Further **Development of the Parallel Program Complex of SL-AV Atmosphere Model** Mikhail Tolstykh, Rostislav Fadeev, Gordey Goyman, Vladimir Shashkin



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What is the atmosphere model



Grid-point description of large-scale atmosphere circulation (including small constituents transport) – usually ~30-40 % of elapsed time.

What is the atmosphere model



The local processes (precipitation, evaporation, mixing) are simulated at every grid box. Usually 60-70 % of elapsed time. Easy to parallelize (only vertical data dependence)

Global models for medium-range weather forecast

- There are 15 global atmosphere models in the world. Only 10 of them are original (*European centre for medium-range* weather forecasts, USA, UK, France, Germany, Canada, Japan, China (since 2015))
- NCEP (USA) model is used in India, Brasil; UK MetOffice model is used in Australia and South Corea
- Typical number of grid points: 10⁹ (9-25 km in horizontal, 50-100 vertical levels).
- Typical code size: 10⁵-10⁶ lines.

Global semi-Lagrangian atmosphere model SL-AV

(Semi-Lagrangian model based on Absolute Vorticity equation)



- Semi-implicit semi-Lagrangian dynamical core of own development. Distinct features – vorticity-divergence formulation, unstaggered Z-grid, 4th order finite-differences (Tolstykh, Shashkin, Fadeev, Goyman, Geosci. Mod. Devel. 2017).
- Most parameterizations algorithms developed by ALADIN/ALARO consortium, with some modifications
- SW and LW radiation CLIRAD SW and RRTMG LW (freeware)
- Multilayer soil model, INM RAS and SRCC MSU

SL-AV versions

Operational for medium-range and long-range weather forecasts at Hydrometcentre of Russia.

Forecast type	Forecast lead time	2016	Next version (2018-2019)
Deterministic medium- range	2-7 days	1600x866x51	~4000x200x100
Long-range (subseasonal, seasonal)	0.5-6 months	256x161x28	640x401x80
Interannual prediction, climate change modelling	Years, decades	400x251x28	400x251x80

Качество прогноза погоды на основе ПЛАВ улучшается с развитием модели

RMSE, H-500, Europe

RMSE, W-250, Europe



RMS error of MSLP 72h forecasts 20-90 N (2015-2017) http://apps.ecmwf.int/wmolcdnv/

Step: 72 RMSEF/msl/n.hem/analysis



SL-AV parallel acceleration w.r.t. 504 cores at traditional x86 Broadwell system



Implementation of the multigrid solver (1)

The use of semi-implicit time stepping and Z-grid leads to the Helmholtz and velocity-reconstruction problems at each vertical level:

$$(K^2 - \Delta)\psi = \mathbf{R} \qquad \begin{cases} \mathbf{k} \cdot \mathbf{V} \times \mathbf{V} = \omega \\ \nabla \cdot \mathbf{V} = D \end{cases}$$

- At the moment, FFT is used in the SLAV model to approximate longitudinal part of Laplace operator and 4-th order compact finite differences(CFD) for the latitudinal part
- Block Thomas algorithm is used to inverse resulting matrix

Usage of FFT and Block Thomas algorithm is a model bottleneck in parallel implementation

Implementation of the multigrid solver (2)

- FFT and compact finite-differences replaced with local second order approximations
- V-cycle geometric multigrid as a base algorithm
 - Prolongation bilinear interpolation
 - Restriction conjugated to the prolongation
 - Smoother red-black Gauss-Seidel
 - Coarse grid generation conditional semi-coarsening (to deal with grid anisotropy)

Solver scaling

MVS10P cluster (Joint Supercomputer Center) with Intel Xeon E5-2690



Forecast accuracy with new parallel solver

Root-mean squared geopotential errors averaged over 31 forecasts and Nortern extratropics for the standard SL-AV version (**red**) and the SL-AV model with multigrid solvers

(**blue**).



Series of 31 numerical weather 72-hour forecasts. Initial data of each day of January 2014 at 12 hours UTC. Model version with 0.9x0.72 degrees resolution

Interannual and decadal prediction

- One of 10 WMO grand challenges
- CMIP6 subproject
- Using the signal from boundary conditions and forcing (deep ocean, small gas constituents)
- So far, insufficient quality
- Ensemble approach is used to improve signal to noise ratio (~10-40 forecasts from slightly perturbed initial data).
- Typical resolution of the atmospheric model 0.5 degrees, 50-100 vertical levels

Where does a decadal prediction fit? (G.Boer)



Decadal prediction:

- annual, multi-annual, up to a decade
- initialized forecasts of both forced and internally generated components of variability

Testing SL-AV medium-resolution code (640x401x50) at 3-processor KNL 7250 system



1 KNL processor is equivalent to 5 Xeon2697v1 8core processors

High sensitivity to the combination of MPI-OpenMP Testing SL-AV with operational mediumrange forecast resolution at the new KNL 7290 system at JSCC



1600x866x51 grid 10 KNL processors are slightly faster than 36 Xeon E2697v1 8-core procs

Best results are for 4 MPI x 16 OMP at each processor

Conclusions

- Multigrid solver scales well for considered problem.
- Intel Xeon Phi (KNL) systems are well suited for long-range forecasts and climate change simulations with the SL-AV model (medium-resolution versions).
- Necessity for fine tuning MPI/OpenMP combination at Intel XeonPhi

Thank you for attention!

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Developers team





Also many students (MIPT, MSU, MEI, MGTU)

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What is ensemble forecast?

The atmosphere is unstable !

 Control forecast
20-60 forecasts starting from specially perturbed initial conditions



Global semi-Lagrangian atmosphere model SL-AV

http://nwplab.inm.ras.ru



Operational for medium-range and long-range weather forecasts at Hydrometcentre of Russia. Medium-range forecasts: (0.16-0.24)° in latitude, 0.225° in longitude, 51 levels (1600x866x51 grid).

New seasonal forecasts version: 0.9°x0.72° lon-lat, 28 or 80 levels (400x251x28÷80).

Model developers :



Also many students (MIPT, MSU, MEI, MGTU)