Recent developments of the global semi-Lagrangian atmospheric model

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Plan

- Evolution of the model. Some results
- Mass-conservative dynamical core
- Implementation of the INM multilayer soil model
- Plans for further development

SL-AV global model

- Semi-Lagrangian semi-implicit fonote-difference dynamical core of own development
- Parameterizations mostly from ALADIN/ LACE consortium
- Vorticity-divergence formulation, Z grid (unstaggered) (Tolstykh, JCP 2002; Tolstykh, Shashkin JCP 2012)

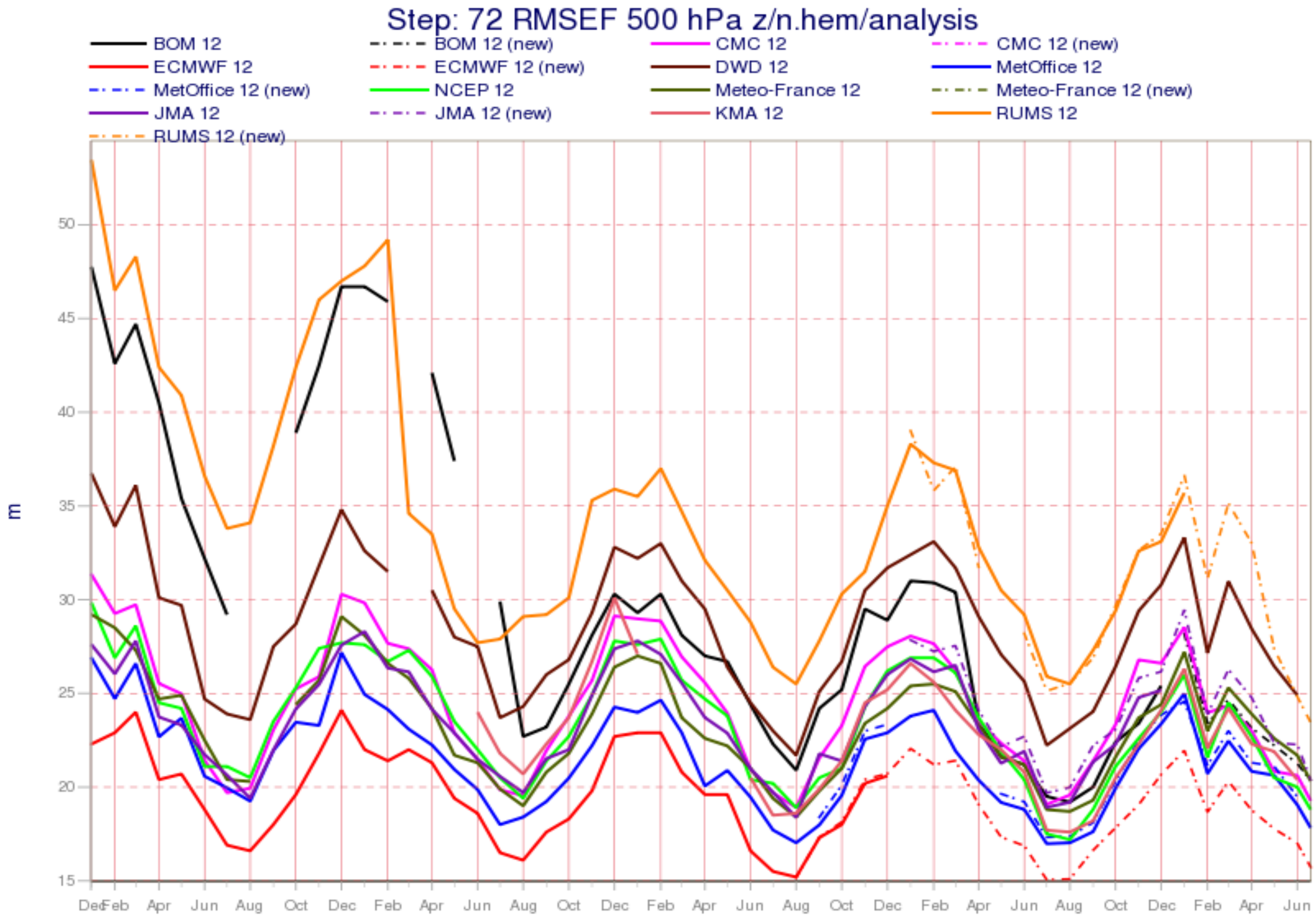
Current versions of the model

- Operational: 0.72x0.9 lat-lon, 28 vertical levels
- Operational seasonal: 1.1x1.4 lat-lon, 28 levels
- Variable resolution version operational in Novosibirsk: 0.5625 deg in longitude; from 28 to 80 km in latitude

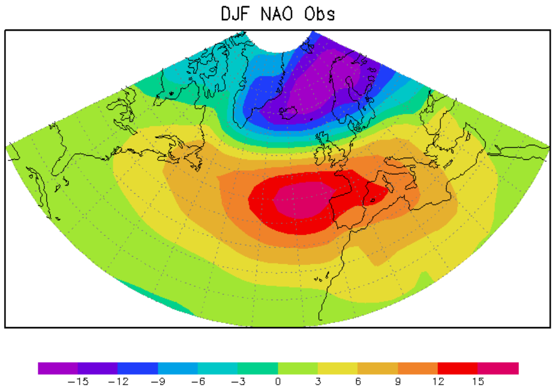
Recent improvement of forecast quality

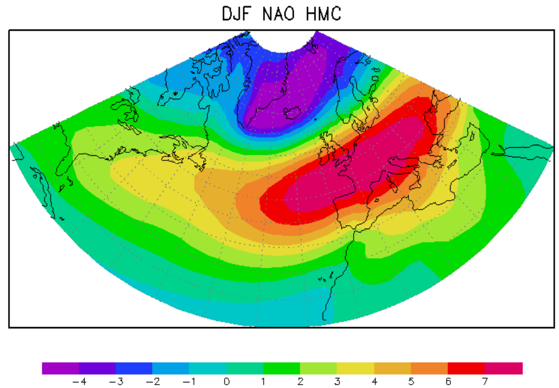
- Incorporation of 3D ozone distribution, some improvement in cloud parameterization (Jan 2013)
- Operational implementation of 3D Var objective analysis at Hydrometcentre (Apr 2013)

RMS error of H500. Northern extratropics, Dec 2008-Jul 2013 Moving average over 1 month. Russia - RUMS (http://apps.ecmwf.int/wmodlcdnv/)

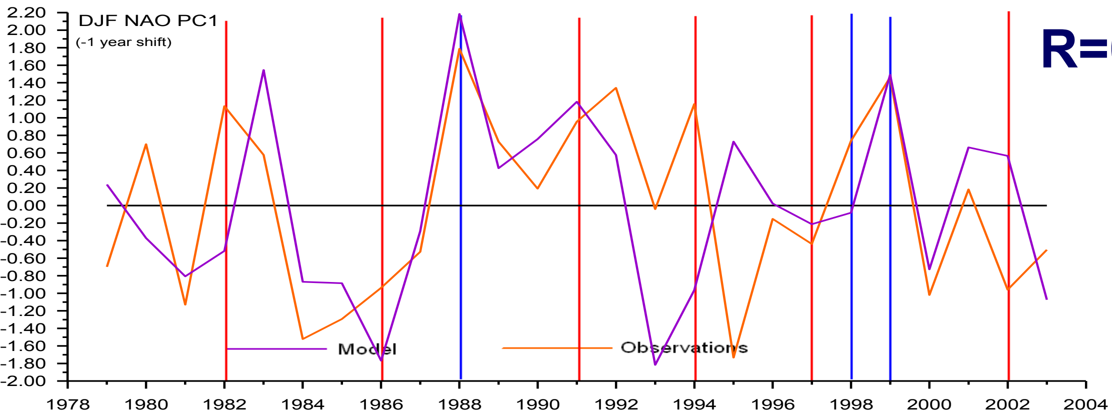


Predictions of the DJF mean NAO index with the seasonal version of SLAV model (by V.N.Kryjov)



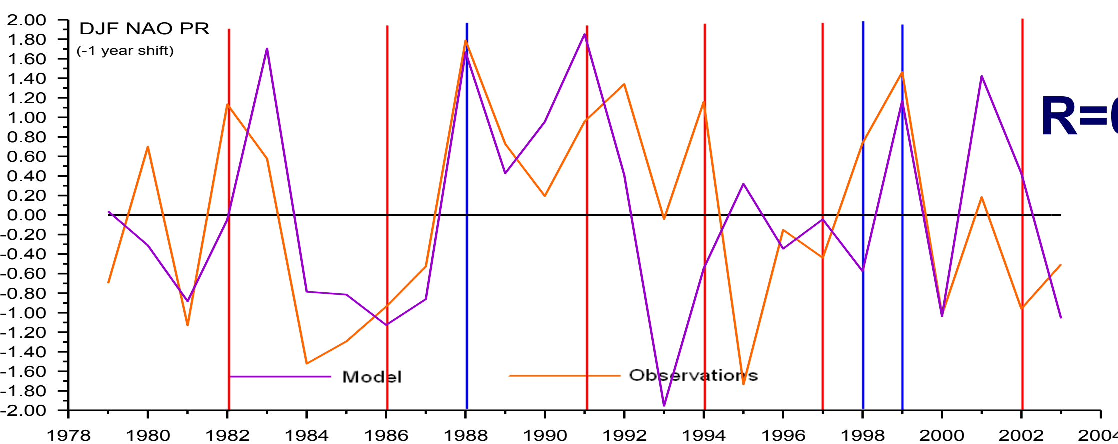


EOF1 of wintertime (DJF) SLP over the North Atlantic in observations (left) and model predictions (right)



R=0.48

Time series of the DJF mean NAO index in observations (PC1o, orange) and in model predictions (violet) as PC1m (middle) and as PR (bottom).

