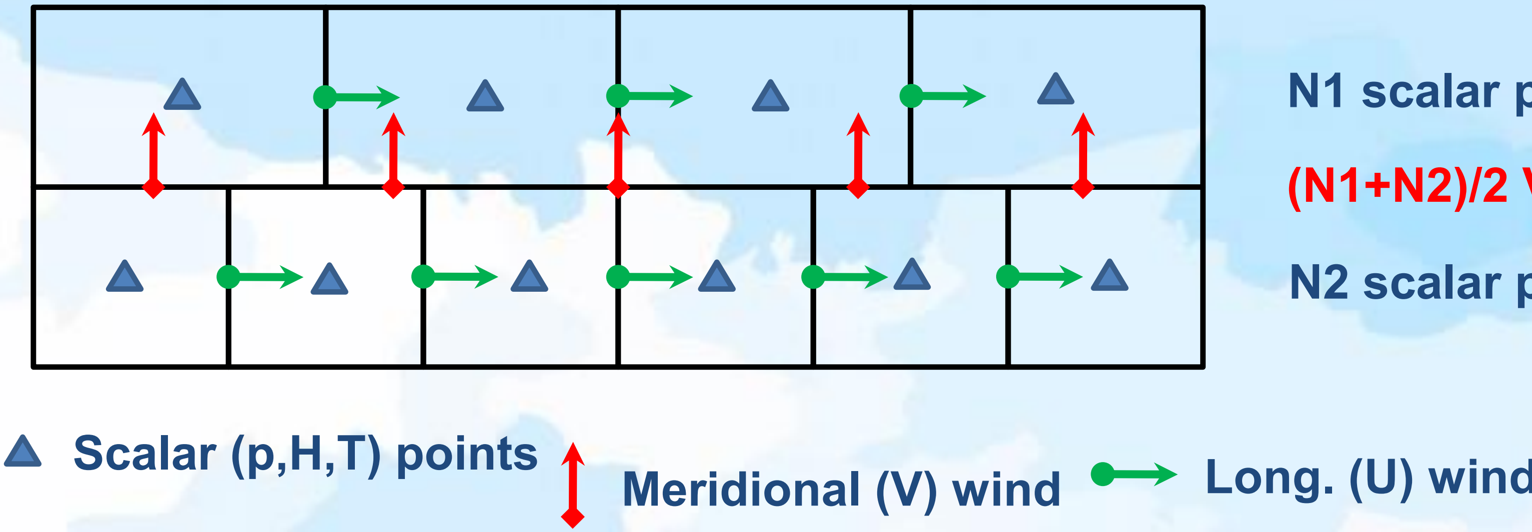
Basic techniques (with respect to our forecast of available computational power ~30000 cores):

- semi-Lagrangian , semi-implicit
- finite-difference / finite-volume
- spherical grid (reduced lat-lon / equiangular cubed-sphere)
- C-staggering (both grids!)





Reduced latitude longitude grid, C-staggered



Why (N1+N2)/2 V points?

Correct 2:1 ratio between (horizontal) vector and scalar degrees of freedom at least at global scale (this is not true for say icosahedral grid => inevitable unphysical modes)

Reduced grid vs equiangular cubed sphere

	Reduced	cubed	conclusion
Div& grad operators	**Purely 2D** (<= different N of points at different latitudes)	**Purely 2D** (<= non-orthogonal+staggered grid+Coriollis)	Almost equal
Departure point interp.	**Purely 2D**(<= different N of points at different lattitudes)	**1D x 1D** (<= rectangular grid structure)	Cubed sphere is cheaper
Parallel issues	**2D –decomposition possible**	**2D-decomposition (easy)**	Exchanges are more complicated at reduced grid
Other	**Pole singularity** (much-much weaker than in regular lat-lon)	Cube faces-edge problems => **grid imprinting**	**Neither grid is ideal :(**
Compatibility with assim, post.proc etc	**Almost ideal**	**Will cause a small revolution**	

What is more important for us? Accuracy? Speed? Scalability?

