Global semi-Lagrangian atmospheric GCM oriented towards simulation of the atmospheric circulation on time scales from 1 to 120 days

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Outline

- Medium-range forecasts (1-10 days)
- Seasonal forecasts (30-120 days)
- Strategy for development of the next generation high-resolution dynamical core

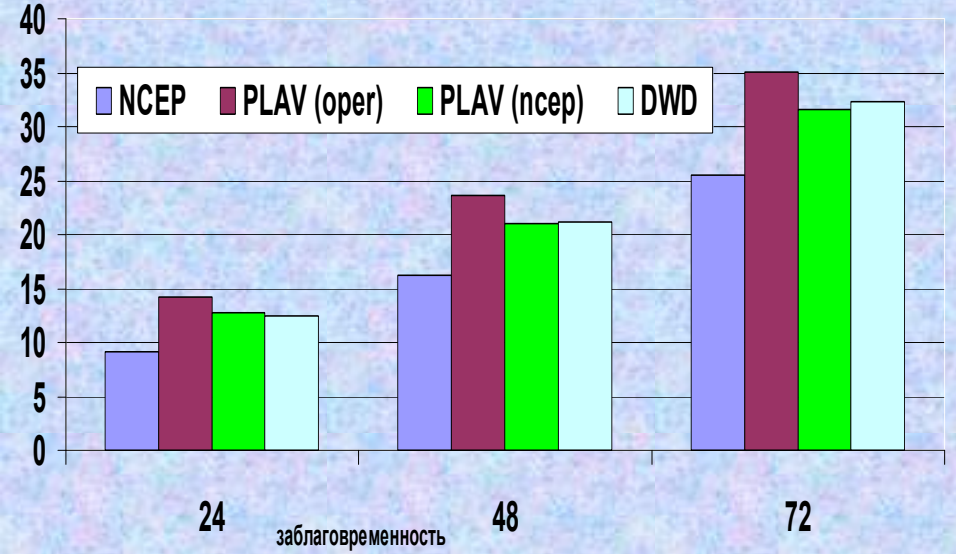
SL-AV model

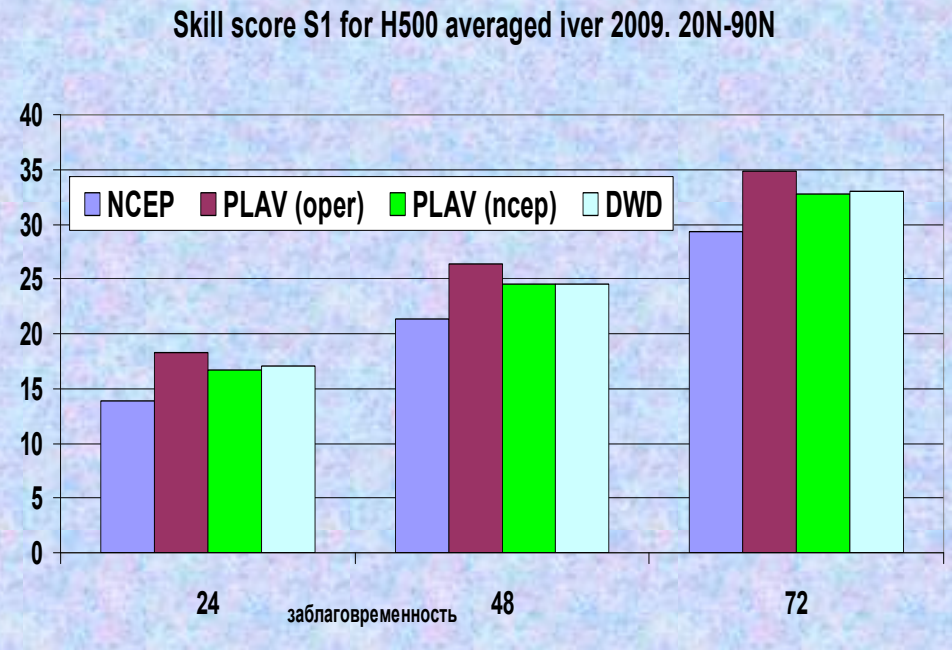
- Dynamical core of own development (vorticity-divergence formulation on the unstaggered grid; 4^{th} order finite differences). Validated in Held-Suarez test (3yr integration)
- Subgrid-scale parameterizations from French model ARPEGE/ALADIN (ALARO branch).

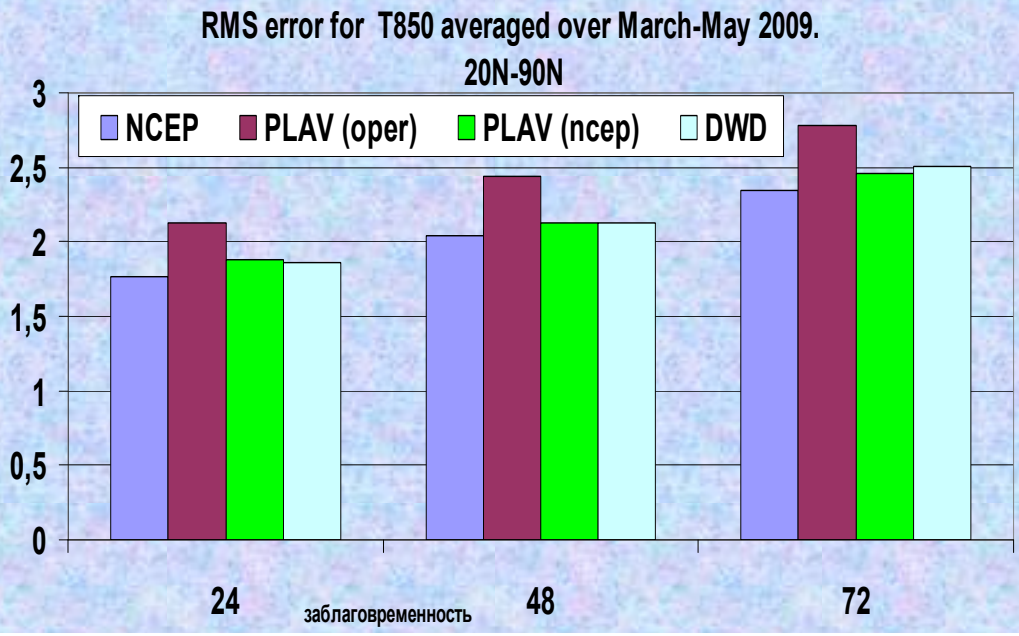
1. Medium range forecasts

- Currently, horizontal resolution 0.9x0.72 degrees lon-lat, 28 levels.
- Runs operationally at RHMC twice a day.
- Forecasts on the web site www.meteoinfo.ru
- New version with 0.45x0.37 horizontal resolution, 50 vertical levels.

