Implementation of SL-AV global atmosphere model with 10km horizontal resolution

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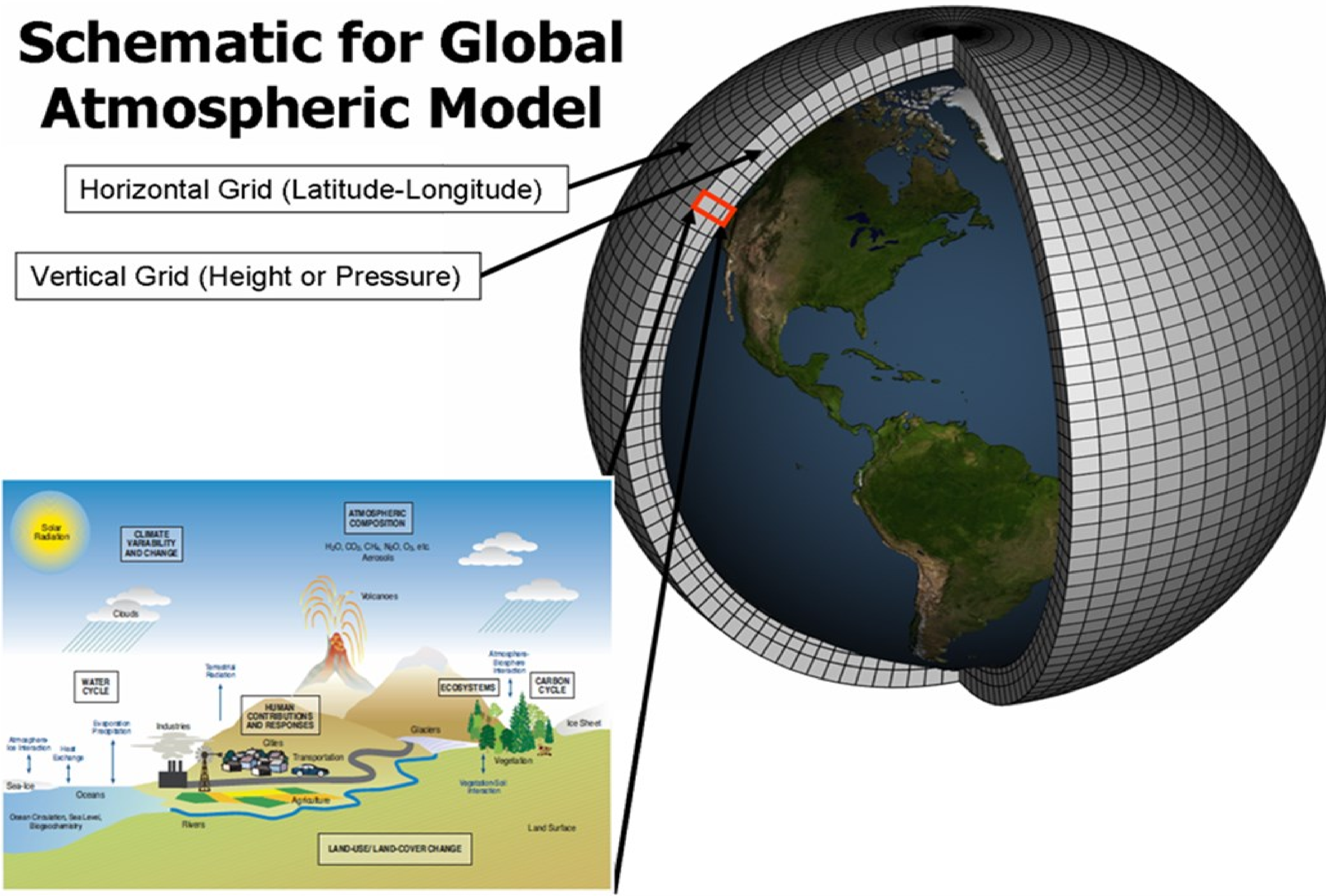
Russian Supercomputing days

Atmospheric model schematics



Global atmosphere model

- **Dynamical core:** solving 3D Reynolds-type equations (averaged Navier-Stokes equations) at the rotating sphere.

  - requires some degree of implicit time integration (can be a semi-implicit scheme or locally vertical solvers)

  - 25-45 % of total elapsed time.