Conclusions

- 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.
- Achieved scalability allows to run future version with ~10km resolution operationally
- Current design of SL-AV dynamical core would not allow nonhydrostatic formulation – new generation is foreseen.

Thank you for attention!

http://nwplab.inm.ras.ru

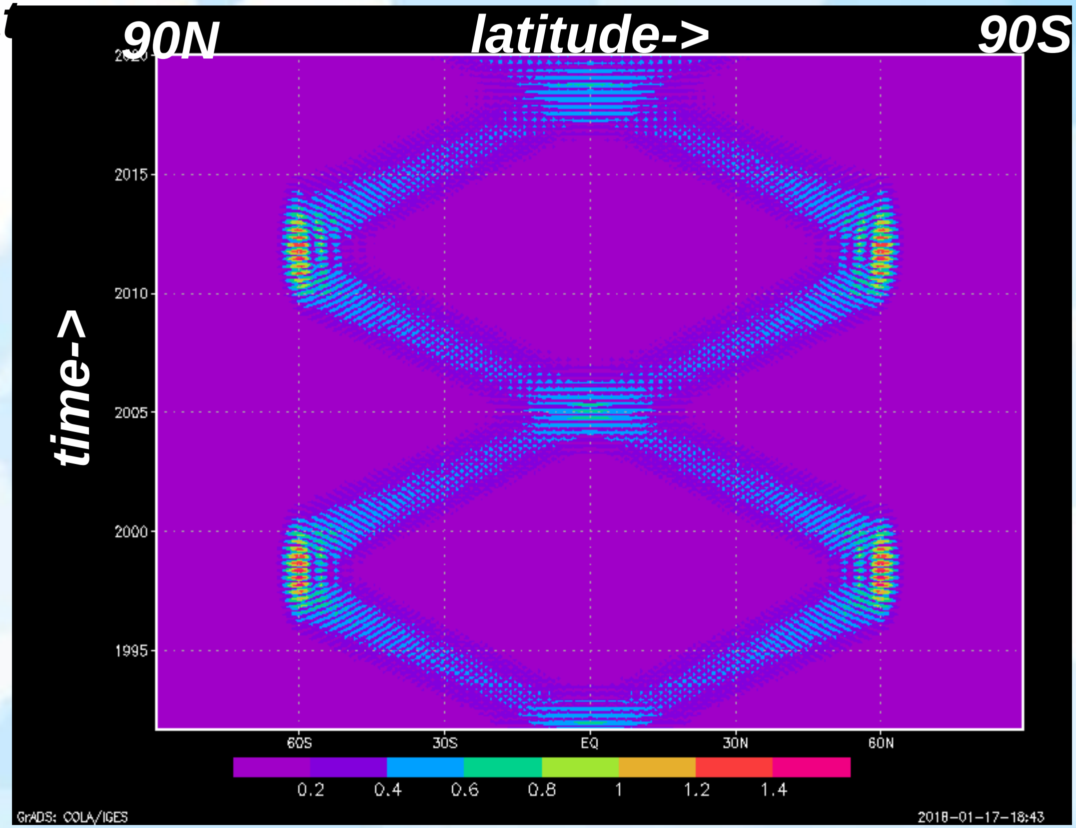
Shallow water linear gravity waves

Short zonal signal propagation to high latitudes

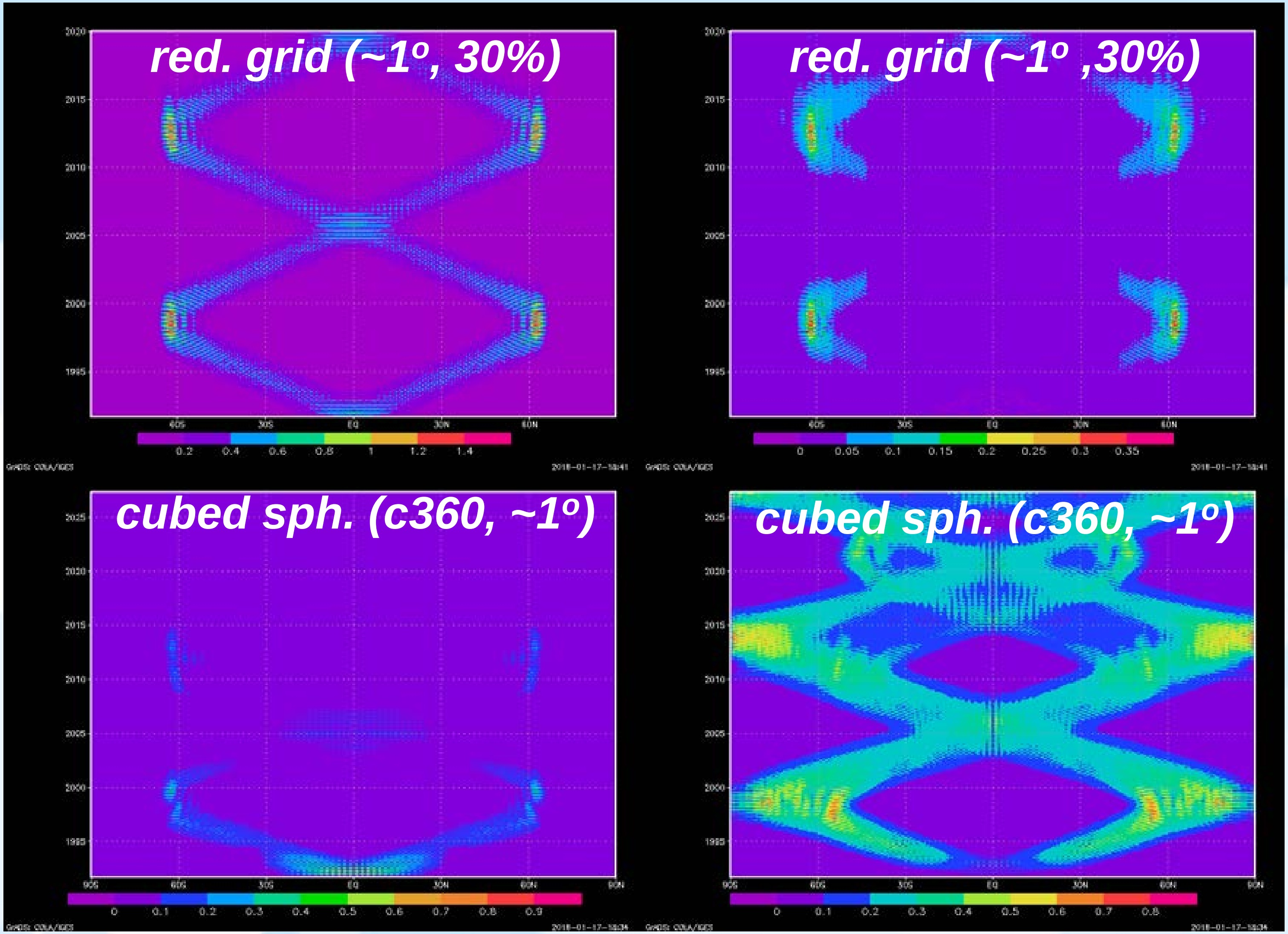
Initial disturbance: $f(\lambda,\varphi) = \exp\left(\left[\frac{-\varphi}{0.1\cdot\pi}\right]^2\right)\cdot\sin(l\varphi)\cdot\sin(k\lambda)$ ***l & k***