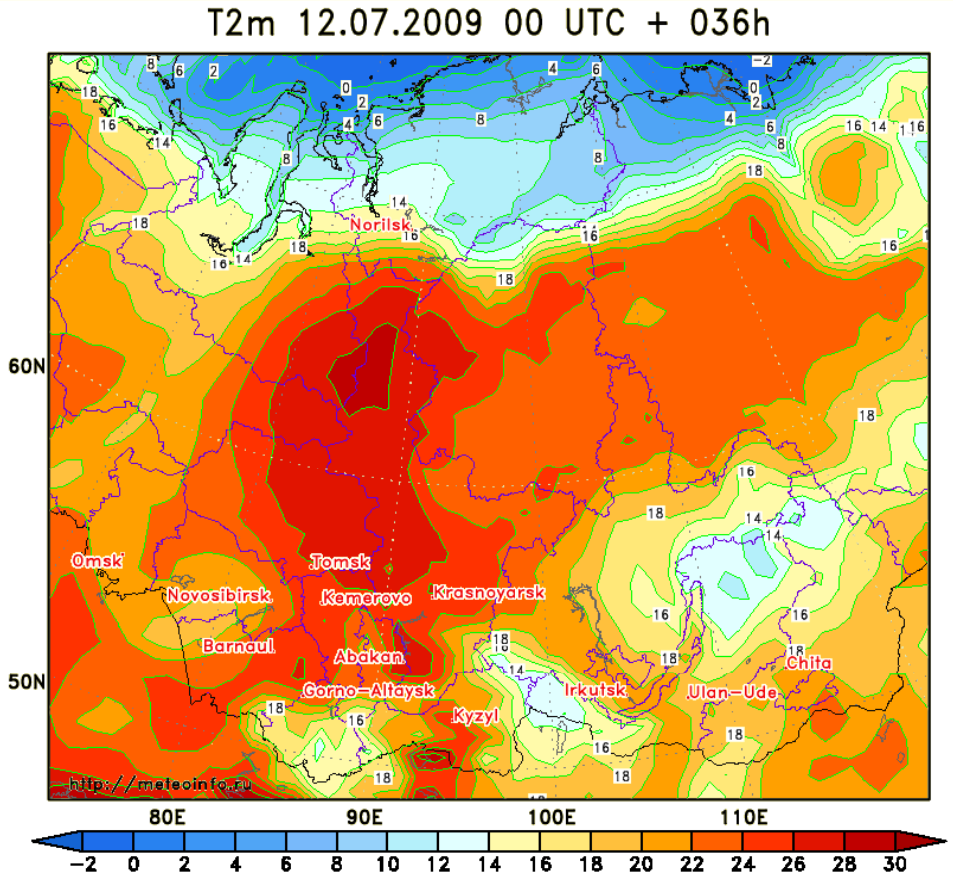
Impact of initial conditions

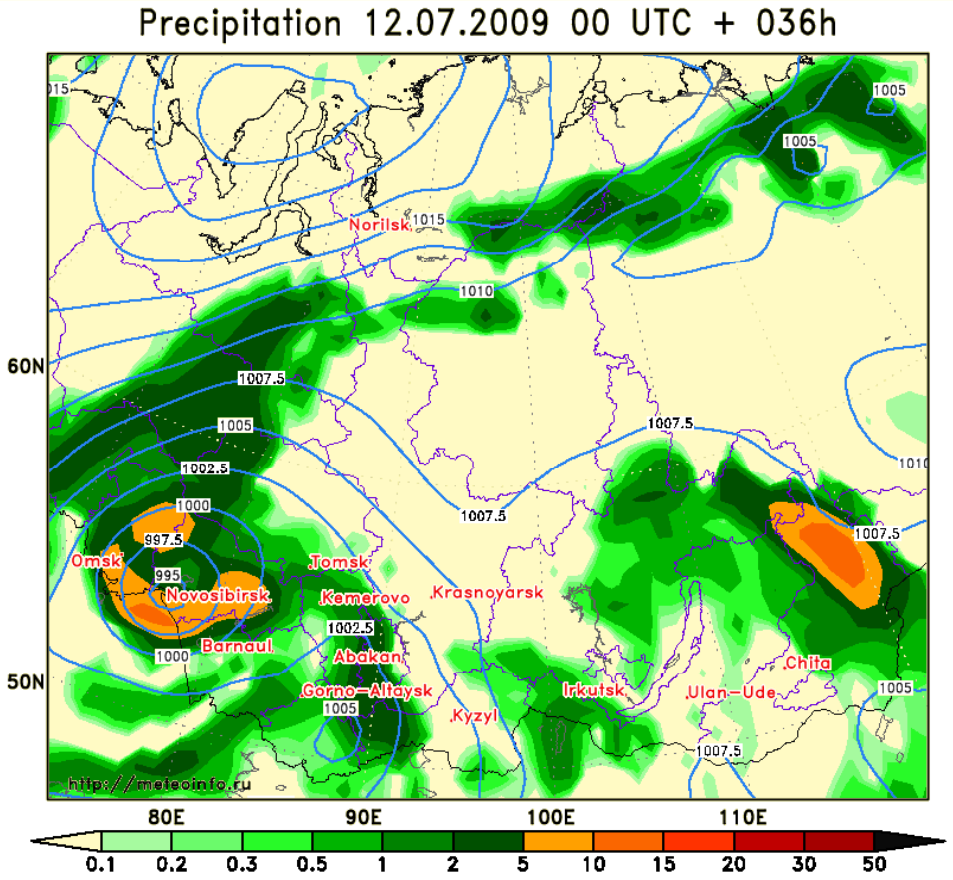






36-hr forecast for this evening

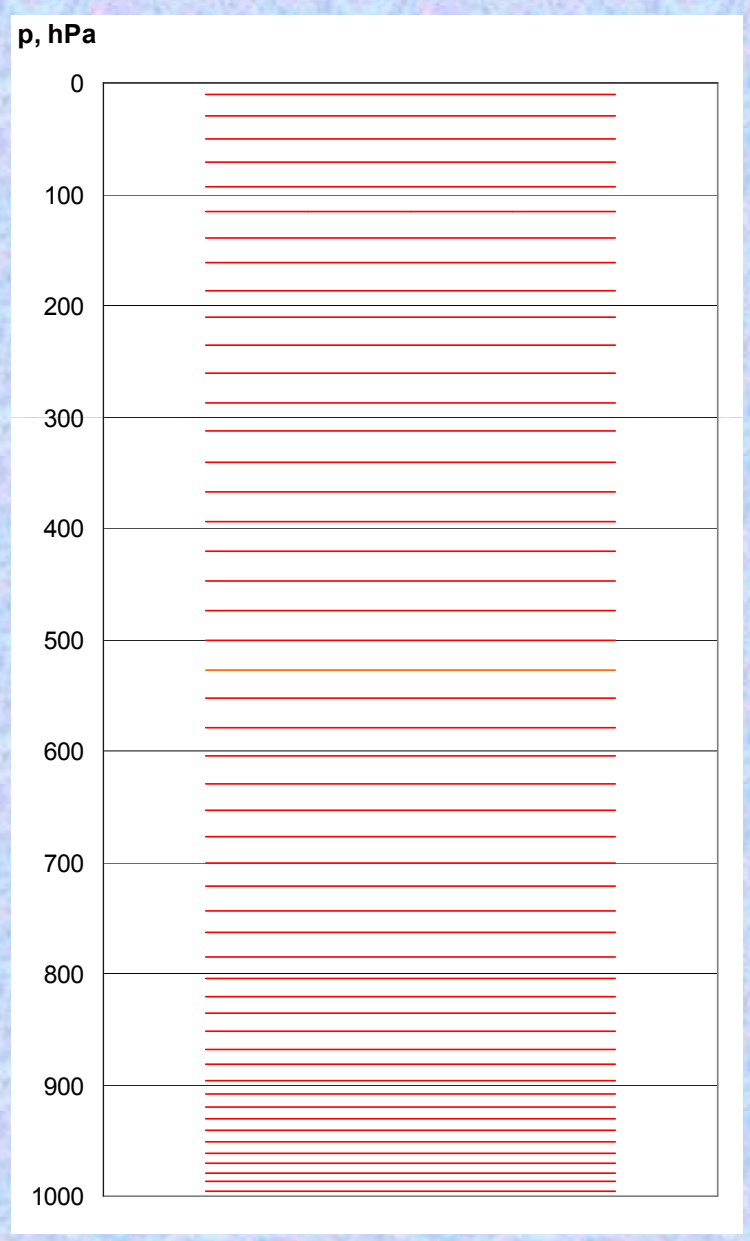


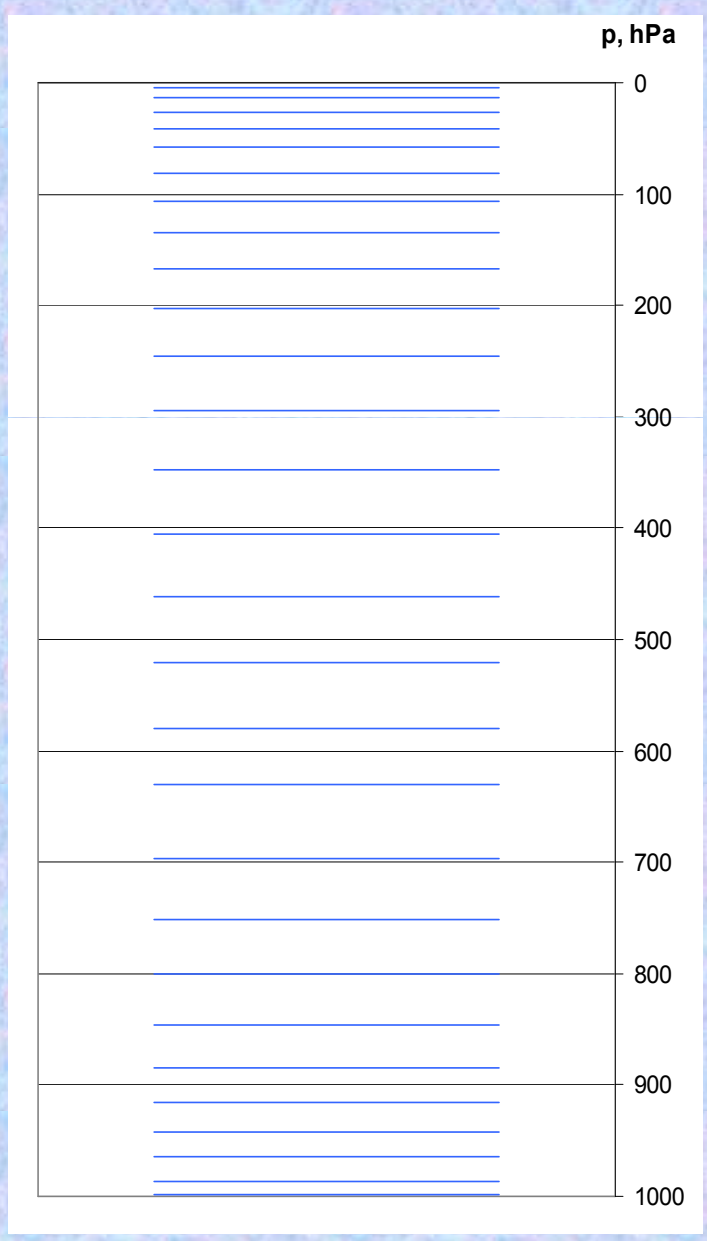