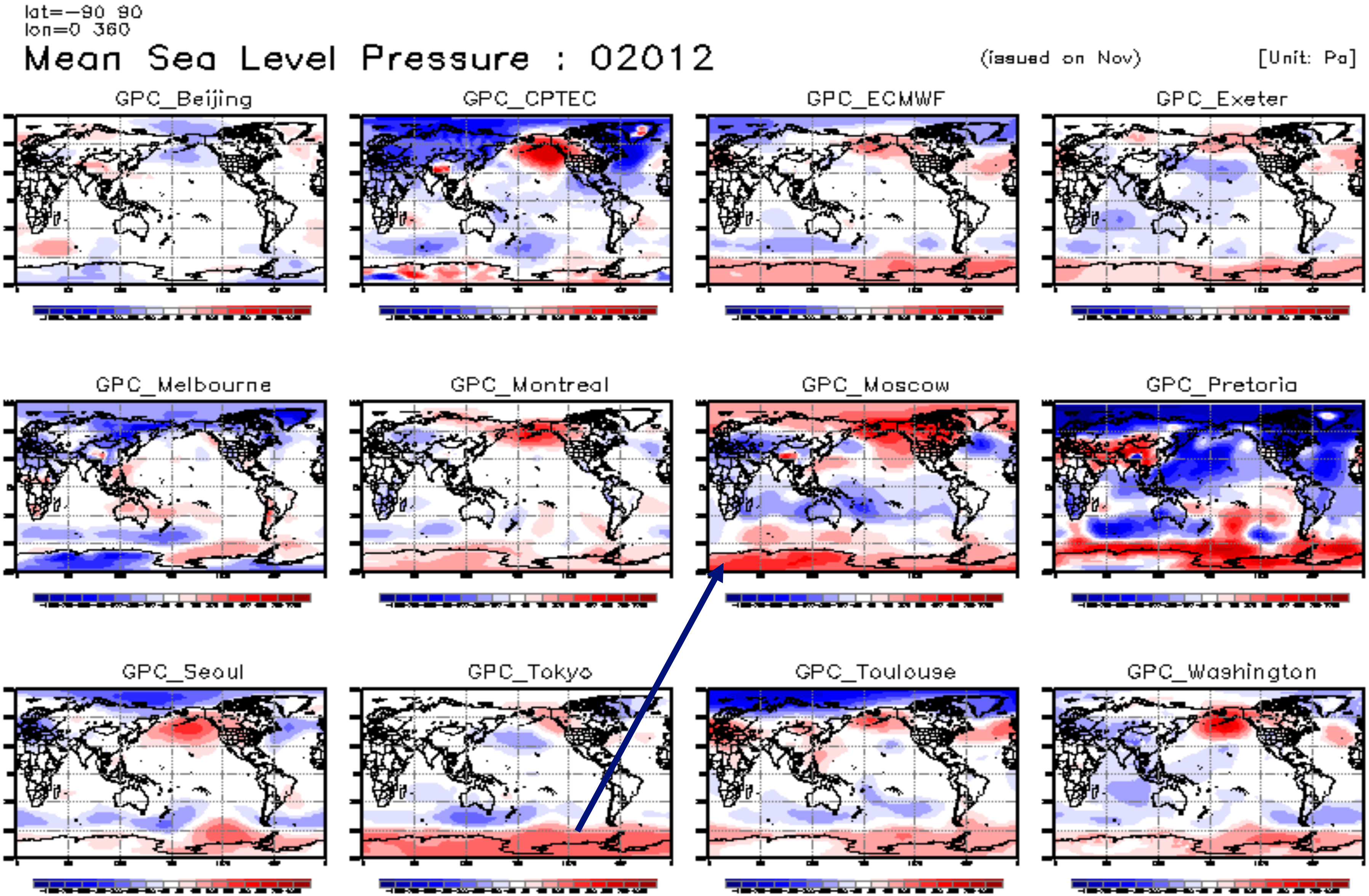


R=0.52

Blue/red vertical lines denote the winters of La-Nina/El-Nino, to which predictions appear not sensitive

GPC predictions of DJF'12-13 mean SLP

(from WMO LC LRF-MME)



Distinct negative phase of the AO predicted!

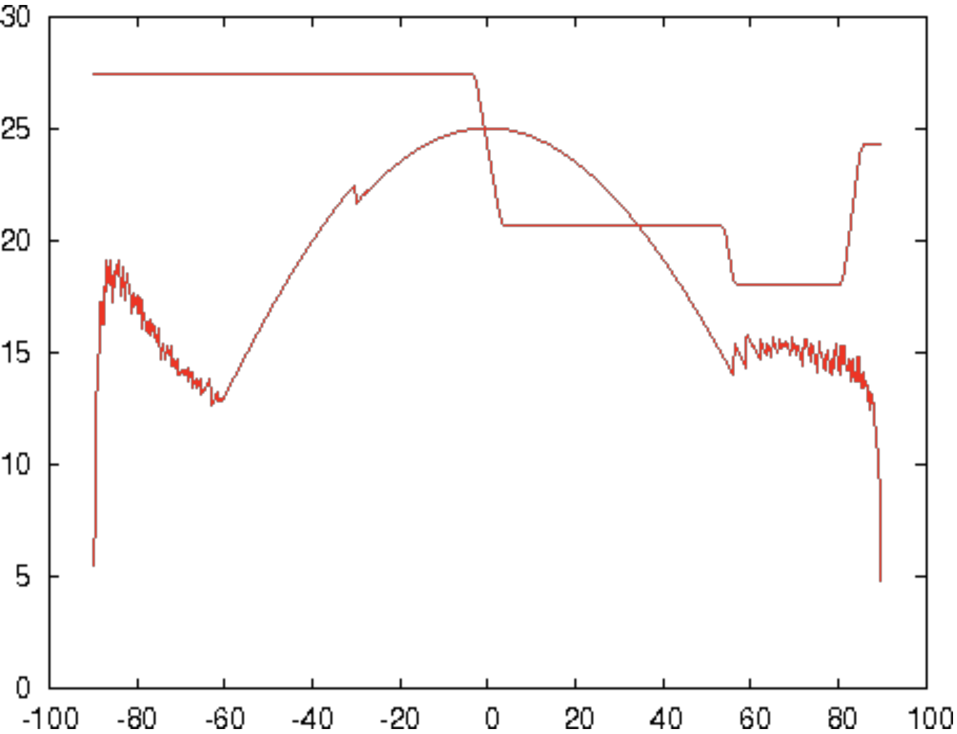
SL-AV global model: new version

- Variable resolution in latitude
- Current version in preparation to parallel runs:

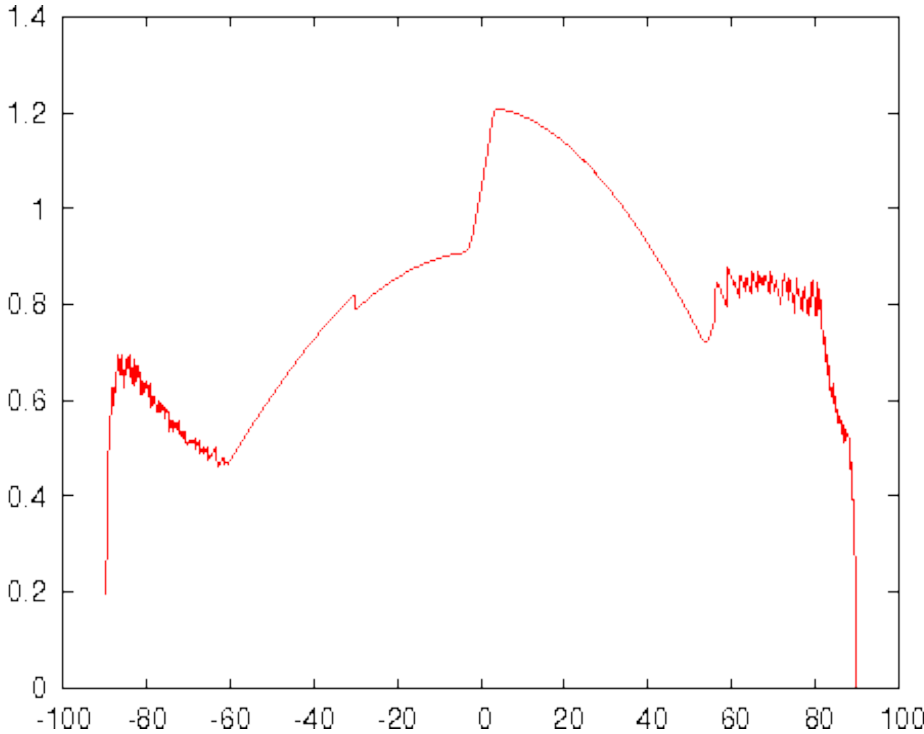
resolution in longitude 0.225, resolution in latitude varied from 27 km in SH to 18 km in NH

- The orography is prepared on the reduced grid
- 51 levels in vertical
- Reduced lat-lon grid implemented in SW model (Tolstykh, Shashkin, JCP 2012)

Grid step in latitude (upper curve) and longitude (lower curve), in km

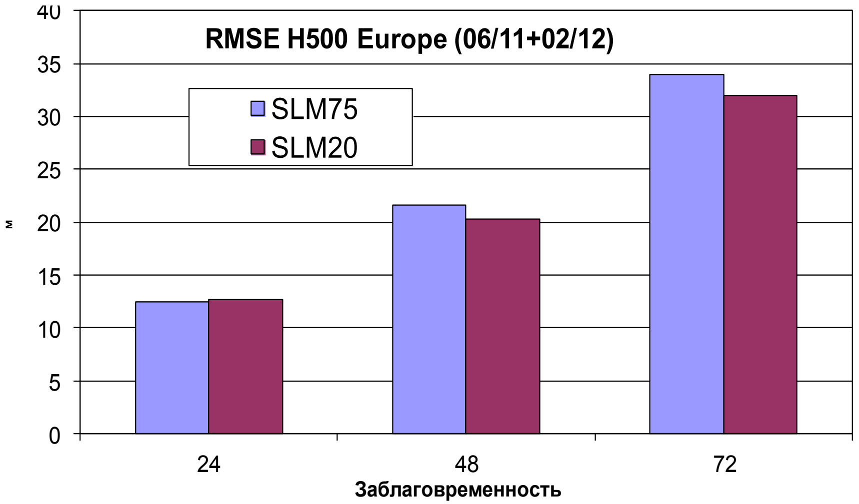


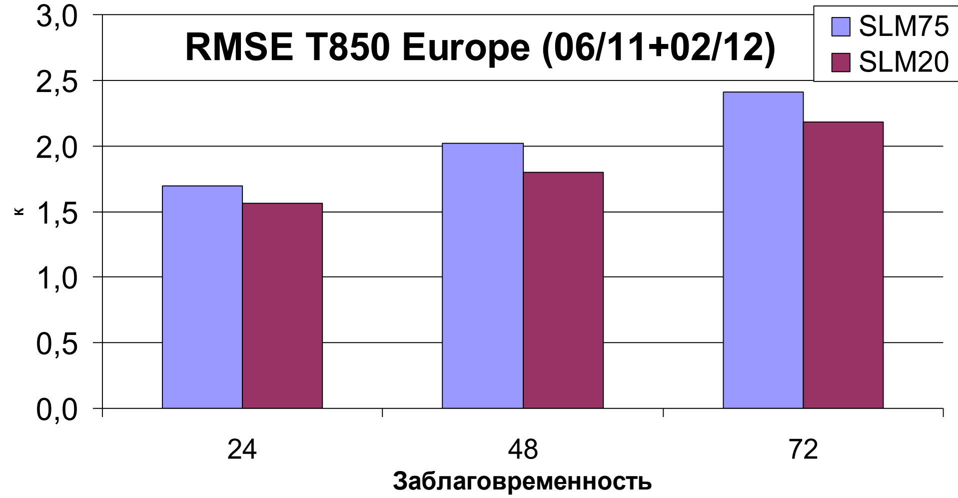
Proportion of 'physical' grid steps Max(dx/dy, dy/dx)

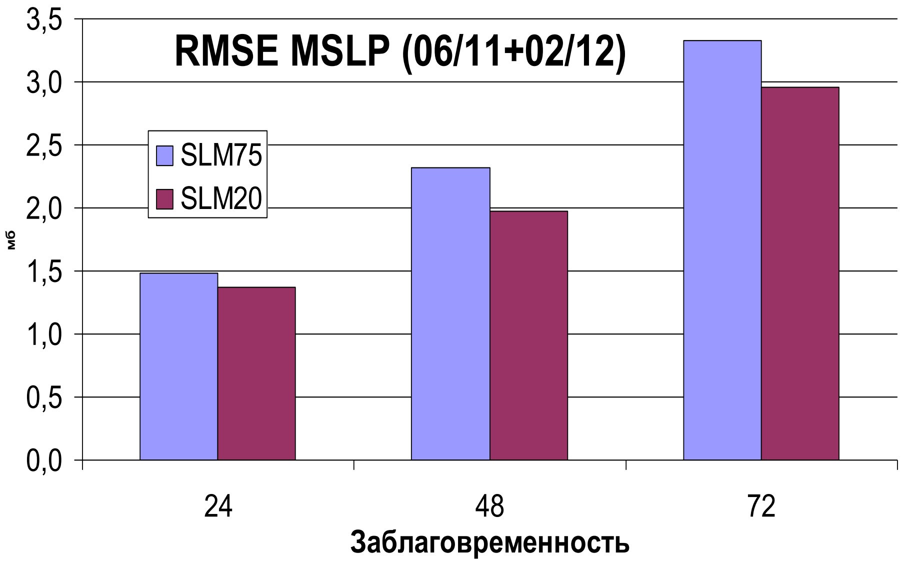


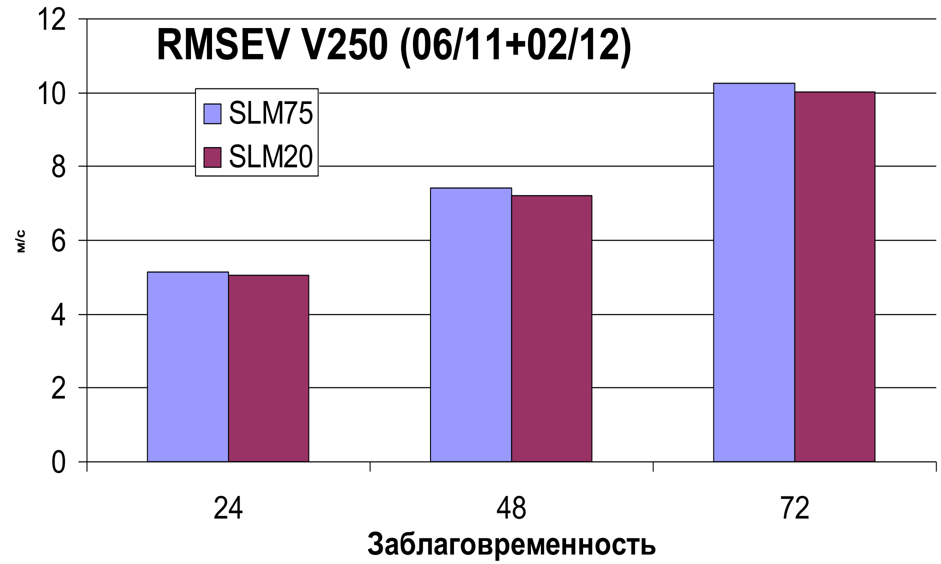
Comparison of the operational (0.9˚x0.72˚, 28 levs) and new (0,225˚x0,18˚, 51 levs) versions of SLAV model

Initial data: NCEP 1˚x1˚.
Jun 2011 + Feb 2012









Standard semi-Lagrangian discretizations are not inherently mass-conservative

- Atmosphere global mass growth (decrease)
- Atmospheric constituents (water vapour, ozone, carbon dioxide etc) mass growth or decrease => Model radiative balance drift
- Spurious generation of atmospheric constituents mass => spurious precipitation and chemical reactions