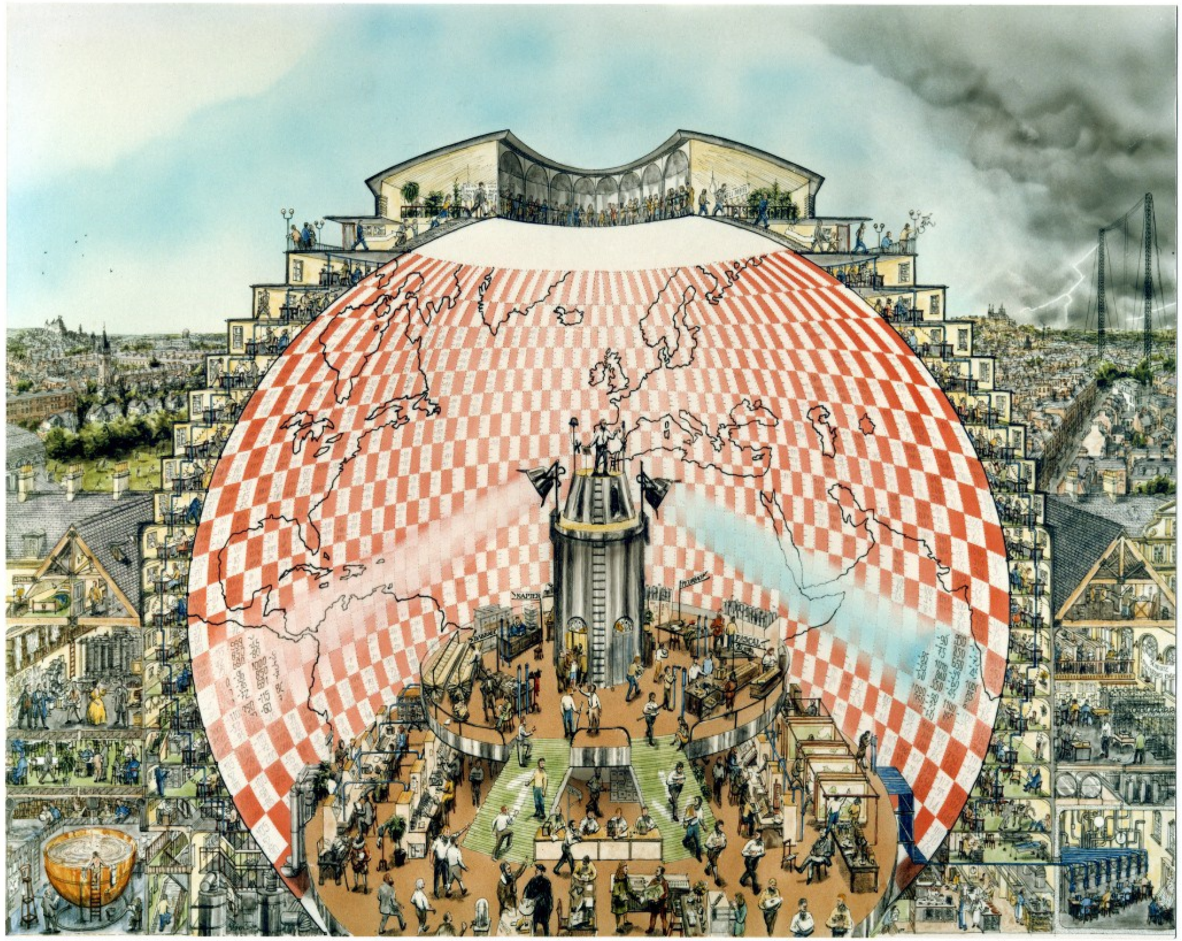
- **Right hand sides (parameterizations of subgrid scale processes)**:

  - usually locally 1D in vertical

  - the values at gridpoint (k,i,j) depend only on the values from (1:Kmax,i,j)

  - 55-75 % of total elapsed time

A view on global numerical weather prediction models



``Weather Forecasting Factory" by Stephen Conlin, 1986.
Based on the description in 'Weather Prediction by Numerical Process', by L.F. Richardson, 1922

http://mathsci.ucd.ie/~plynch/Publications/RFFF-WX-02-NoAbs.pdf Courtesy of P.Lynch

