Improving SL-AV Global Atmosphere Model Computational Efficiency with I/O and Algorithmic Optimizations

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Russian Supercomputing days
Анализ неопределенности
Вероятностный прогноз

Т = Истина
Начальное состояние

Анализ неопределенности
Вероятностный прогноз

Forecast Time
Atmospheric predictability
Atmospheric model schematics

Schematic for Global Atmospheric Model

- Horizontal Grid (Latitude-Longitude)
- Vertical Grid (Height or Pressure)
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 \((1:K_{\text{max}},i,j)\)
  - 55-75 % of total elapsed time
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

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
(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 model

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


- 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).
Motivation

1. New version SLAV10 with ~10 km horizontal resolution (3600x1946x104 grid)
   • Operational resources are now limited to ~3000 processor cores taking into account other applications
   • Need to compute forecast for 24 hours in less than 20 min - 32.5 min wall-clock time per forecast day before optimizations (42 in 2019)

2. Long-range ensemble prediction – extraction of weak signal from strong noise. Needs large ensembles. (400x250x96 grid, ~75 km resolution)
Works on code optimization

- Algorithmic improvements in dynamics
- NetCDF-based parallel I/O in all the operational technology
- Memory access optimizations
Algorithmic improvements in dynamics

• Move calculation of horizontal diffusion for divergence after the final computation of pressure and temperature

• Allows to increase the time step by a factor of 2-3 without introducing numerical noise near steep orography
NetCDF-based parallel I/O

• It was presented some years ago at RusSCdays
• Now implemented also in preprocessing, postprocessing, improve metadata for compatibility.
• File size: 28 Gbytes in NetCDF, 15 Gbytes in old index-seq. GRIB format
• Additionally, use Lustre FS command like
  lfs setstripe -1 <file>
Elapsed time in seconds for used in different I/O steps of SL-AV model code while using 2916 cores at Cray XC40
Optimization of memory access

Original version of the model used array with dimensions \((6 \times \text{NLEV}, \text{NLON}, \text{NLAT})\) to store model state \((u, v, T, \text{div, vor, P})\)

We have switched to the usage of 6 separate arrays with dimensions \((\text{NLEV, NLON, NLAT})\) that improves data locality

**Original array storage timing:**
- Step with radiation 6.3 s
- Step without radiation 3.58 s

**New version timing:**
- Step with radiation 5.1 s
- Step without radiation 2.23 s
Results for SLAV-10

- The elapsed time of 24-hour weather forecast with SLAV10 model is reduced at Cray XC40 system
- Algorithmic improvement (increase the time step) and parallel I/O optimizations:
  - from 32 to ~20 min (depending on output frequency)
- Memory access:
  - further reduction to 13 min
Results for long-range forecast version

• No NetCDF parallel output yet. Time step cannot be increased because of accuracy considerations (it is already 24 min)

• Elapsed time to compute single ensemble member forecast for 4 months is reduced from 1hr51 min to 1hr 29 min
Conclusions

• Acceleration of the new SL-AV10 version allows complex tuning of its parameterizations for subgrid-scale processes in reasonable time

• Acceleration of the long-range forecast version allows to put freed resources to increase the ensemble size
Thank you for attention!