Finite-volume (Locally-conservative) form of tracer advection equation

Tracer advection equation:

$$\frac{dq}{dt} = \frac{\partial q}{\partial t} + u\frac{\partial q}{\partial x} = 0$$

q – specific tracer concentration [kg / *kg*]

Continuity equation:

$$\frac{d\rho}{dt} + D\rho = 0$$

ρ – air density [kg / m^3], D – wind velocity divergence

Integral form of the tracer advection equation:

$$\frac{d}{dt}\int_{A(t)} \rho q \cdot dxdydz = 0$$

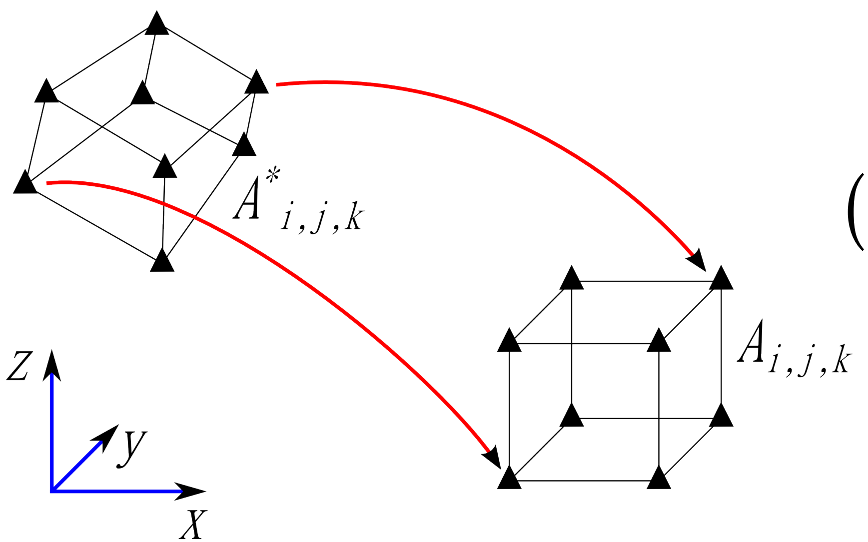
Conservation of the mass in the Lagrangian volume *A(t)*

Finite-volume (Locally-conservative) discretization of the tracer advection equation

1. $A(t^{n+1}) = A_{ijk}$ – coincides with an arbitrary grid cell

2. $A(t^{n}) = A^*_{ijk}$ – departure cell

3. *Masses of the tracer contained in A_{ijk} and A^*_{ijk} are equal*



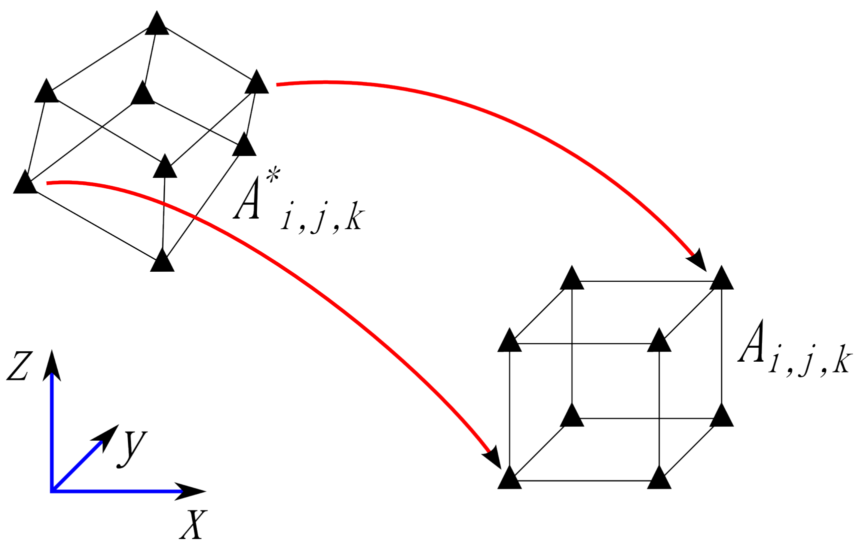
$$\left(\rho q\right)^{n+1}_{ijk} = \frac{1}{V(A_{ijk})} \int_{A^*_{i,j,k}} \left(\rho q\right)^n dxdydz$$

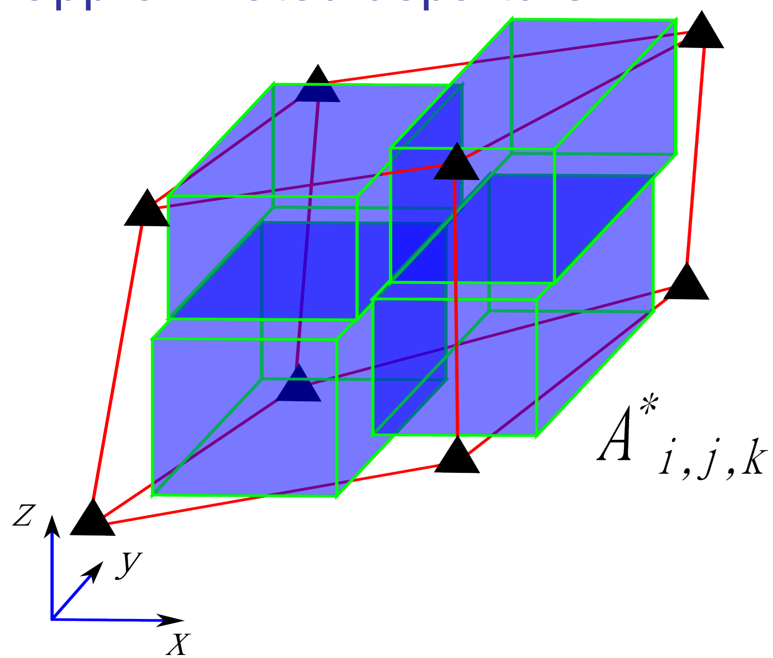
Finite-volume (Locally-conservative) discretization of the tracer advection equation

1. Reconstruction of A^*_{ijk} using wind (reconstructions of upstream trajectories)

2. Approximation of the departure volume A^*_{ijk} using polyhedron with sides parallel to the coordinate planes

2. Calculation of the mass contained in the approximated departure volume A^*_{ijk}





Semi-Lagrangian semi-implicit locally mass-conservative discretization of the continuity equation

Integral form of the hydrostatic continuity equation in sigma-pressure vertical coordinate, p_s is the surface pressure:

$$\frac{d}{dt}\int_{A(t)} p_s \cdot dxdyd\sigma = 0$$

Linearization around reference pressure p_{ref}:

$$\frac{d}{dt}\int_{A(t)} \left(p_s - p_{ref}\right) dxdyd\sigma = -\int_{A(t)} \left(p_{ref} D\right) dxdyd\sigma$$

Discretization (using the same scheme as for the tracer advection equation):

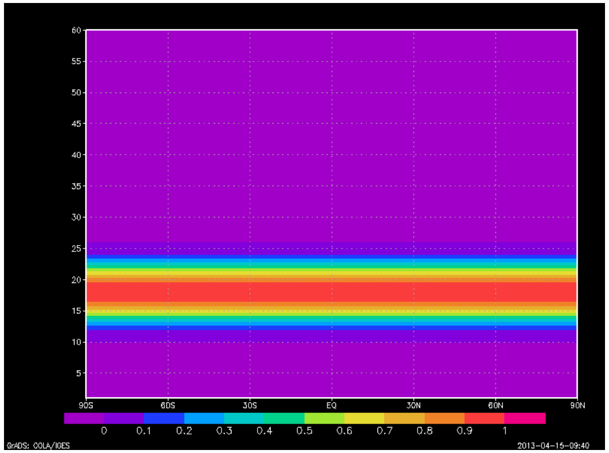
$$\left(p_s - p_{ref}\right)_{ijk}^{n+1} V(A_{ijk}) - \int_{A_{ijk}^*} \left(p_s - p_{ref}\right)^n dxdyd\sigma =$$

$$-\frac{1}{2}\Delta t \left(p_{ref} D\right)_{ijk}^{n+1} V(A_{ijk}) - \frac{1}{2}\Delta t \int_{A_{ijk}^*} \left(p_{ref} D\right)^n dxdyd\sigma$$