New version of SL-AV medium-range forecast model

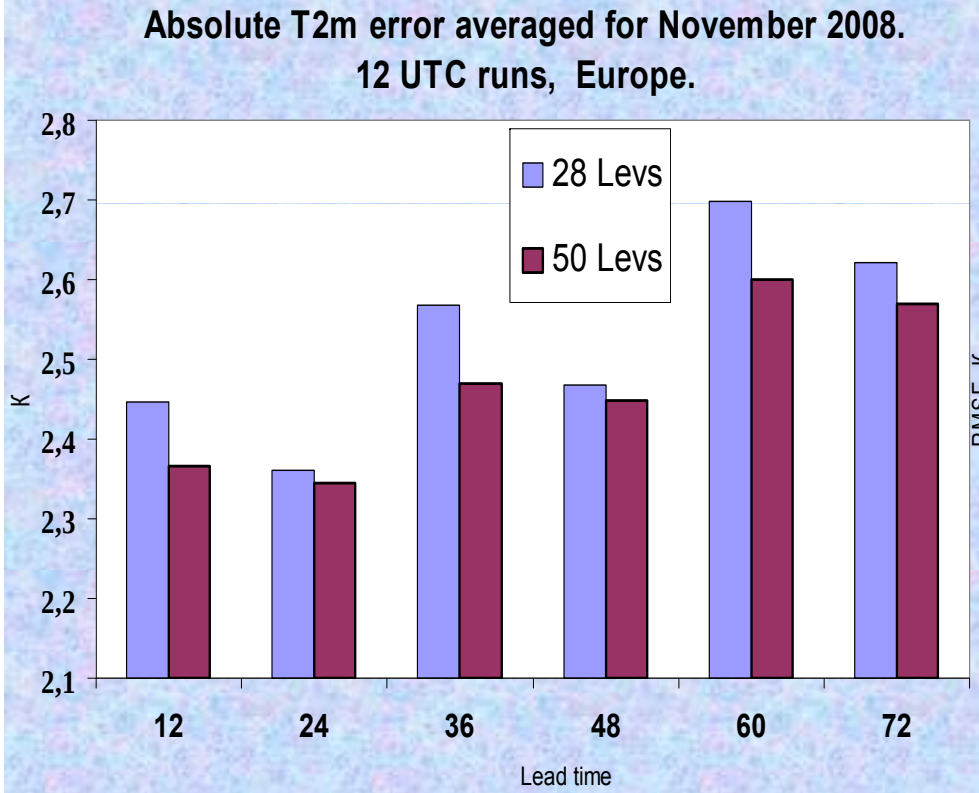
- First, the increase of the vertical resolution from 28 to 50 levels
- Then the horizontal resolution was increased to 0.45x0.37 in the Northern hemisphere.