Current global NWP models

WGNE table

http://wgne.meteoinfo.ru/nwp-systems-wgne-table/wgne-table/

Horizontal resolution

~ 7-25 km

Vertical resolution

50-137 levels

Grid dimension ~10^9

Forecast Centre (Country)	2019	2020
ECMWF (Europe)	Coupled O-A 0.25 TCo1279 L137 (~9km)	Coupled O-A 0.25 TCo1279 L137 (~9km)
Met Office (UK)	10km L70 7days	10km L70 7days
Météo France (France)	~T_L1198c2.2 L105 (7km on W Europe to 36km)	~T_L1798c2.2 L105 (from 5km on W Europe to 24km)
DWD (Germany)	13 km L90 (6.5 km L60 for Europe)	13 km L120 (6.5 km L80 for N-Atlantic, Europe)
HMC (Russia)	0.225°x(0.17-0.24)° L51	0.1°x0.08° L104
NCEP (USA)	C768 L64 (13 km)	C768 L64 (13 km)
Navy/FNMOC/NRL (USA)	T425L60	T681L60
CMC (Canada)	Yin-Yang (0.14°x0.14°) L84 coupled atm-ocean-ice	Yin-Yang (0.14°x0.14°) L84 coupled atm-ocean-ice
CPTEC/INPE (Brazil)	20km L64	TBD
JMA (Japan)	TL959 L100	TL959L100
CMA (China)	GRAPES(0.25, L90)	GRAPES(0.15, L90)
KMA (Korea)	12km L120	
NCMRWF (India)	10kmL70	
BoM (Australia)	12 km L120	12 km L120

Future global weather prediction models

- Resolution ~3-5 km (~10^{10} degrees of freedom)
- Fully compressible equations
- Scalable at O(10^5 processor cores)
- Include atmospheric composition models

(Air mass conservation)

Russian operational SLAV model

Federal Service for Hydrometeorology
and Environmental Monitoring

HYDROMETEOROLOGICAL
CENTRE OF RUSSIA

10-days operational medium range forecasts

0.225° in lon, 0.16°-0.24° in lat, 51 levels.

LETKF-based ensemble prediction system

0.9° in lon, 0.72° in lat, 96 levels.

Subseasonal and seasonal probabilistic forecast

Subseasonal-to-Seasonal
S2S
Prediction Project

(WMO S2S Prediction project)
1.4°x1.1°L28 currently,
0.9°x0.72°L96, by the end of this year.