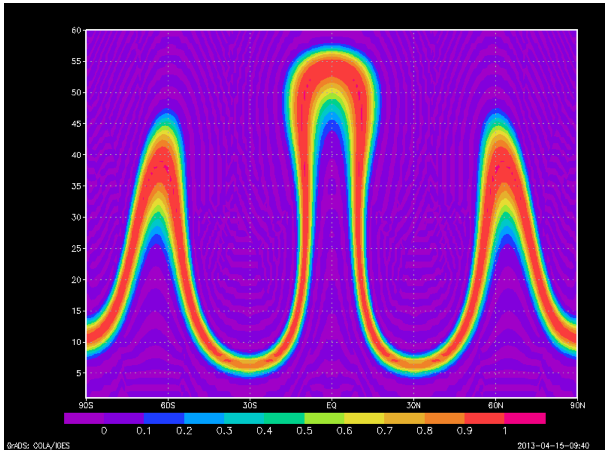
Numerical experiments (tracer advection). Idealized Hadley cell flow (Jablonowski et al. 2012)

Wind field:

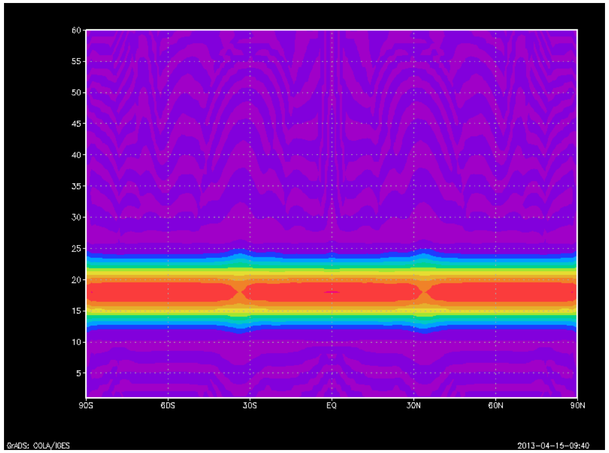
1. Deformation in latitude-elevation plane in the course of 12 h, then
2. Turn around and going back to initial conditions



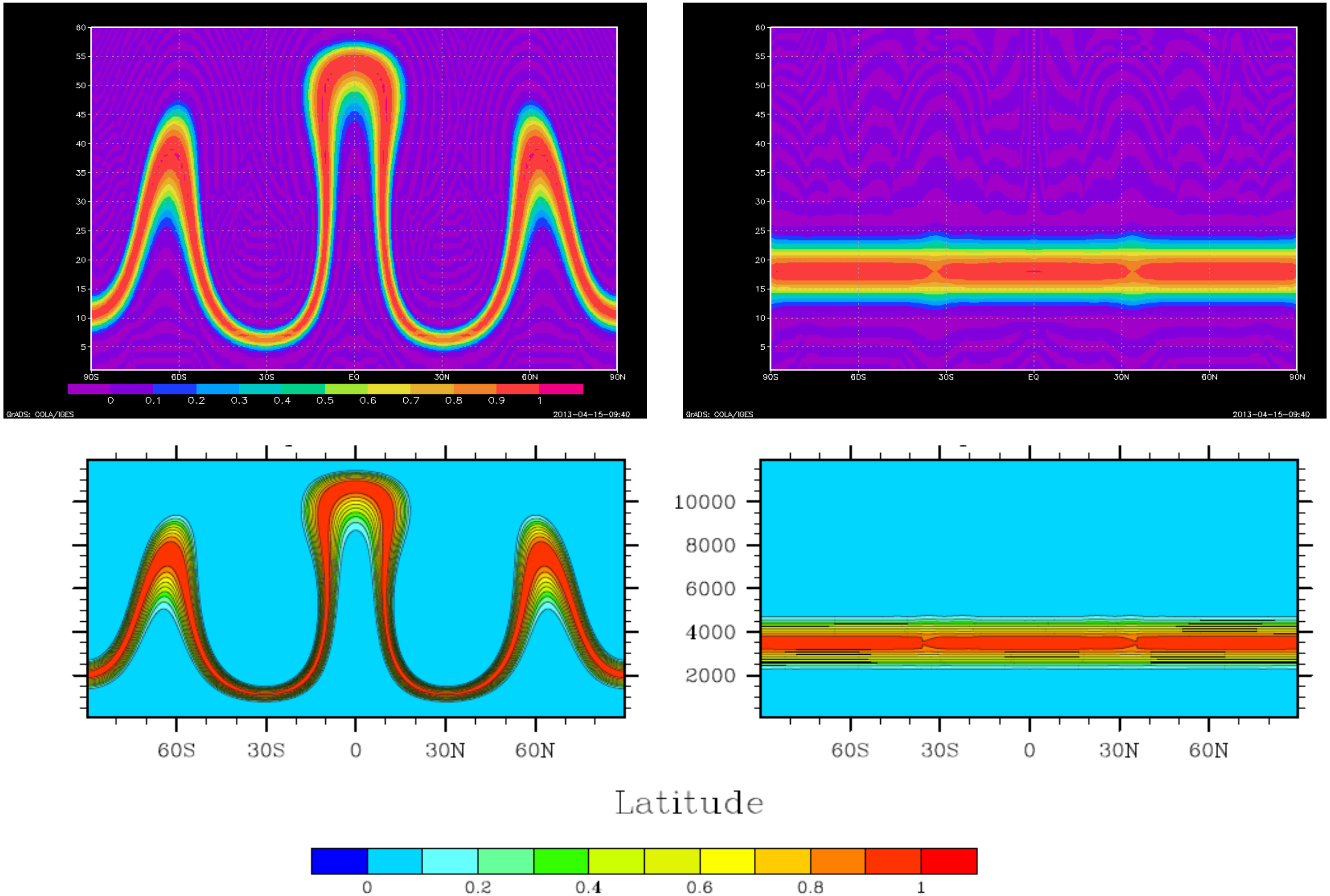
Initial tracer specific concentration field (exact solution after 24 hours)



Tracer specific concentration field after 12 hours



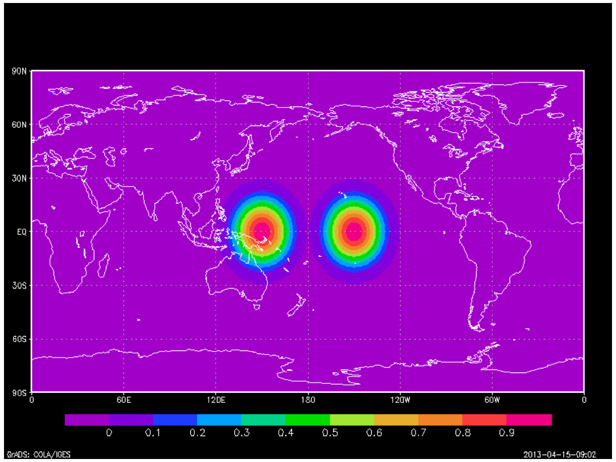
Tracer specific concentration field after 24 hours (numerical solution)



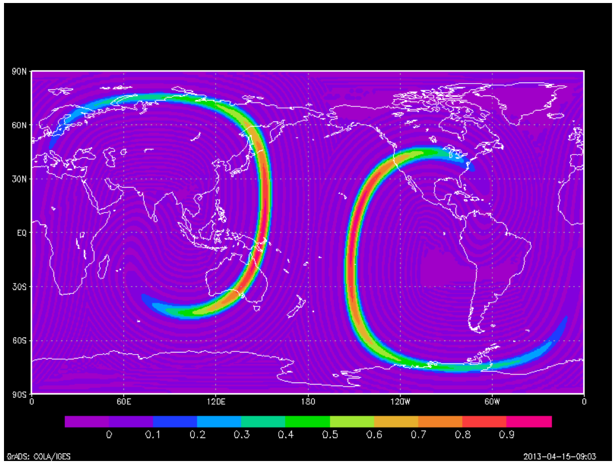
Specific tracer concentration after 12 h (left) and 24 h (right). Numerical solutions by mass-conservative SLAV (top) and Metoffice ENDGAME (bottom)

Numerical experiments (tracer advection).
3D deformational flow (Jablonowski et al. 2012)

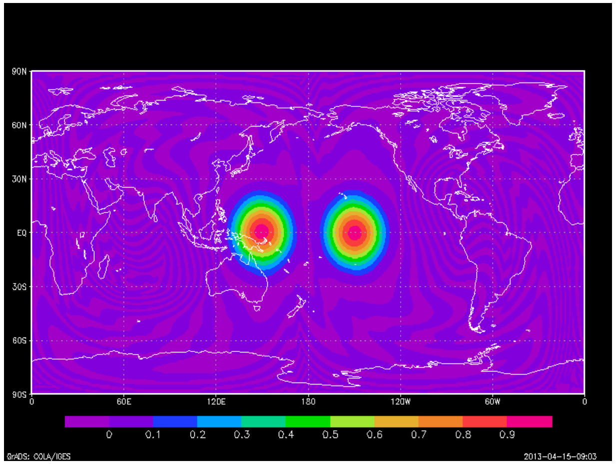
Wind field:
1. Deformation of the initial tracer distribution in the latitude longitude plane, oscillations in the vertical direction.
2. Turn around after 6 days and getting back to the initial distribution