=> 4h scale

in lon and lat



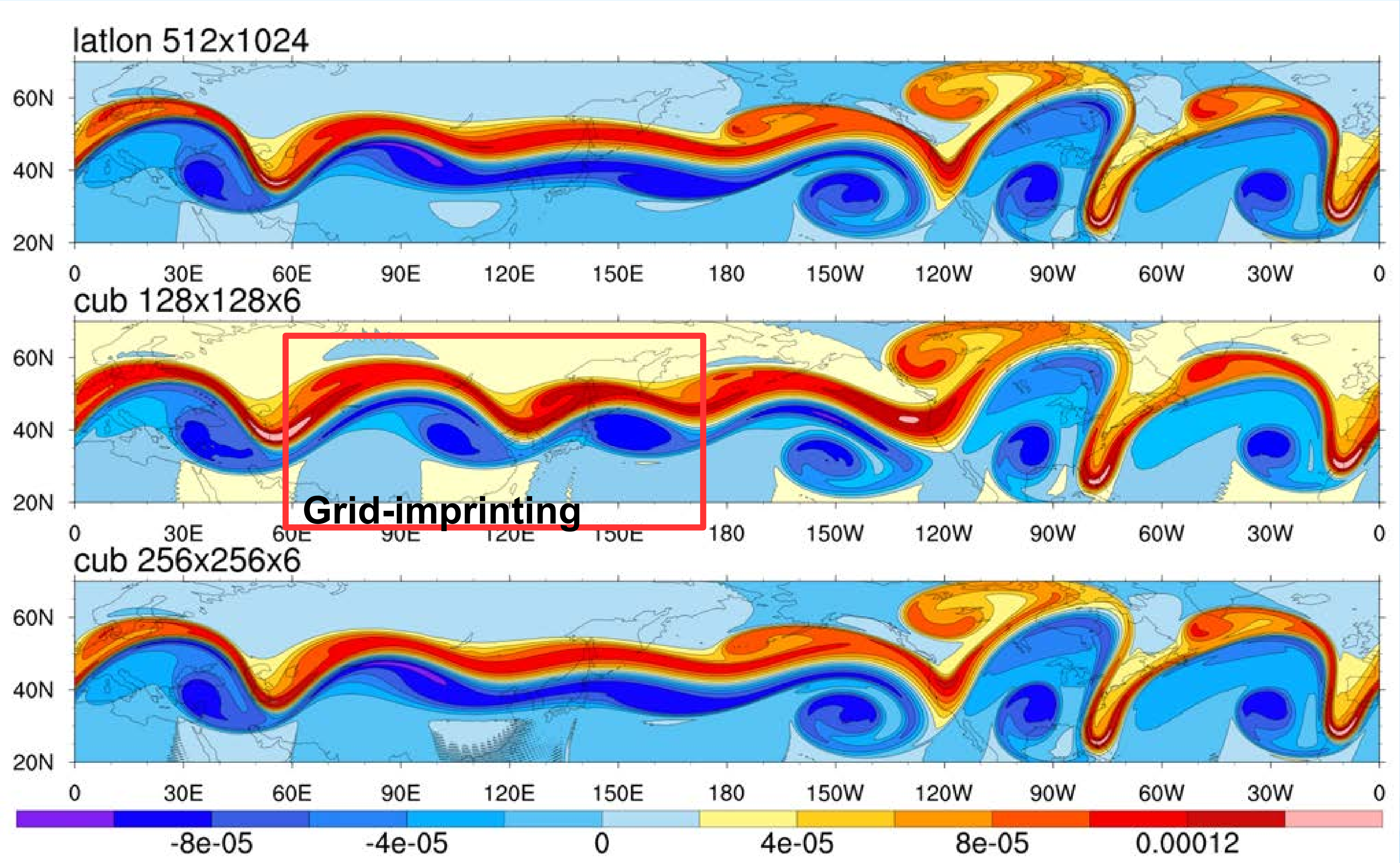
Regular grid solution (almost exact) , amplitude of initial zonal wave



Initial z.wave amp **spurious z.waves amp. (aliasing)**

Almost ideal solution at red.grid, much stronger decay & aliasing at cubed sphere of comparable resolution! (Both – C-grid, 2nd order FD)

Barotropic instability SWE test-case on cubed-sphere



Rel. vort at day 6. Grid imprinting reduces with grid refinement