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

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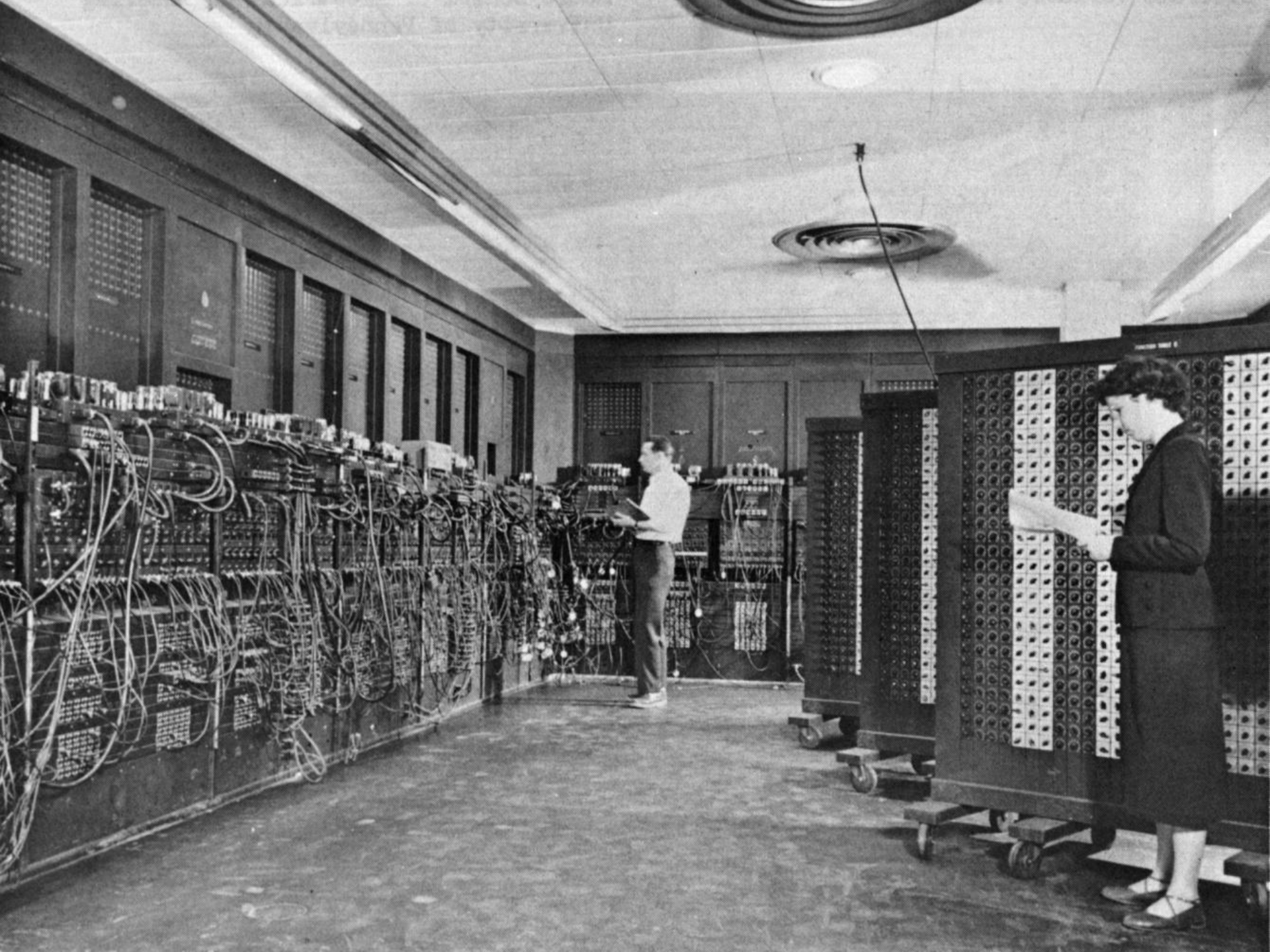
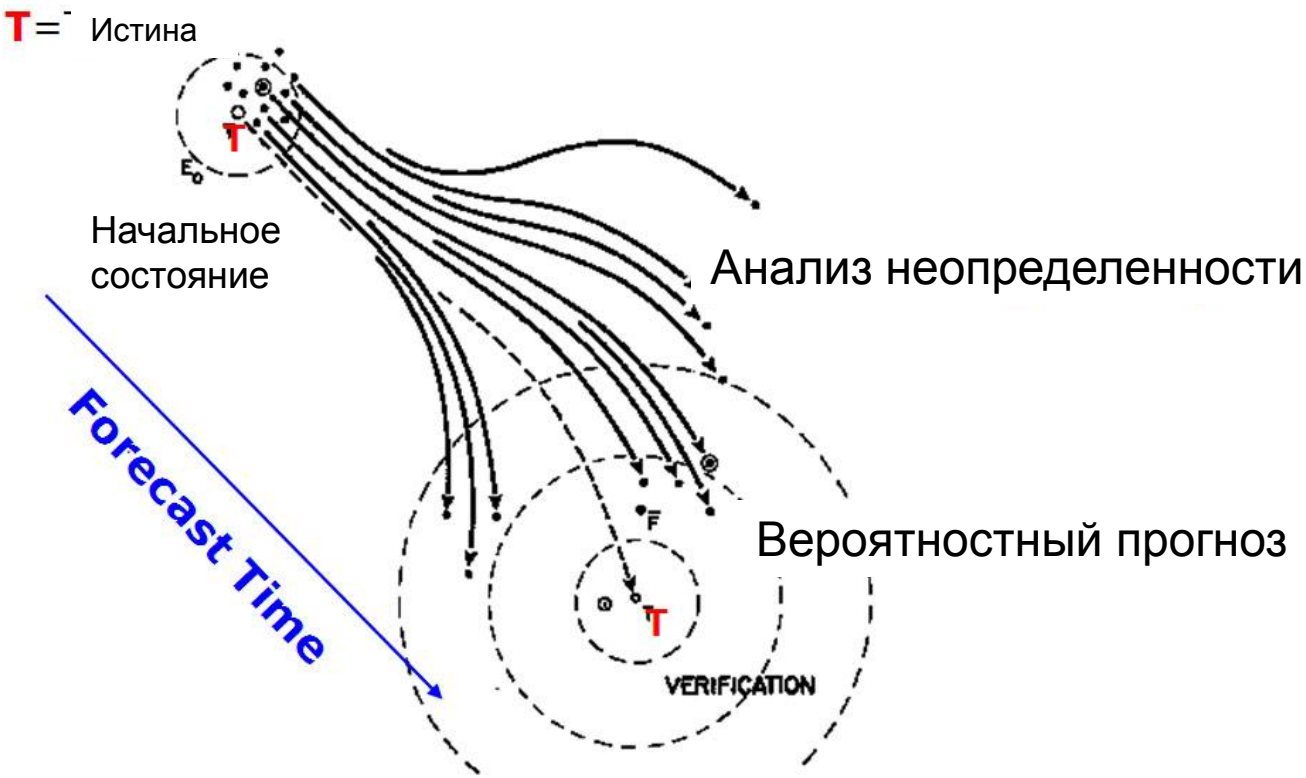
28/09/2021
Russian Supercomputing days