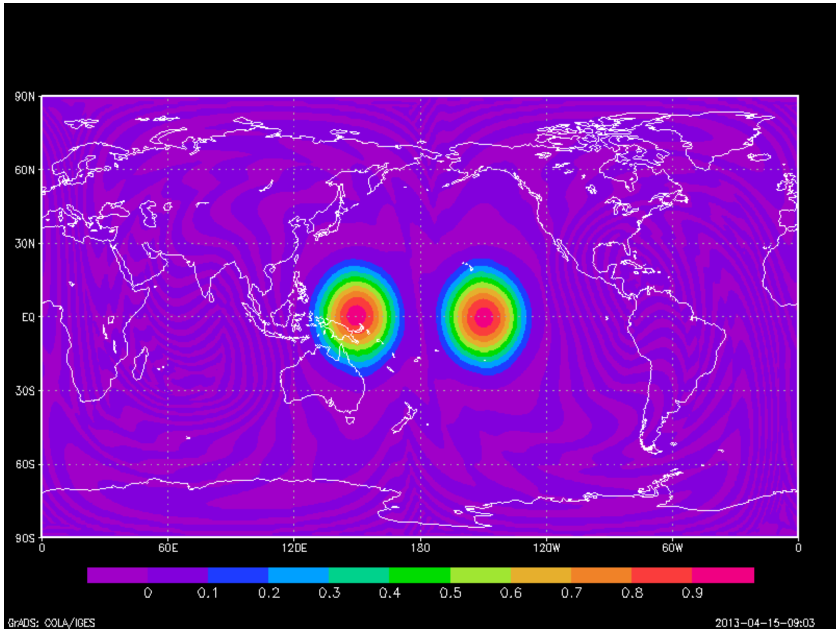
Initial tracer specific concentration field (exact solution after 12 days)

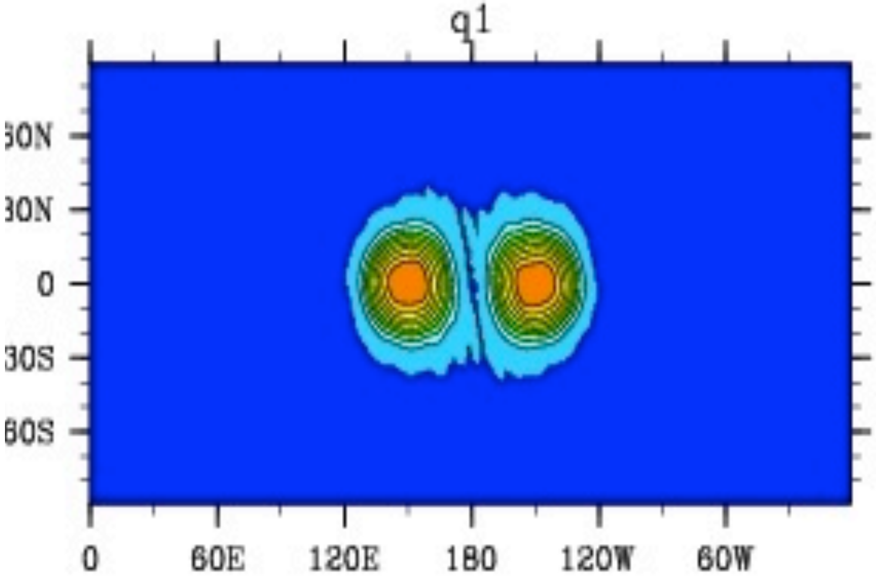


Tracer specific concentration field after 6 days (maximum deformation)



Tracer specific concentration field after 12 days (numerical solution)





Specific tracer concentration after 12 h (left) and 24 h (right). Numerical solutions by mass-conservative SLAV (left) and ECMWF IFS (right)

Numerical experiment (tracer advection).

- Global mass of the tracer is conserved up to machine precision
- Convergence rate between 2 and 3
- Numerical solution error norms 3-5 times smaller then in the case of standard semi-Lagrangian scheme with cubic Lagrangian interpolation

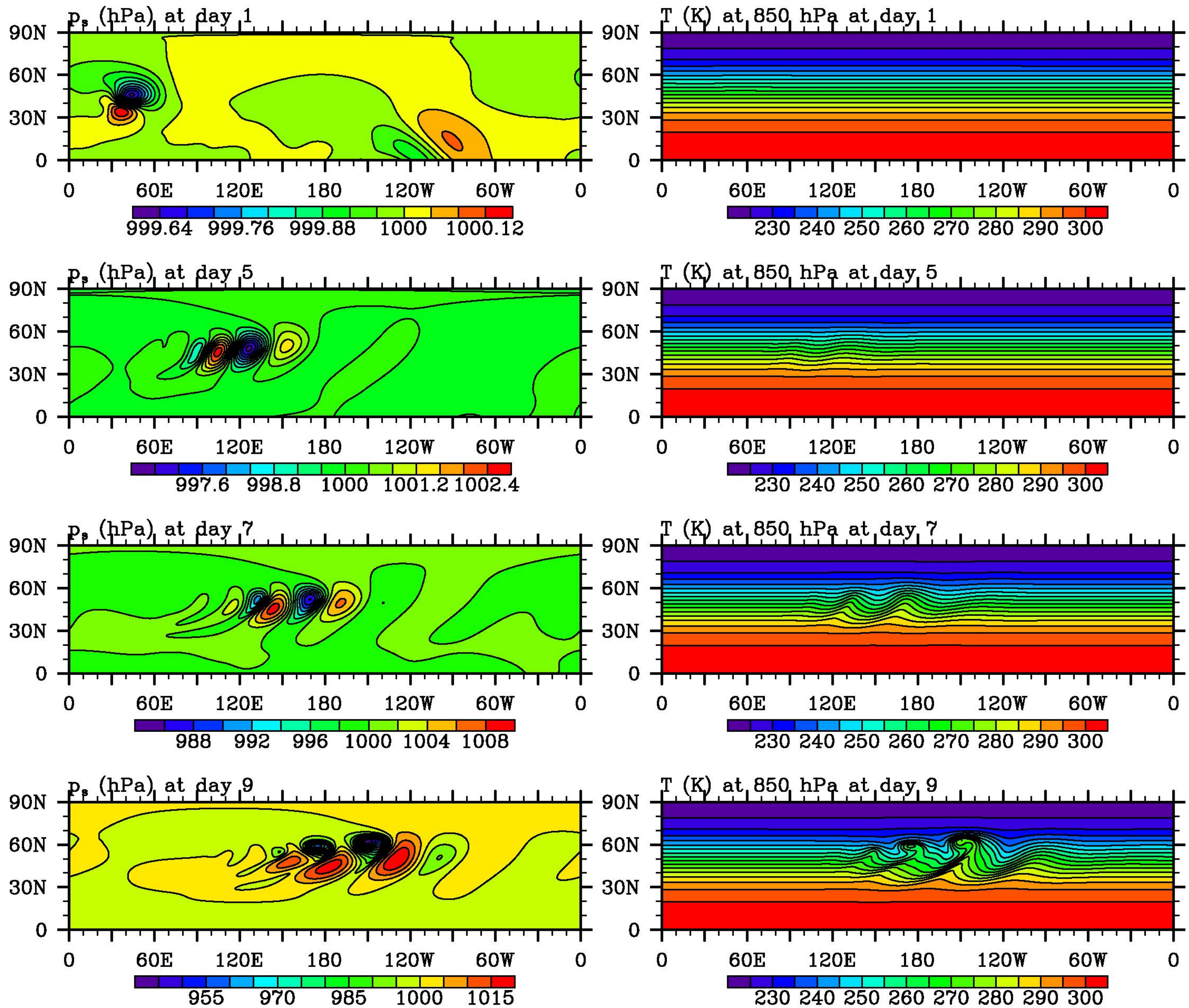
Numerical experiments (dynamics of hydrostatic atmosphere).