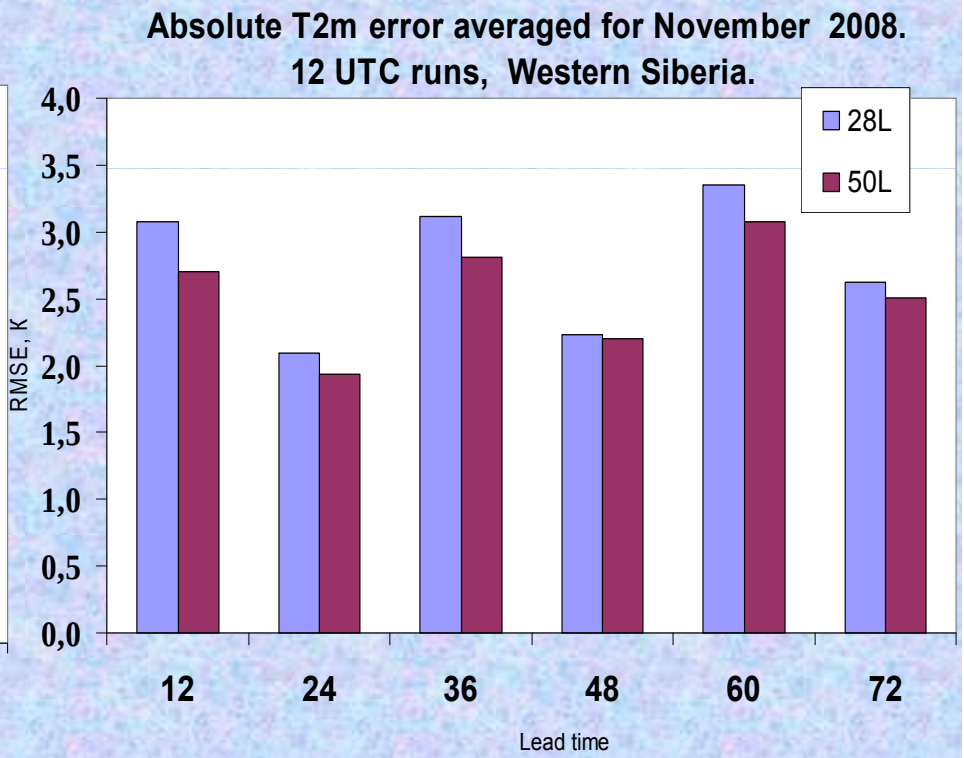
Layout of vertical levels: 50 and 28



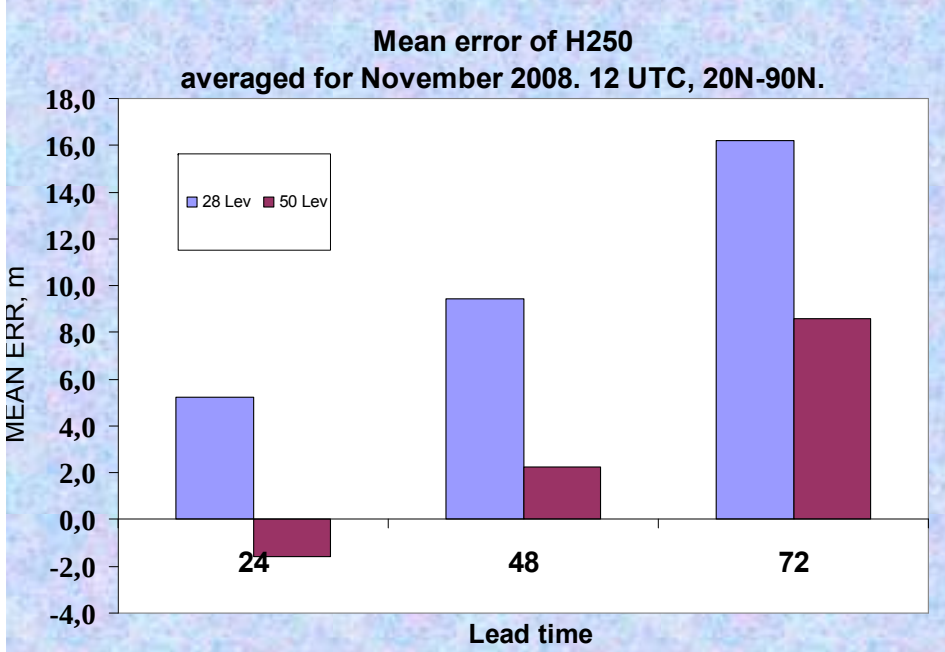


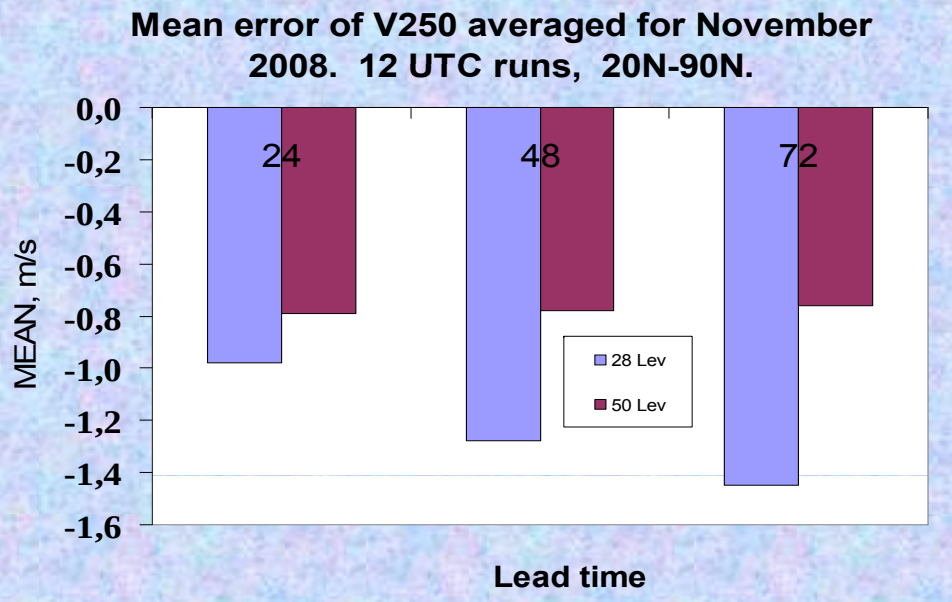
T2m forecast in the 0.9x0.72 model with 28 and 50 levels



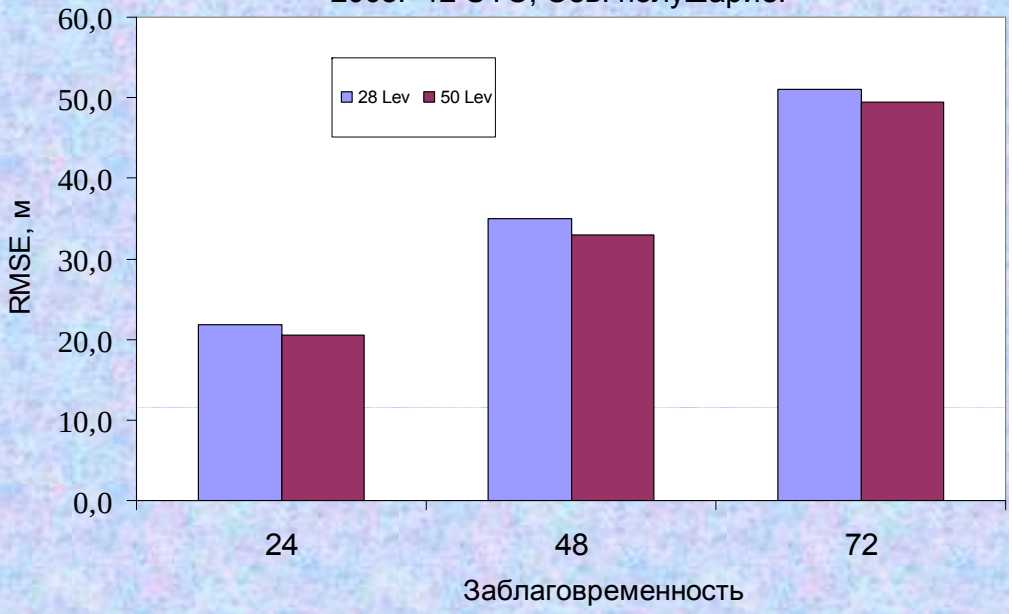


Some scores for 50 and 28 levels versions

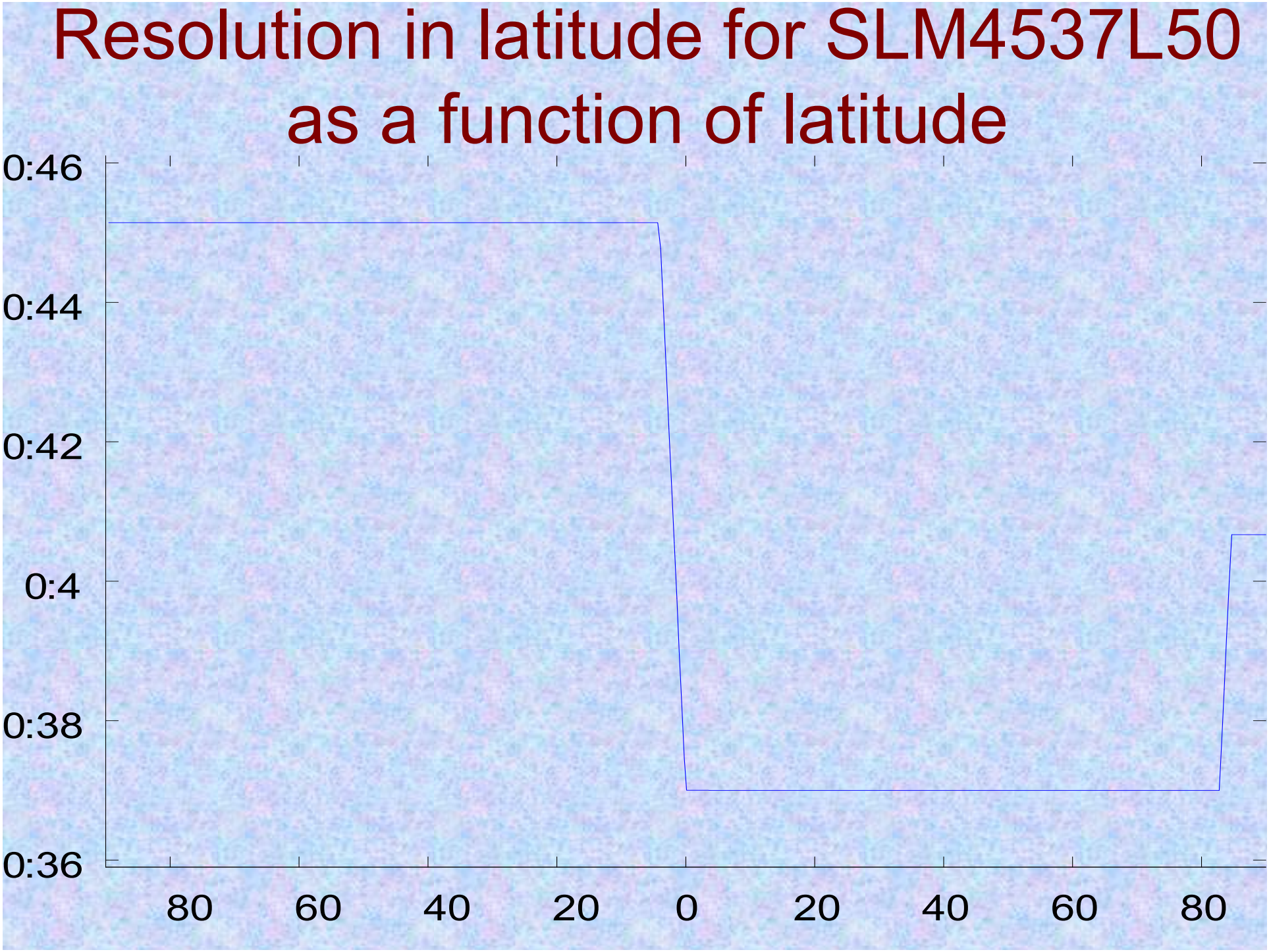




Среднемесячная среднекв. ошибка прогноза H250 за ноябрь 2008. 12 UTC, Сев. полушарие.



