Global multi-scale atmosphere model SL-AV

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

- **Finite-difference semi-implicit semi-Lagrangian** dynamical core of own development. Vorticity-divergence formulation, unstaggered grid (Z grid), 4\(^{th}\) order finite differences

- Possibility to use **reduced lat-lon grid** in dynamical core. (Tolstykh, Shashkin JCP 2012; Shashkin, Fadeev Tolstykh, JCP 2016; Tolstykh, Shashkin, Tolstykh et.al., Geosci.Mod.Dev., 2017).

- **Mass-conserving version** (Shashkin, Tolstykh GMD 2014)
SL-AV global atmosphere model

- 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).
- Marine stratocumulus parameterization
Current applications of SL-AV model:

- Operational medium-range weather prediction up to 10 days; probabilistic seasonal forecast at Hydrometcentre of Russia.
- Weather prediction up to 3 days at Novosibirsk.
- 60 days weekly forecast (S2S Prediction project, WMO) – quite old SL-AV version! Need of urgent update.
SL-AV code parallel speedup at Cray XC40 w.r.t to 504 cores

Horizontal grid of 3024x1513 points (~13 km). 126 vertical levels
Percentage of different dynamics part in elapsed time vs. processor number
SL-AV code elapsed time at Intel Xeon7290 (KNL) w.r.t to 288 hyperthreads

Horizontal grid of 1600x865 points (~22 km). 51 vertical levels
Annual mean precipitation (mm/day)

Obs GPCP
TRMM (1979-2010)

TRMM: TROPICAL RAINFALL MEASURING MISSION
https://climatedataguide.ucar.edu/climate-data/trmm-tropical-rainfall-measuring-mission
QBO. U at equator, 1979-1989: SL_AV model (top), ERA_Interim (bottom)
Zonal mean U and T (DJF, 1979-2006), SL-AV (left), ERA-Interim (right)
These improvements in model climate produced a reduction of operational medium range forecasts errors

Operational version of the model: resolution in longitude 0,225°, in latitude from 0,16° in NH to 0,245° in SH, 51 vertical levels

https://apps.ecmwf.int/wmolcdnv/
Reduction of SL-AV RMS forecast error (01.2016-07.2018). H500 at 72 hrs (left), W250 at 72 hrs (right)

Reduction in H500 RMS error: ~2,3 m (24hrs), 2,5m (72hrs), W250 RMS error: ~0,6 m/s (24hrs), 0.8 m/s (72 hrs). Lag between SL-AV and main group: ~1.2 m/s in W250 at 72 hrs, ~4,5 m in H500 at 72hrs
Improvements in RMS forecast error while using ECMWF upper-air initial data

Jan 2018.
Southern extratropics - left, Northern ones – right; top - H500 , bottom- W250

Reduction in 72 hrs forecast error: geopotential – 2-4 m, wind ~ 0.8 m/s.
Future development of SL-AV dynamical core

- Target horizontal resolution of about 5km (we hope closer to 1 km).

Basic techniques (with respect to our forecast of available computational power ~30000 cores):
- semi-Lagrangian, semi-implicit
- finite-difference / finite-volume
- spherical grid (reduced lat-lon / equiangular cubed-sphere)
- C-staggering (both grids!)
Reduced latitude longitude grid, C-staggered

Why \((N1+N2)/2\) V points?
Correct 2:1 ratio between (horizontal) vector and scalar degrees of freedom at least at global scale (this is not true for say icosahedral grid => inevitable unphysical modes)
## Reduced grid vs equiangular cubed sphere

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<th>Reduced</th>
<th>cubed</th>
<th>conclusion</th>
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<tr>
<td>Div&amp; grad operators</td>
<td>Purely 2D (&lt;= different N of points at different latitudes)</td>
<td>Purely 2D (&lt;= non-orthogonal+staggered grid+Coriolis)</td>
<td>Almost equal</td>
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<td>Departure point interp.</td>
<td>Purely 2D (&lt;= different N of points at different latitudes)</td>
<td>1D x 1D (&lt;= rectangular grid structure)</td>
<td>Cubed sphere is cheaper</td>
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<td>Parallel issues</td>
<td>2D –decomposition possible</td>
<td>2D-decomposition (easy)</td>
<td>Exchanges are more complicated at reduced grid</td>
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<td>Other</td>
<td>Pole singularity (much-much weaker than in regular lat-lon)</td>
<td>Cube faces-edge problems =&gt; grid imprinting</td>
<td>Neither grid is ideal :(</td>
</tr>
<tr>
<td>Compatibility with assim,</td>
<td>Almost ideal</td>
<td>Will cause a small revolution</td>
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<td>post.proc etc</td>
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What is more important for us? Accuracy? Speed? Scalability?
Conclusions

• New version of SL-AV model with 100 vertical levels reproduces main characteristics of modern climate, including stratosphere oscillations.

• Improvements in model climate helped to reduce medium-range forecasts errors.

• Achieved scalability allows to run future version with ~10km resolution operationally

• Current design of SL-AV dynamical core would not allow nonhydrostatic formulation – new generation is foreseen.
Thank you for attention!

http://nwplab.inm.ras.ru
Shallow water linear gravity waves
Short zonal signal propagation to high latitudes

Initial disturbance:

\[ f(\lambda, \varphi) = \exp \left( \left[ \frac{-\varphi}{0.1 \cdot \pi} \right]^2 \right) \cdot \sin(l\varphi) \cdot \sin(k\lambda) \]

\( l & k \)

=> 4h scale

in lon and lat

Regular grid solution (almost exact), amplitude of initial zonal wave
Almost ideal solution at red. grid, much stronger decay & aliasing at cubed sphere of comparable resolution! (Both – C-grid, 2nd order FD)
Barotropic instability SWE test-case on cubed-sphere

Rel. vort at day 6. Grid imprinting reduces with grid refinement