Baroclinic wave test case (Jablonowski, Williamson, QJRMS, 2006)

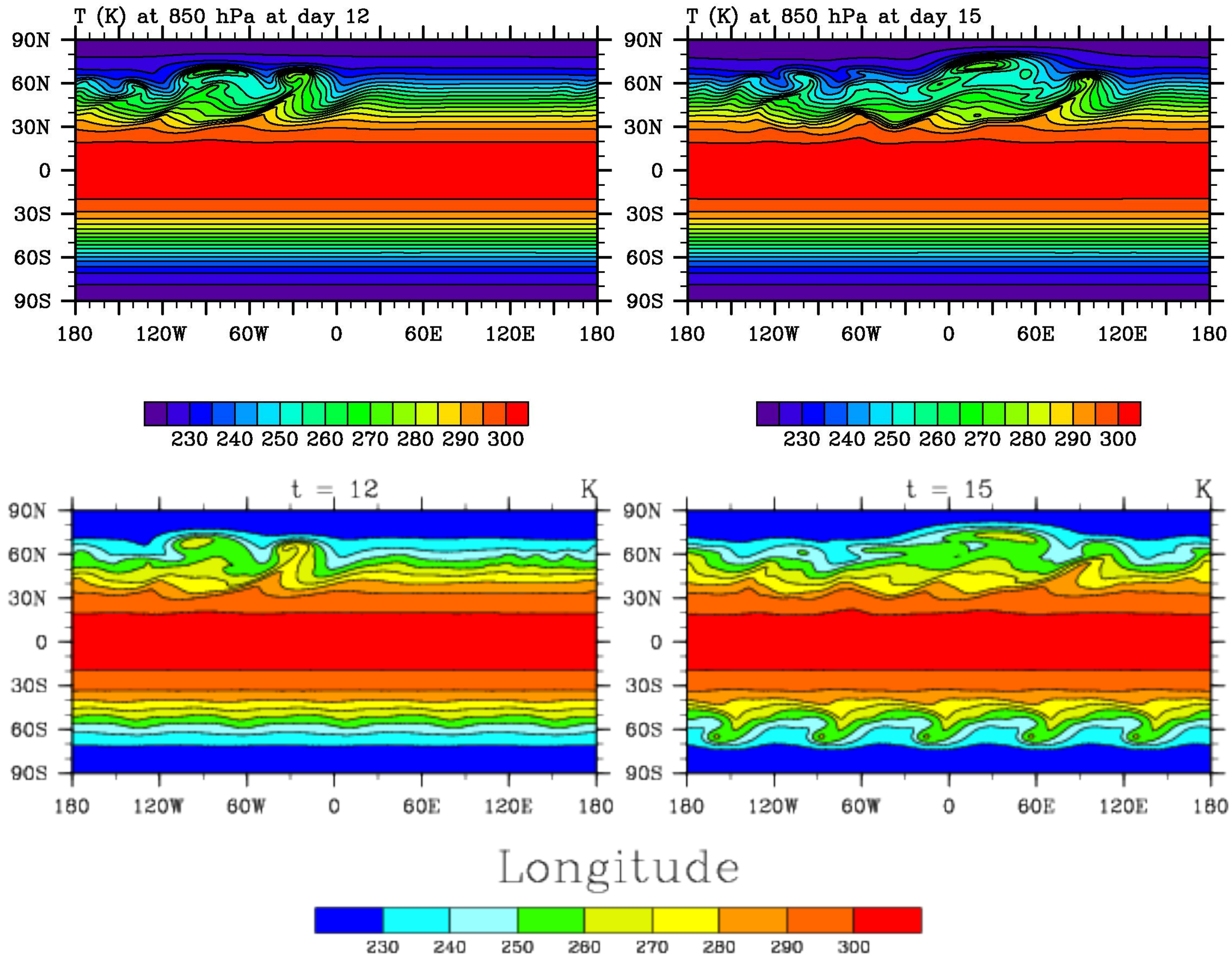
Initial conditions:

- Geostrophically balanced zonal flow with two midlatitude jets
- zonal wind speed perturbation overlaid

Development of baroclinic wave
(see next slide)



Development of the baroclinic wave. Surface pressure (left), 850 hPa temperature (right). From top to bottom – day 1, day 5, day 7, day 9.



850 hPa temperature after 12 (left) and 15(right) days. Mass-conservative SLAV solution (upper row) and hexagonal ICON model solution (lower row).

Numerical experiments (dynamics of hydrostatic atmosphere)

- Good agreement between mass-conservative SLAV solution and othe models solutions (including standard non mass-conservative SLAV)

- Difference norms between mass-conservative SLAV solution and high resolution reference solutions are below the uncertainty limit (Jablonowski, Williamson, QJRMS, 2006)

- Global mass of the atmosphere is conserved up to machine precission (Monotonic mass decrease in standard SLAV)

- Mass conservative SLAV was stable and adequate in 72 hour real initial conditions simulations

INM soil heat and moisture transfer model in a multilayer vertical domain (Lykossov, Volodin) Distinctive features:

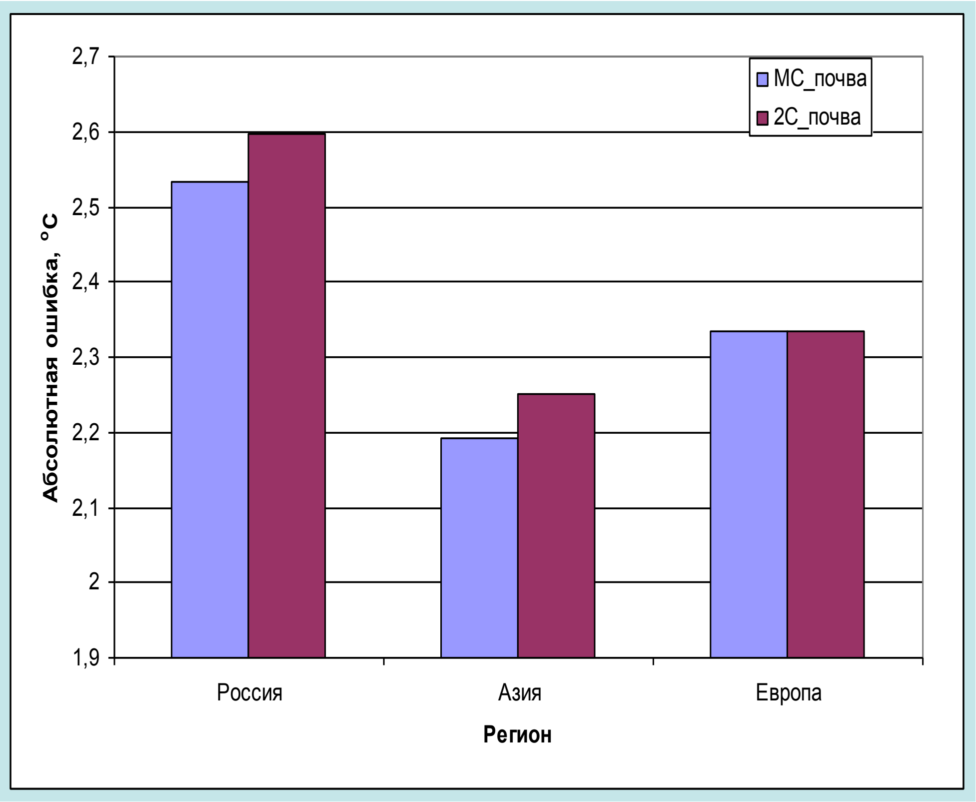
1. Simultaneous solution of the heat, water vapor, liquid ice diffusion and soil ice dynamics equations

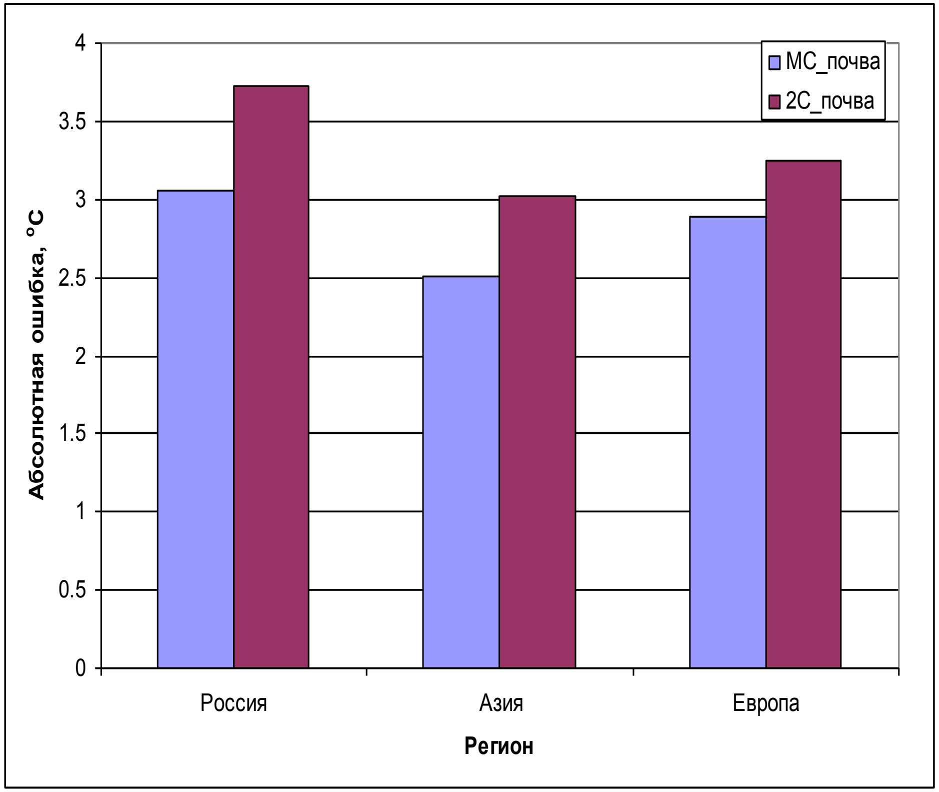
2. Accurate description of the phase transitions