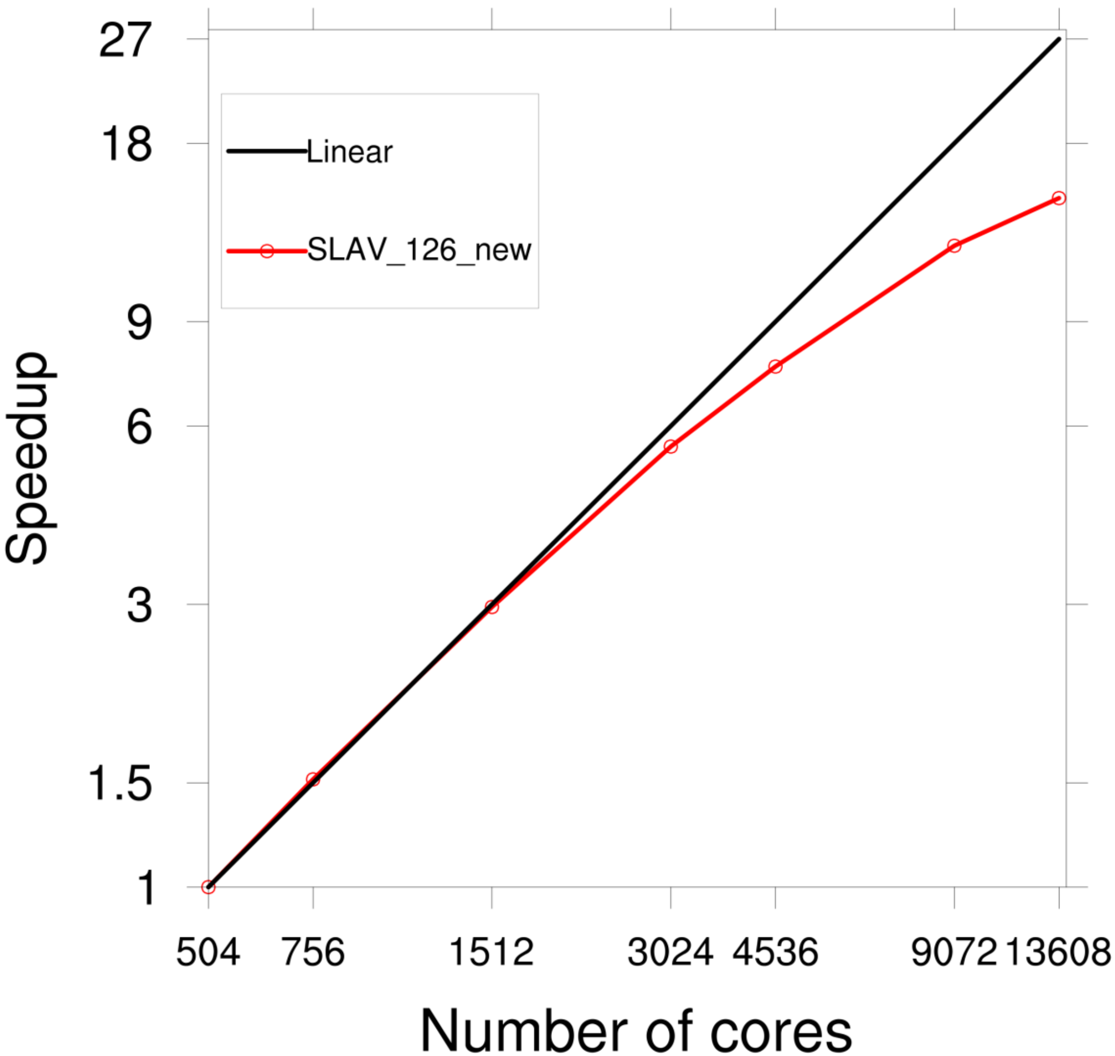
SL-AV global atmosphere mode

SL-AV: Semi-Lagrangian, based on Absolute Vorticity equation

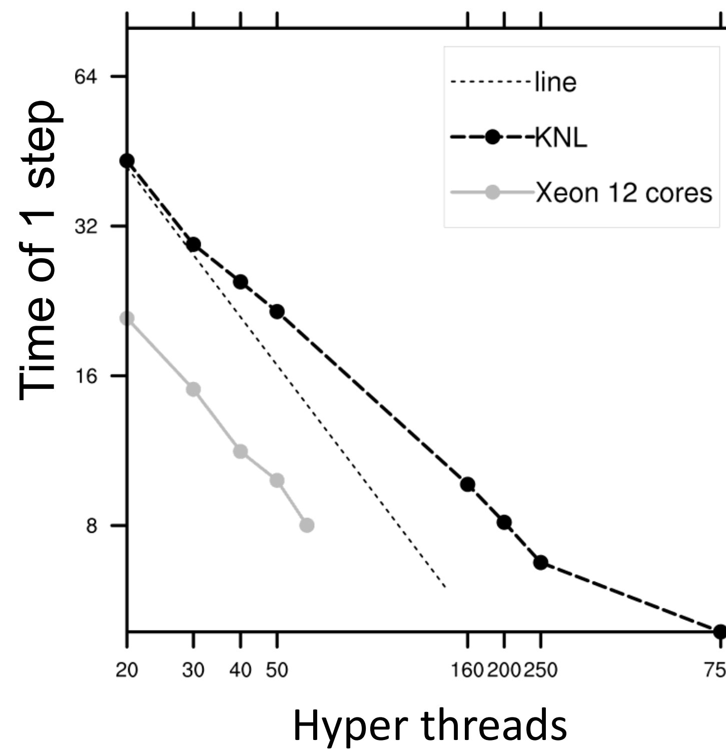
- Finite-difference semi-implicit semi-Lagrangian dynamical core (Tolstykh et al, GMD 2017). Vorticity-divergence formulation, unstaggered grid (Z grid), 4th order finite differences. Possibility to use variable resolution in latitude.
- Many parameterizations algorithms for subgrid-scale processes developed 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).