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Начальное состояние
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Forecast Time
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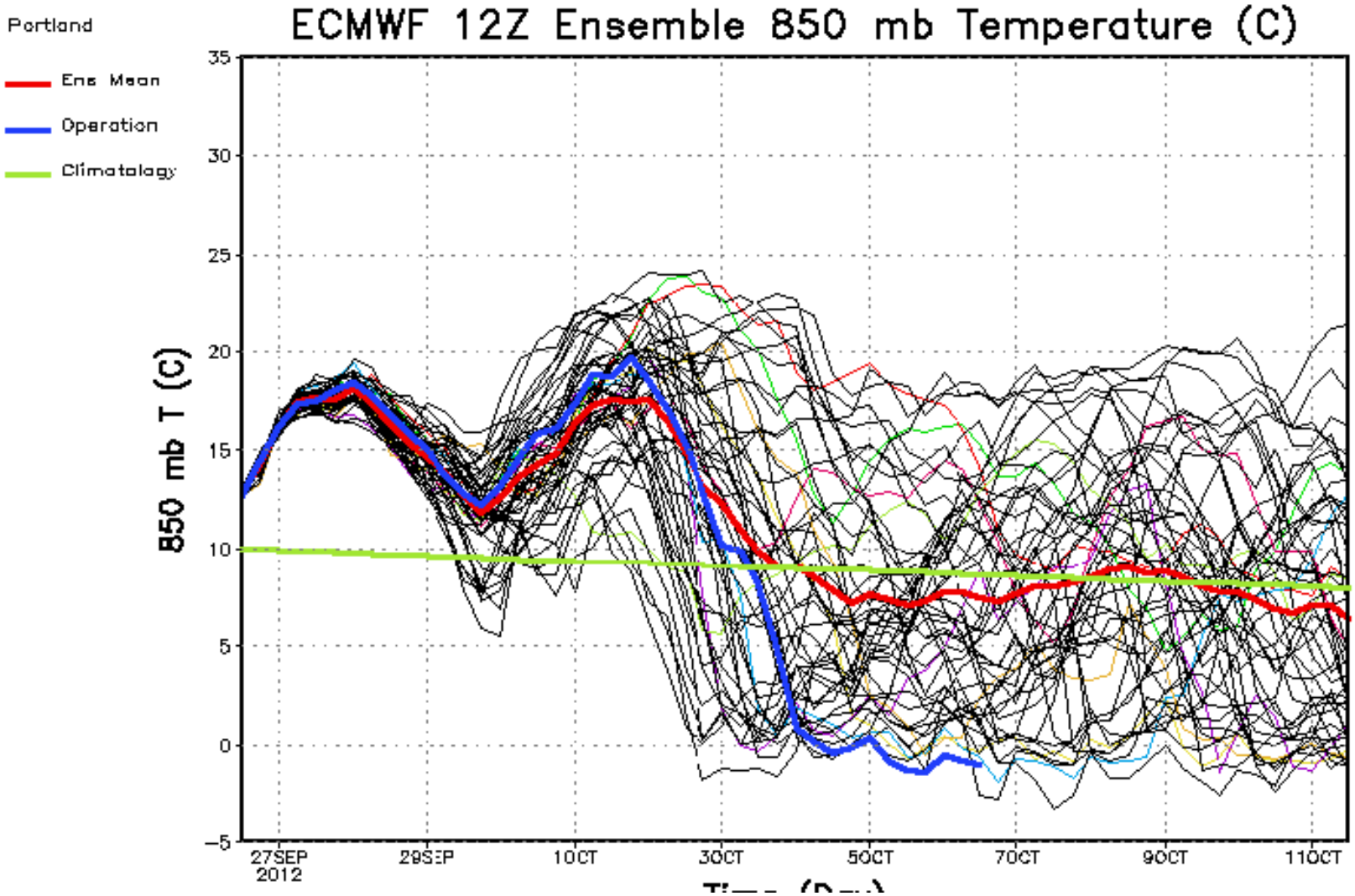
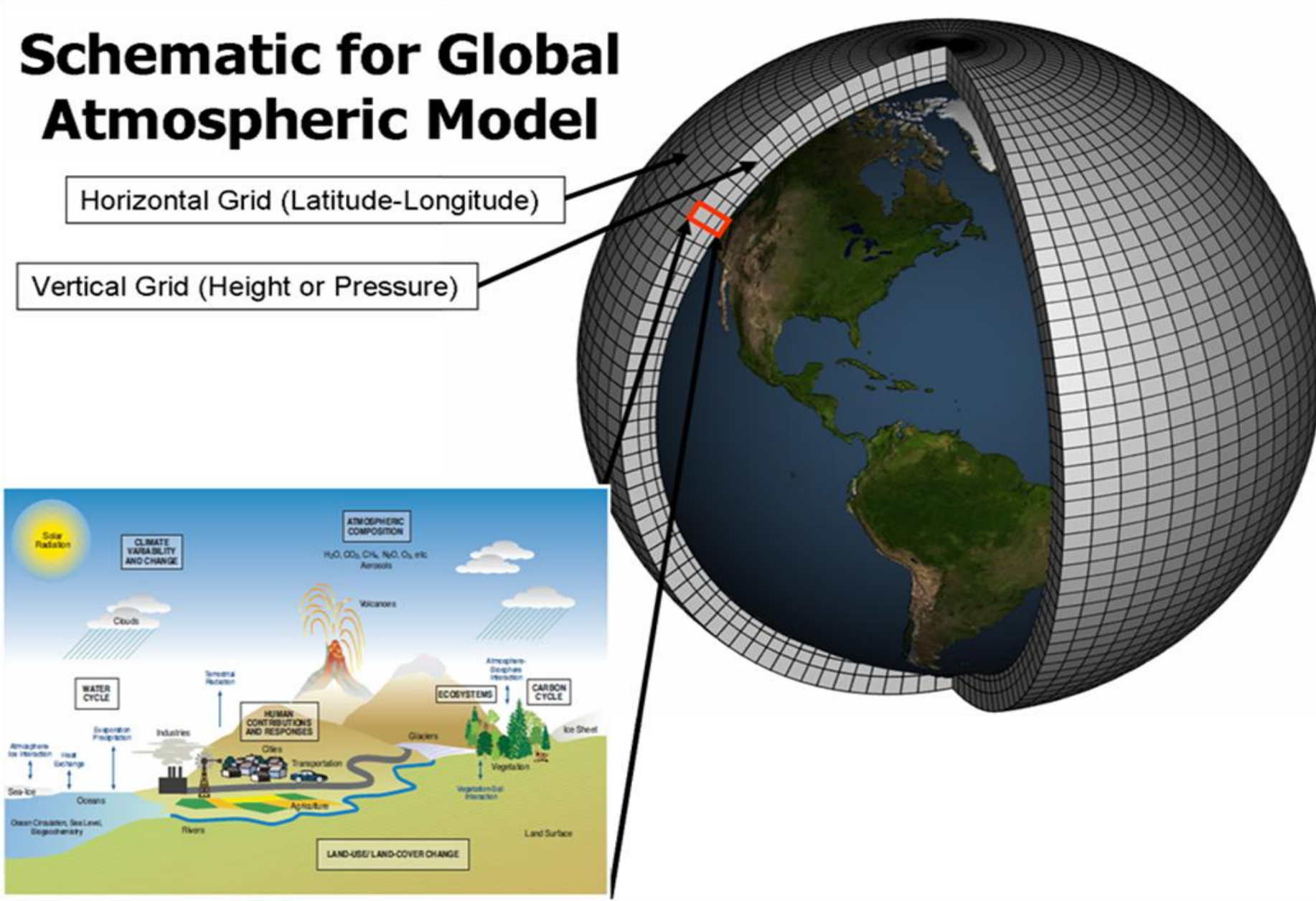
VERIFICATION

