Global mass-conservative semi-Lagrangian shallow water model on the reduced grid

Полулагранжева модель мелкой воды на сфере на редуцированной сетке, сохраняющая массу

Shashkin V. V., Tolstykh M.A.

INM RAS, Hydrometeorological centre of Russia

Motivation

SL-AV (ПЛАВ) Model (Tolstykh 2010):

- Main Russian global operational model for medium-range and seasonal forecasts
- Global finite-difference semi-Lagrangian semi-implicit dynamical core
- Scales up to 100-300 cores, MPI+OpenMP

Motivation for further development of dynamical core:

- Regular lat-lon grid => Highest resolution 20-30 km
- No mass-conservation (tracer and atmosphere) => ex. Spurious sources and sinks of humidity, wrong model precipitations
- Hydrostatic equations => Highest resolution about 10km

New version of the dynamical core

Desired features of new version:

- Resolution of 5-10 km
- Quasi-monotonic (reduced) grid (fig. 1)
- Non-hydrostatic
- Mass-conservation (tracer and atmosphere)
- More scalability

Mass conservation and reduced grid are implemented in the shallow water version

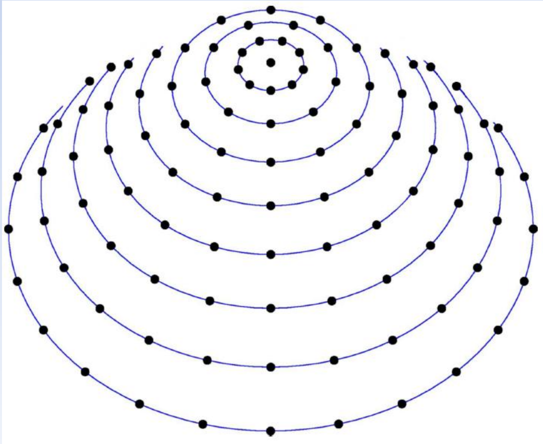

Figure 1. Reduced lat-lon grid

Global Mass-Conservative Shallow water model on the reduced grid (SL-AV-2D)

- Shallow water equations on the sphere:

$$\frac{d}{dt}\left(\vec{v} + 2\Omega \times \vec{r}\right) = -\nabla\Phi$$

$$\frac{d\Phi}{dt} = -D\Phi$$

Φ - depth of the fluid multiplied by g

$\vec{v}$ - horizontal wind velocity

$D = div\,\vec{v}$

$\vec{r}$ - radius vector of a point

Mass conservation

$$\frac{d}{dt}\int_{0}^{2\pi}\int_{-\pi/2}^{\pi/2}\Phi\cos\theta\, d\lambda\, d\theta = 0$$

Locally conservative SL advection algorithm (Conservative Cascade Scheme, Nair, 2002), version for reduced grid

Conservative Helmholtz problem solver (<= semi-implicite time integration) – finite volume, 2nd order of accuracy

- Version with using of Conservative Cascade Scheme for discretization of absolute vorticity equation

Numerical tests

- Global steady state geostrophic flow (№2 – Williamson et al. 1992)
- Zonal flow over an isolated mountain (№5 – Williamson et al. 1992)
- Rossby-Haurwitz wave propagation (№6 – Williamson et al. 1992)
- Quasi real-data (№7a-c – Williamson et al. 1992)
- Barotropic instability (Galewsky et al. 2004)

Regular and reduced (Fadeev, 2006) grids of various resolutions

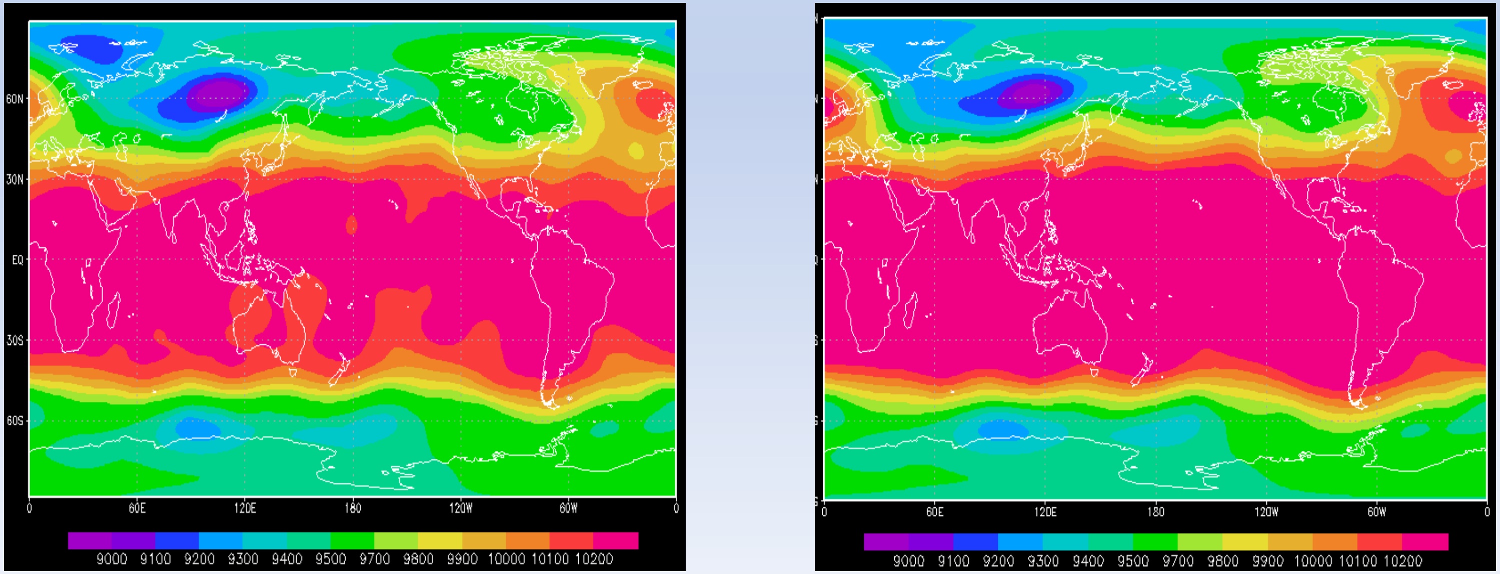

Figure 2. Quasi real-data test (case “c”). Left panel – numerical solution of high resolution (T213) spectral model (day 5), right panel – numerical solution of the mass-conservative semi-Lagrangian model (day 5), resolution – $1{,}5^0 \times 1{,}5^0$

Conclusions

Summary of numerical results:

- L2 normalized errors (depth field) of the numerical solutions of mass-conservative and basic non-conservative models are practically indistinguishable
- The impact of the reduced grid in the most complicated tests is negligible
- Using of conservative cascade scheme for discretization of absolute vorticity equation improves accuracy of the model only in “quasi real-data” test cases №7a-c, Williamson et al. 1992

Future plans:

- We are working now on the implementation of 3D locally-conservative semi-Lagrangian advection scheme
- The implementation of mass-conservative version of global semi-Lagrangian SL-AV (Tolstykh, 2010) model is planned

Thank you for your attention!

- See “Global mass-conervative semi-Lagrangian shallow water model on the reduced grid” poster (V.V. Shashkin, M.A. Tolstykh) poster for more details

The work was supported by RFBR grant 10-05-01066 and RAS basic research program №14