SLAV strong scaling at Cray XC40 x86 Broadwell

3024x1513x126 grid, max. 6 OpenMP threads.
53% efficiency at 13608 cores, 64 % at 9072 cores



SLAV20 **Intel Xeon Phi2** strong scaling (black line) in comparison with RHMC classic cluster (grey line).



Motivation

- New version SLAV10 with ~10 km horizontal resolution (3600x1946x104 grid)
- Operational resources are limited to ~4000 processor cores
- Need to compute forecast for 24 hours in less than 20 min
- 42 min wall-clock time per forecast day before optimizations
- Some centers gain a lot from switching from double to single precision (ECMWF, NCEP) Váňa, F., Düben,P., Lang,S., Palmer,T., Leutbecher,M., Salmond,D., Carver,G.: Single Precision in Weather Forecasting Models: An Evaluation with the IFS. Mon. Weather. Rev.**145**, 495–502 (2017).

Semi-Lagrangian advection

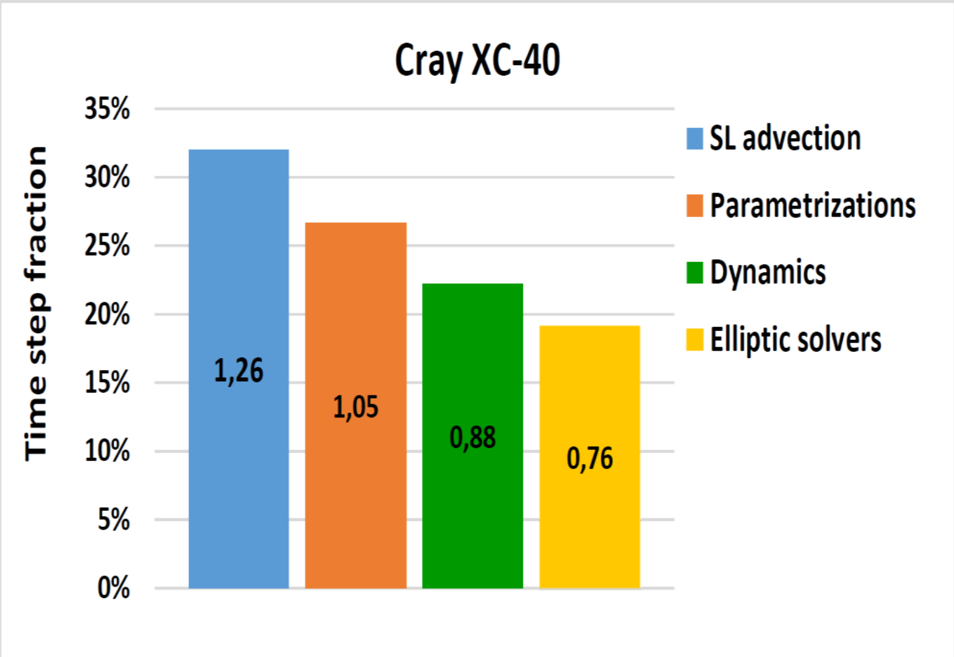
- Allows large times steps (typically, 5-10 CFL)
- Due to this fact, large data communication pattern.
- Some ways around (communications on demand, computations at the data side)