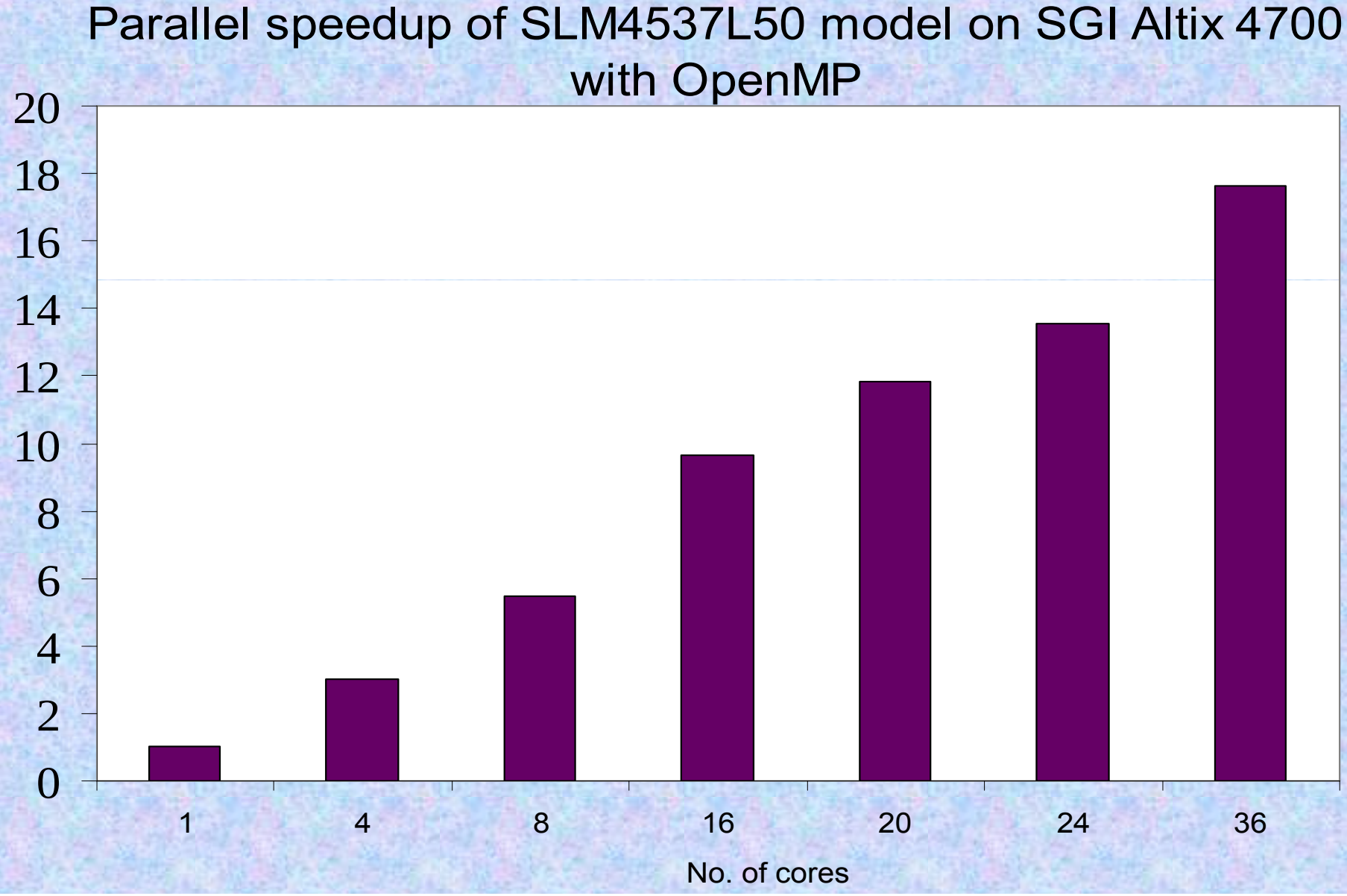
Resolution in latitude for SLM4537L50 as a function of latitude



First results for SLM4537L50

- Reduction of skill score (gradient error) with respect to 0.9x0.72 version.
- Parallel speedup with OpenMP as expected.

Wall-clock time for 1-day forecast 36 cores = 22 min



2. Seasonal forecasts

- Forecast of a mean seasonal anomaly of atmospheric circulation with respect to climate.
- Usually for 4 months with 1 month lead time
- Ensemble technology is commonly used
- Computationally expensive => requires efficient atmospheric model

SL-AV atmospheric model, seasonal version

- Global semi-Lagrangian finite-difference model.
- Semi-Lagrangian advection enables large time steps (~4-5 CFL)
- Horizontal resolution 1,40625°x1 lon-lat,125°, 28 vertical levels
- No vegetation in the old version, ISBA scheme in the new version
- The model contributes to the multi-model ensemble of APCC. Forecasts are at http://www.meteoinfo.ru/season

Validation issue

- The forecast lead time is too long to enable reliable statistics in reasonable time
- Two kinds of forecasts are considered:

  - historical forecasts (hindcasts), e.g. starting from reanalyses

  - real time forecasts starting from RHMC analyses (size of prognostic ensemble -10, breeding is used to generate this ensemble)

Drawbacks of the old seasonal version

- Unrealistic high precipitation in tropics, wrong geographical distribution (lack of precipitation in continental tropics)
- T850 too warm over Antarctida, too cold (by 2 degrees) over tropics
- H500 is 30-40 m lower

All this was attributed to the absence of modern surface (soil-vegetation-snow) parameterization

New version of seasonal prediction model

- In the old version, there was no vegetation; 100 % daily relaxation to climate values of deep temperature Tp and water content Wp
- New version – parameterization of interaction between soil, vegetation, snow, soil ice and the atmosphere ISBA (Noilhan, Planton 1989, Giard, Bazile, 2000)
- Also:

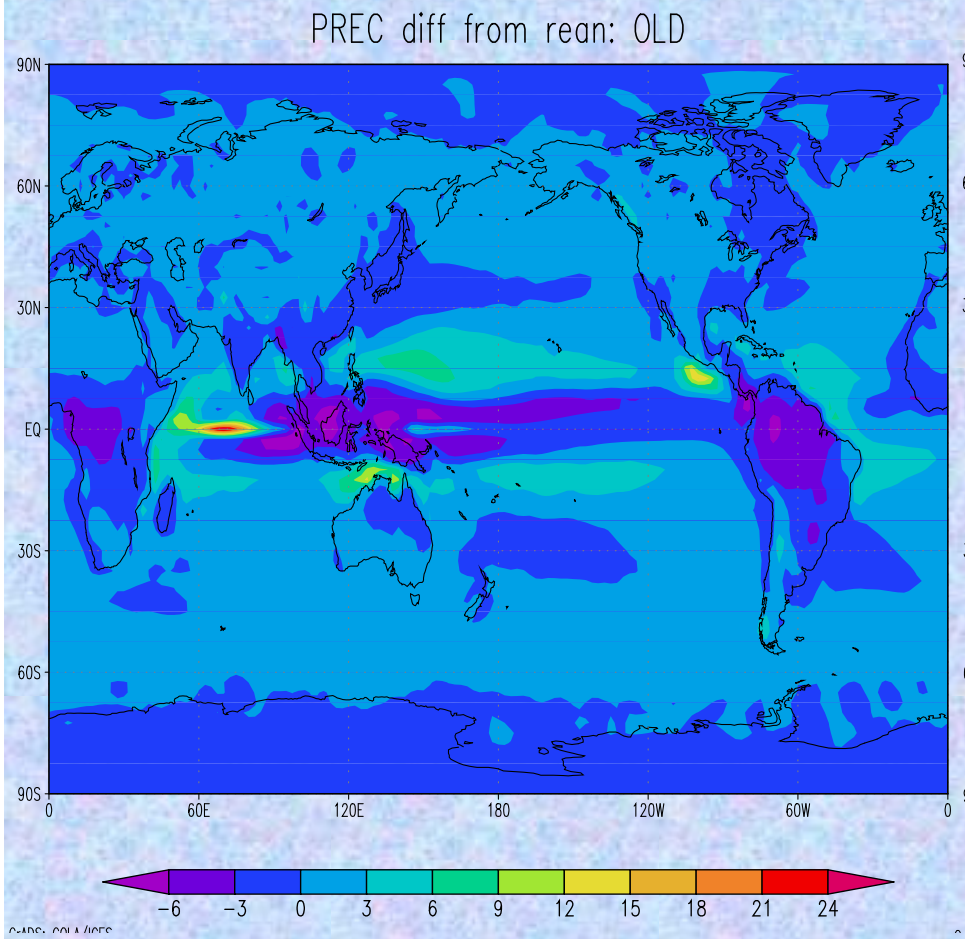
  - New version of solar and thermal radiation

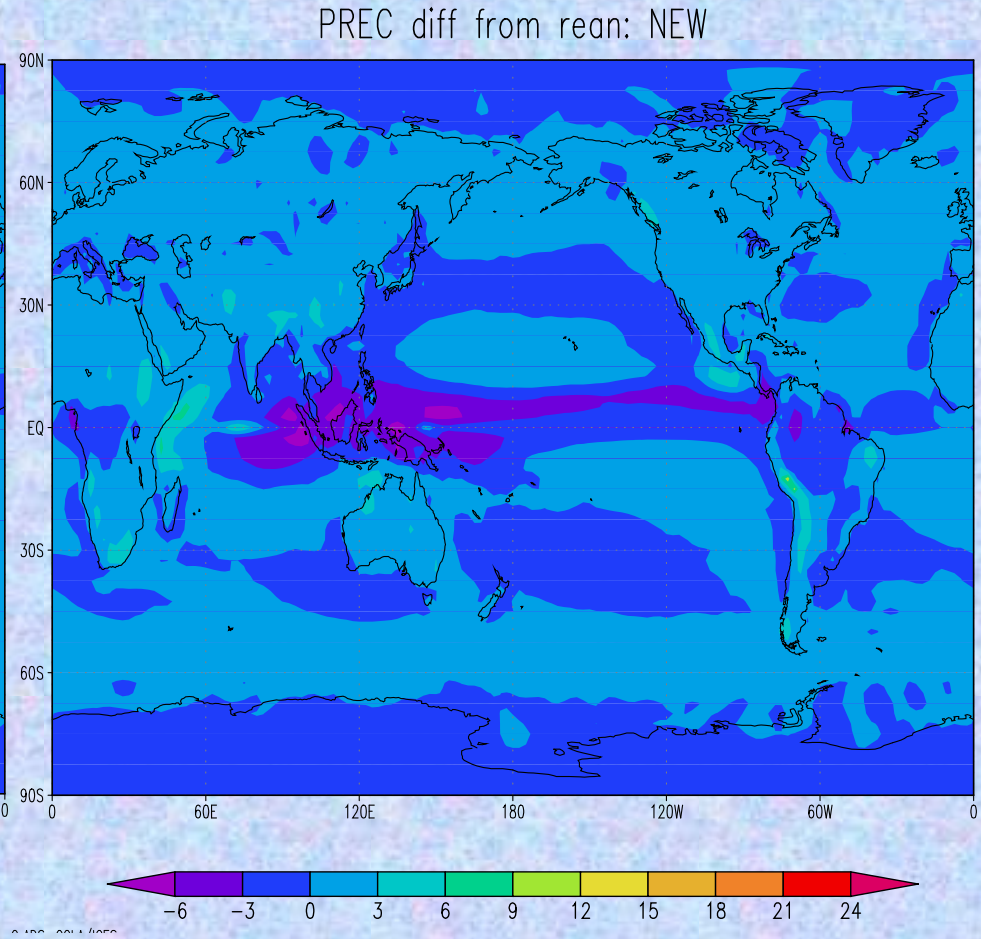
  - Some changes in PBL and cloudiness parameterizations

Evaluation of the new version

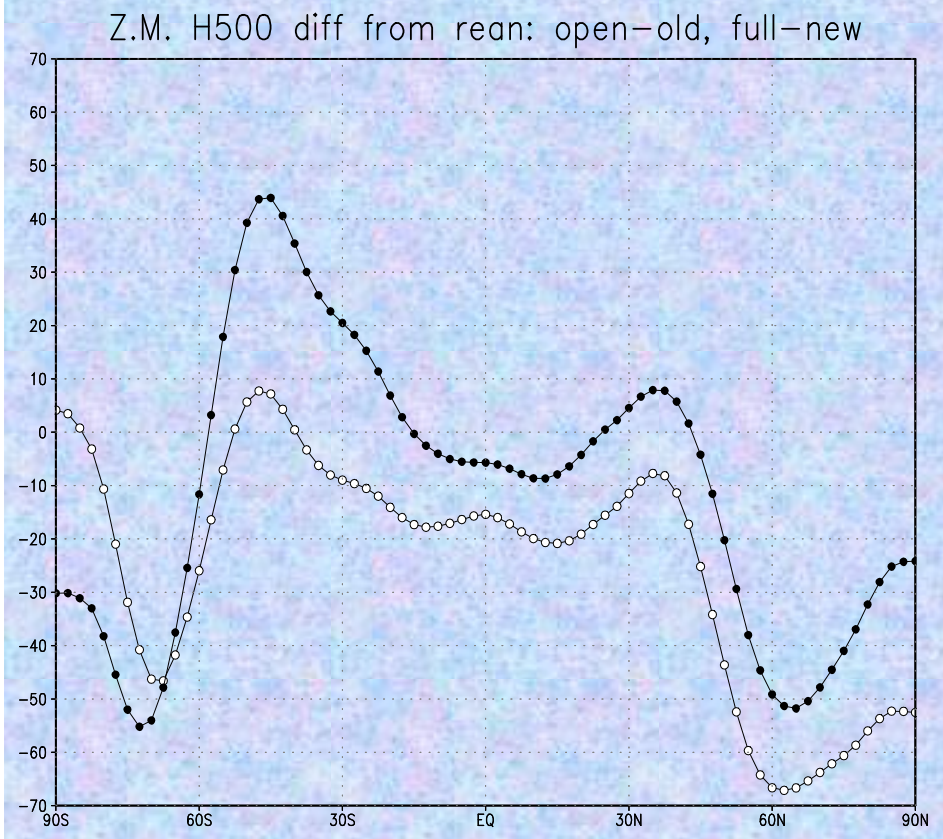
- Historical “forecasts” (SMIP-2/HFP protocol) using NCEP/NCAR reanalysis-2 data as initial data and verification data.
- 120-days runs, data for days 31-120 used for verification.
- 25 years, 4 seasons, 10 ensemble members.
- Comparison with the old version.