3. Vertically inhomogeneous soil profile. Soil texture is dependent on the location and depth

4. Flexible choice of the vertical layers' depths, including the possibility to simulate deep permafrost

Impact of soil parameterization on 72-hours medium range forecasts: T2m abs. error, 30 forecasts for April 2012 00UTC Red – 2-layer ISBA, blue – INM soil model (Russia, Asia, Europe)





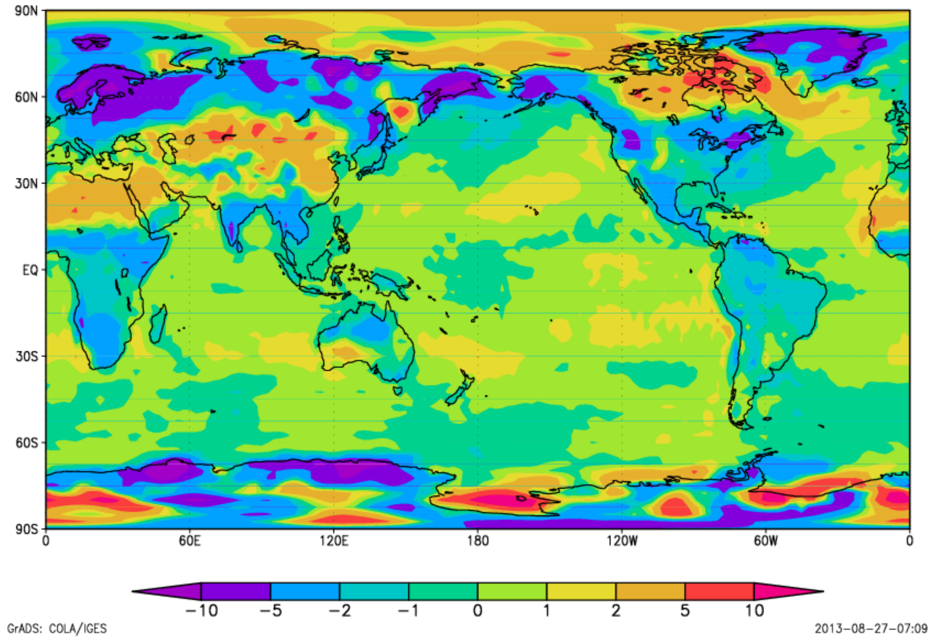
Initialization technique:

1. Stand-alone INM soil heat and moisture transfer model simulations based on ECMWF reanalysis data. Perpetual year 1980.

2. Quasi-assimilation with a correction of the first 3 upper soil layers' temperature within the SL-AV model driven by ECMWF reanalysis data for 1981.

3. Seasonal forecasts for the spring 1982, starting in the end of January 1982

a



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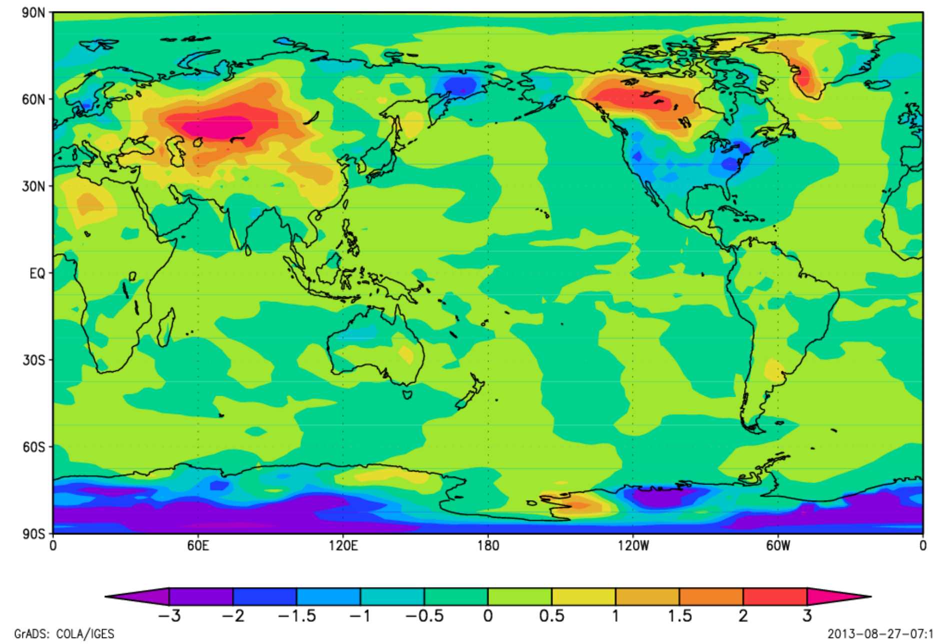
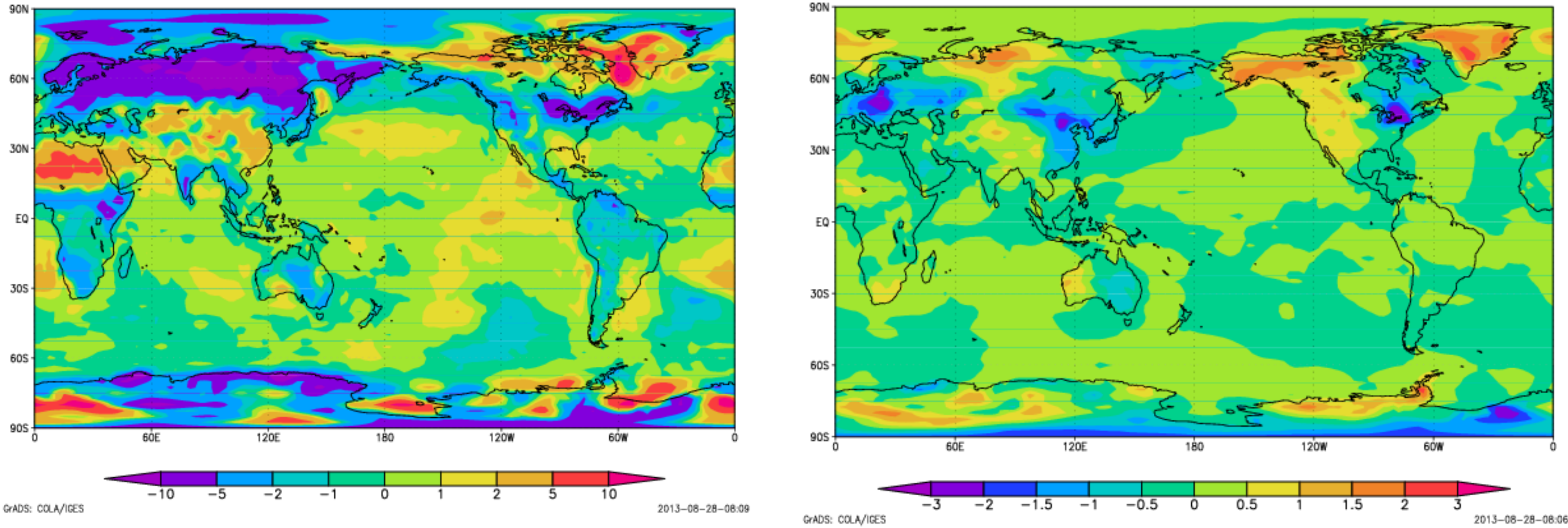


a) T2m mean bias for the simulations with a standard (ISBA) soil parameterization

and b) the difference in the T2m bias between the simulations with a standard and a new (INM multilayer) soil parameterization.

Seasonal forecast for March 1982 starting from the end of January.

a b



a) T2m bias for the simulations with a standard (ISBA) soil parameterization

and b) the difference in the T2m bias between the simulations with a standard and a new (INM multilayer) soil parameterization. Seasonal forecast for March 1983 starting from the end of January.

Further developments

- RRTM-G SW and LW radiations with McICA (freeware. Used by ECMWF, NCEP, NCAR,…). Very expensive computationally!
- Initialization technique for multi layer soil moisture based on extended Kalman filter (similar to ECMWF)

Thank you for attention!