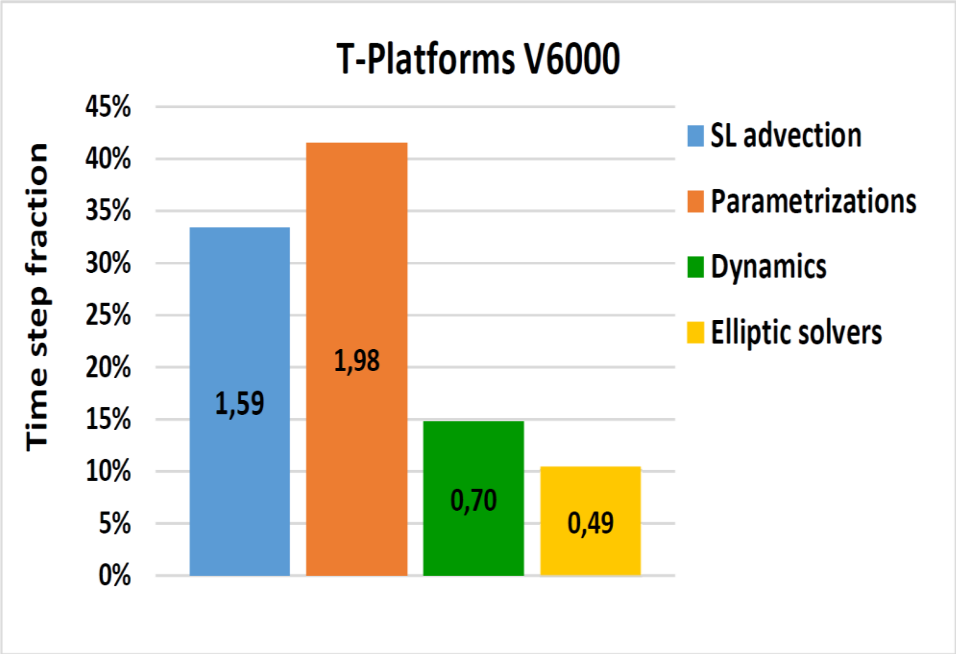
Profiling of initial version

Cray XC40:108 36-cores nodes, Broadwell, 6 MPI x 6 OpenMP, Aries

T-Platforms V6000: 97 40-cores nodes, Skylake, 8 MPI x 5 OpenMP, Infiniband HDR.

Percentage of time used in different parts of SL-AV model code while using 3888 cores of Cray XC40 (left) and 3880 cores of T-Platforms V6000 (right) systems before optimizations. Number inside the column denotes the wall-clock time of respective code part (in seconds).





Approaches to code optimization

- Switching most time-consuming part to single precision (semi-Lagrangian advection)
- Optimizing the vector length in the block computing RHS of the equations (parameterizations of subgrid scale processes)
- Reduction of data amount in transpositions by making them single precision instead of double precision

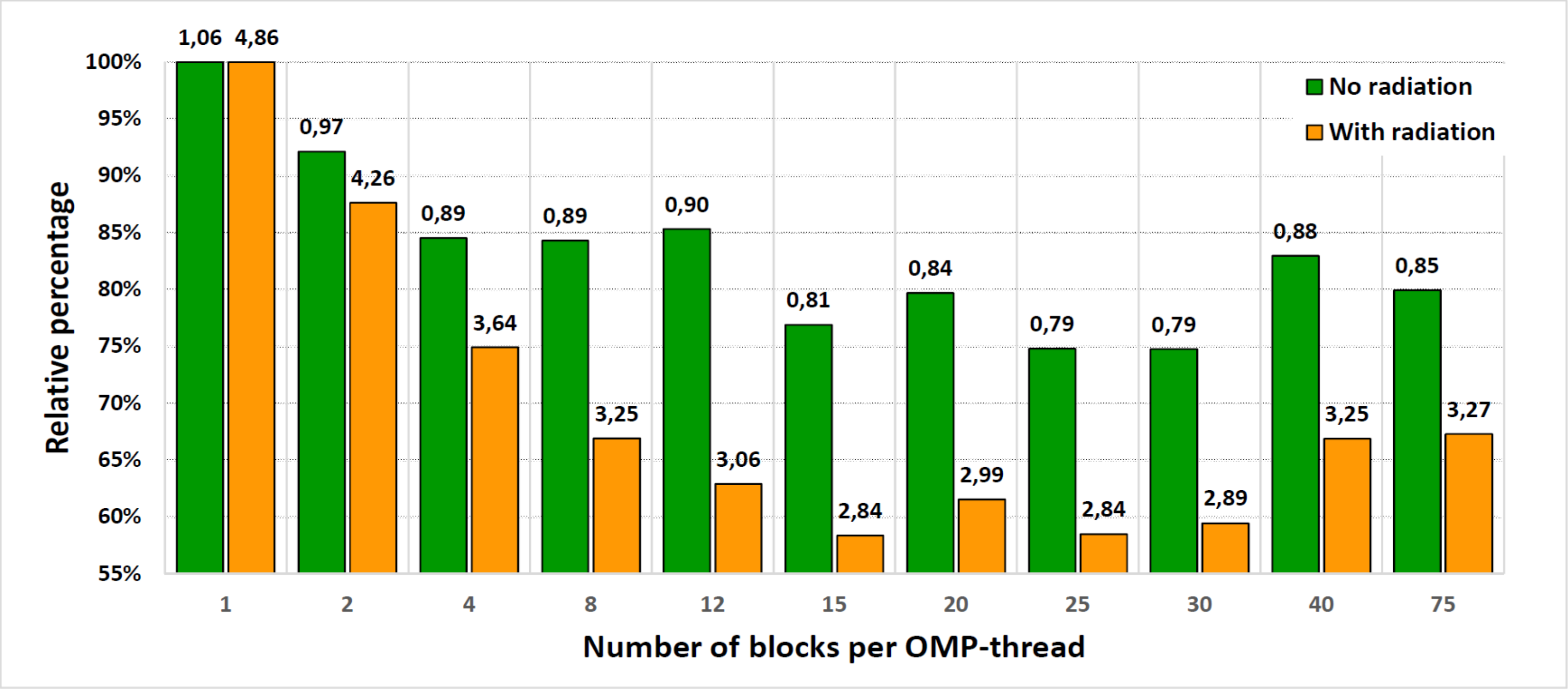
Optimization of vector length in RHS computations