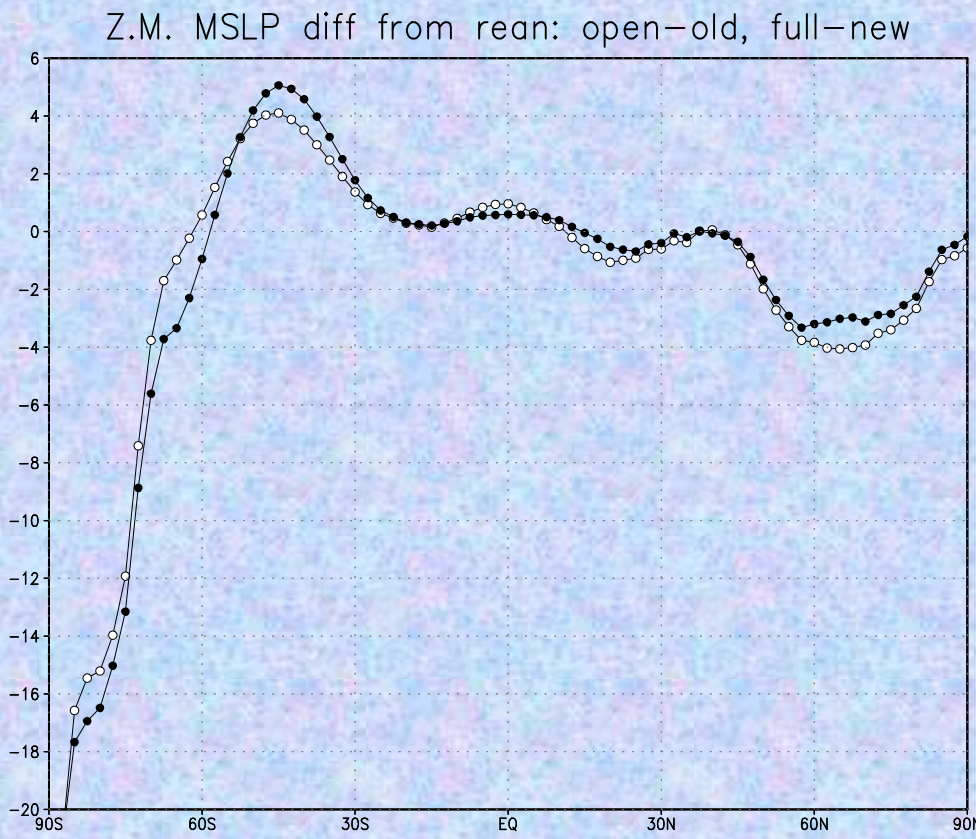
Differences with the reanalysis: Precipitation



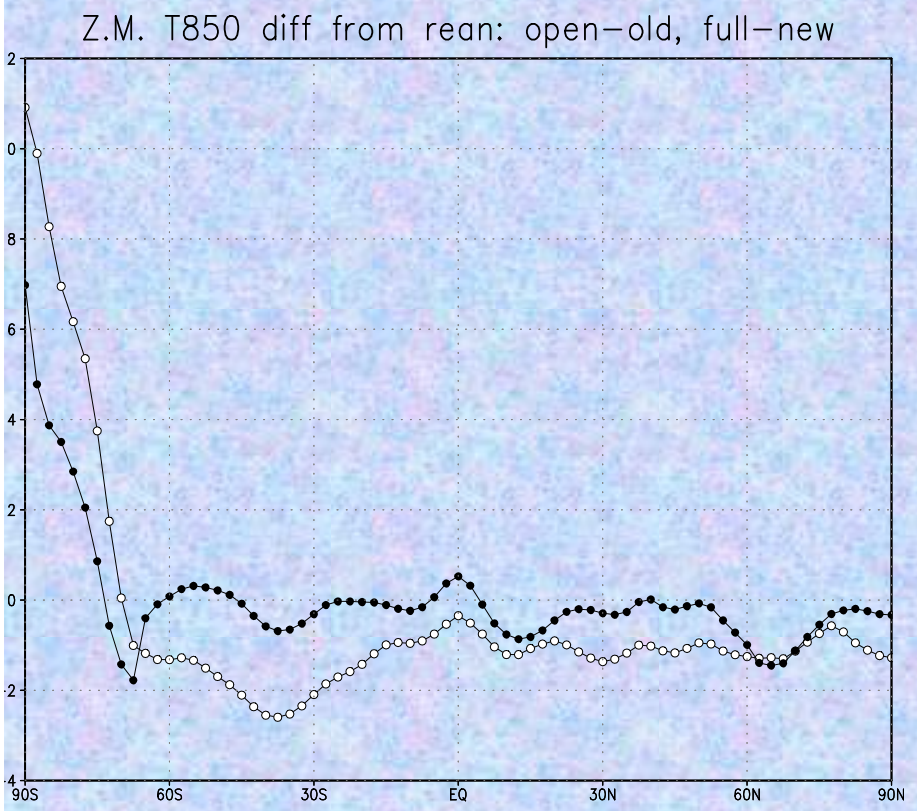


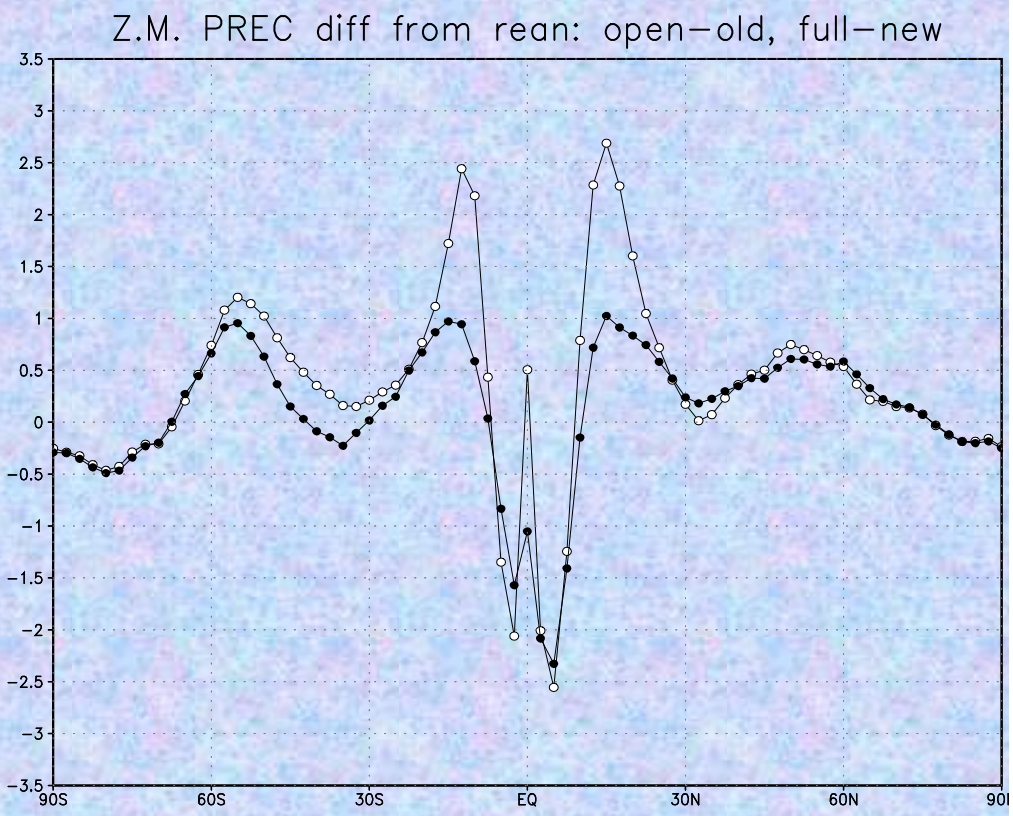
Differences with the reanalysis: H500 (left), MSLP (right)