Atmospheric predictability



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

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 model

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).

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

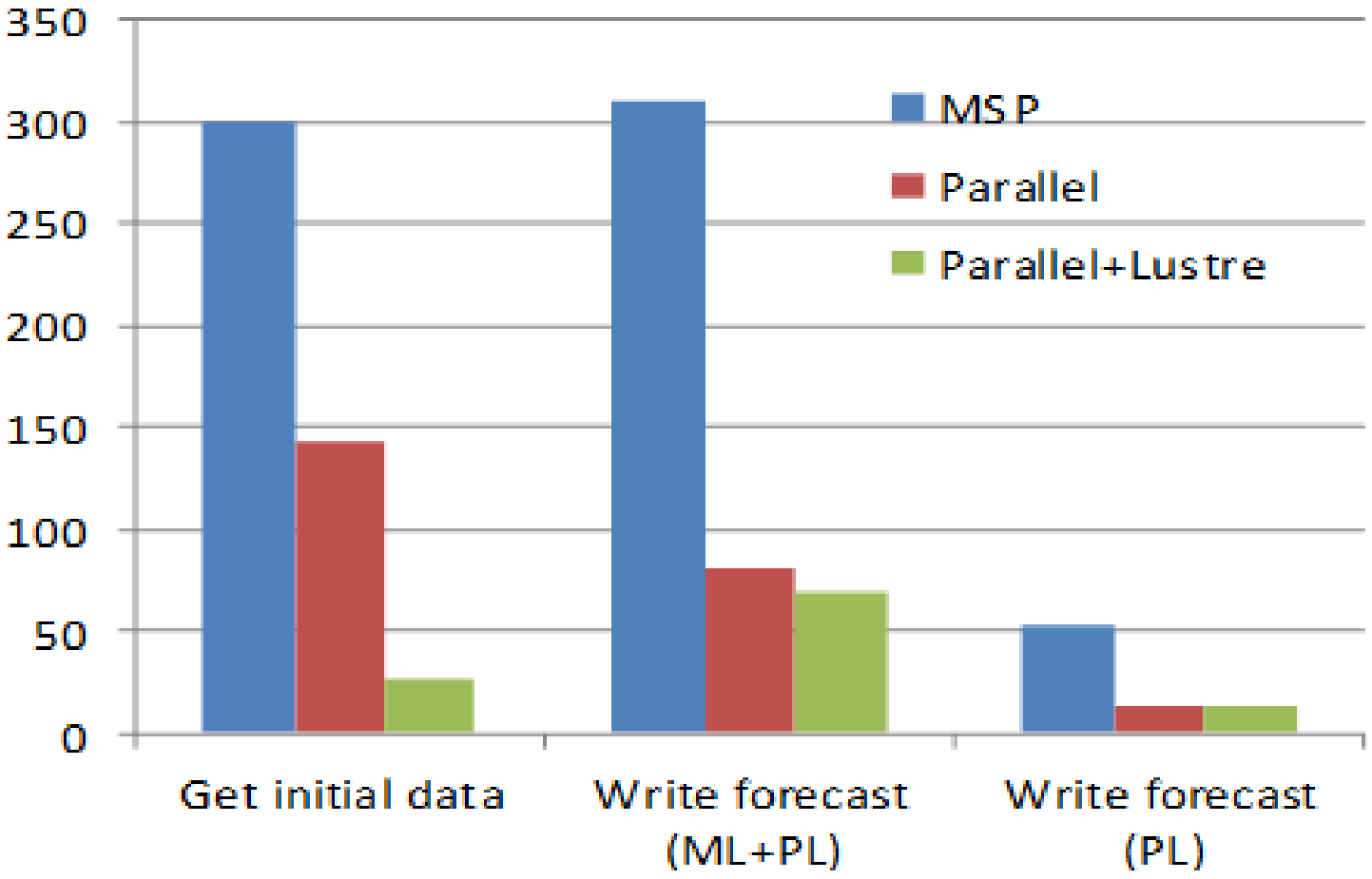
- Move calculation of horizontal diffusion for divergence after the final computation of pressure and temperature
- Allows to increase the time step by a factor of 2-3 without introducing numerical noise near steep orography

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*NLEV, NLON, NLAT) to store model state (u, v, T, div, vor, P)

We have switched to the usage of 6 separate arrays with dimensions (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!