- (i,k,j) index ordering in most part of RHS code where i – longitude, k – vertical index, j – latitude. Typical local arrays are dimensioned with (Imax,Kmax)
- i is the variable of OpenMP parallelization

(range 1:3600) – the vector length is $3600/N_{openmp}$

- The code already uses thread-local arrays
- Splitting this dimension into smaller parts improves memory access

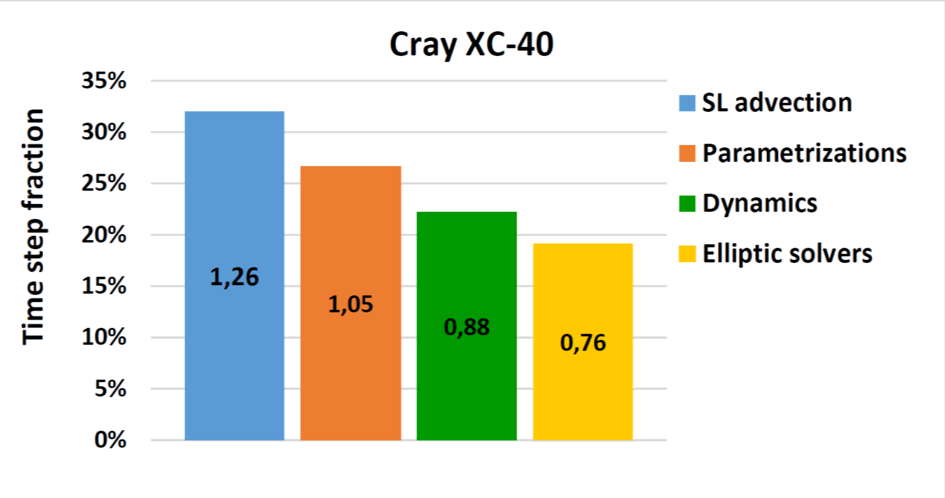
Results of vector length optimizations in RHS calculations (parameterizations of subgrid scale processes)

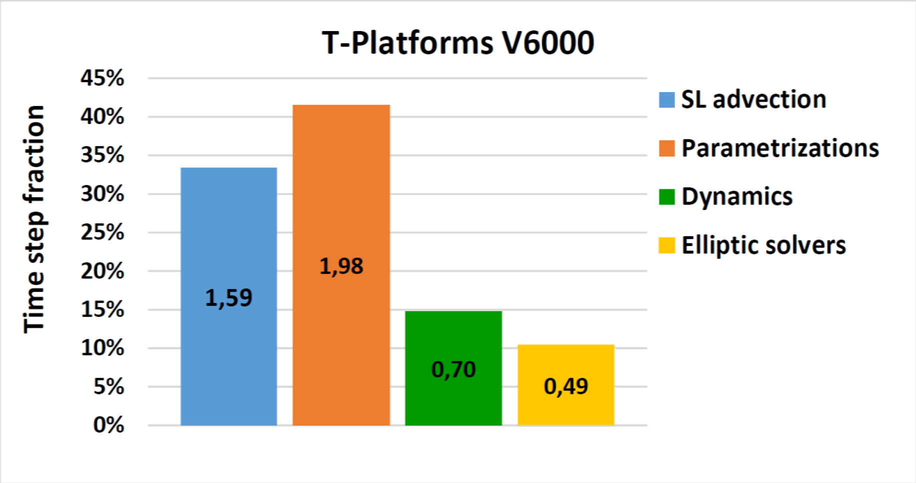


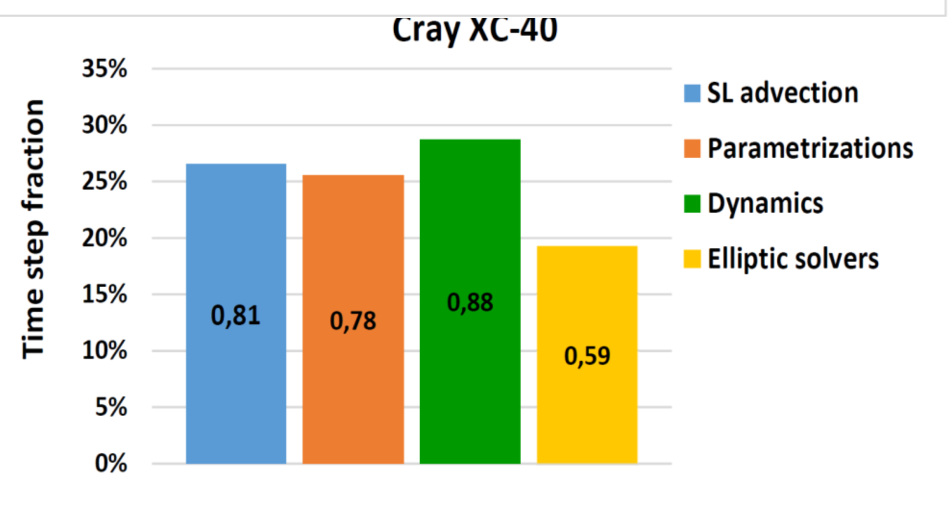
Cray XC40. The numbers above the bars show the wall-clock time in seconds.

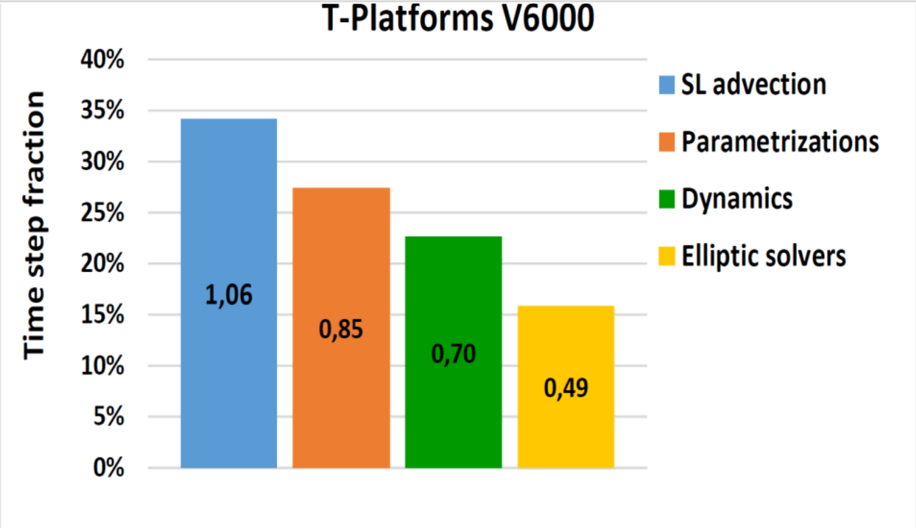
Percentage of time used in different parts of SL-AV model code while using 3888 cores at Cray XC40 (left) and 3880 cores at T-Platforms V6000 (right); before (top) and after (bottom) optimizations.

Number inside the column denotes the wall-clock time of respective code part (in seconds).









Conclusions

- The elapsed time of 24-hour weather forecast with SLAV10 model is reduced by 22.5 % at Cray XC40 system, from 42 min to 32.5 min.
- Still a way to go. Future work:

- further implementations of single precision
- Increasing the time step

Thank you for attention!