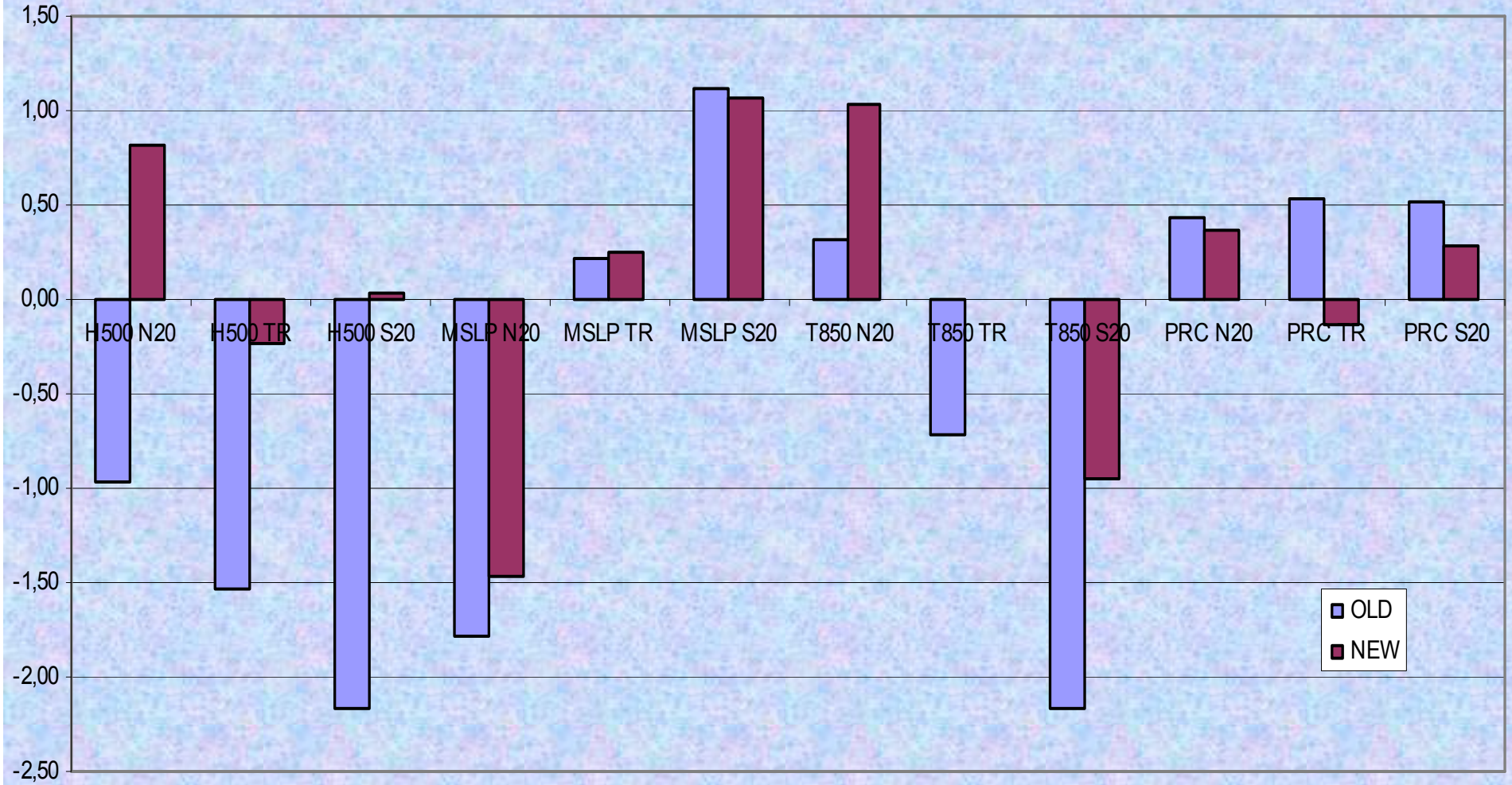


Differences with the reanalysis: T850 (left), Precipitation (right)

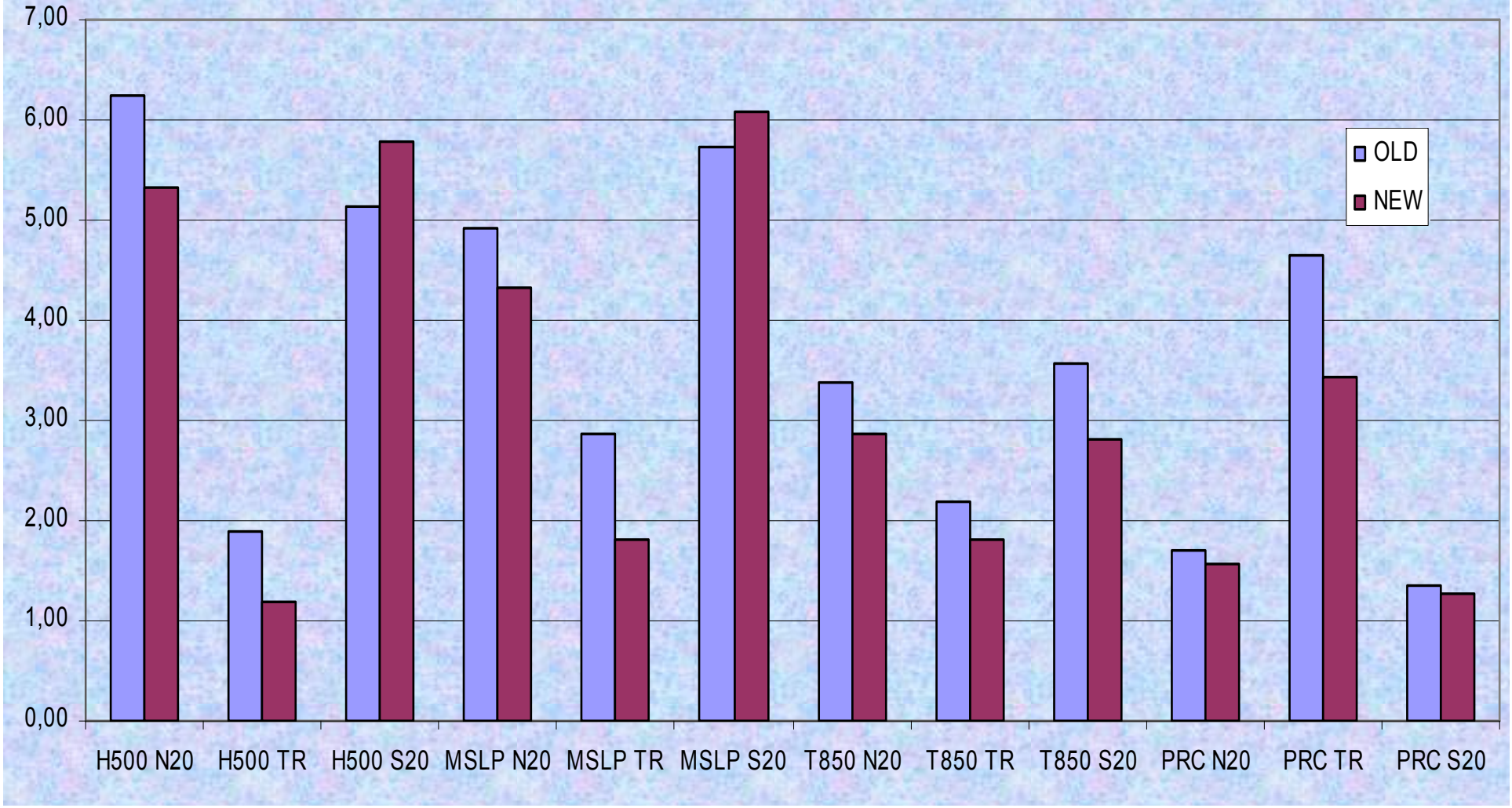




Averaged over 4 seasons and 25 years mean error for seasonal hindcasts: H500*0.1, MSLP,T850,PREC (S20=90S ... 20S; N20=20N …90N; TR=20S…20N)



Averaged over 4 seasons and 25 years RMSE for seasonal hindcasts: H500*0.1, MSLP,T850,PREC (S20=90S ... 20S; N20=20N …90N; TR=20S…20N)



3. Strategy for development of the next generation dynamical core

Current state of global NWP models

- Typical horizontal resolution at the end of 2009 – 20-30 km
- Japan is the leader with 20 km, next year ECMWF will be the leader with 15 km

The increase of the processor number necessary for operational implementation of the SL-AV model

- 70 km, 28 levels – 4 processors
- 37 km, 50 levels – 40 processors
- 20 km, 50 levels - about 350 processors
- 10 km , 100 levels – supposedly 6000 processors

Development of new dynamical cores for global NWP models

- Currently, a half of global NWP models us based on spectral techniques
- It scales up to~0.5N_harm* N_openmp(*N_lev) processors, ~5000 for T1279.

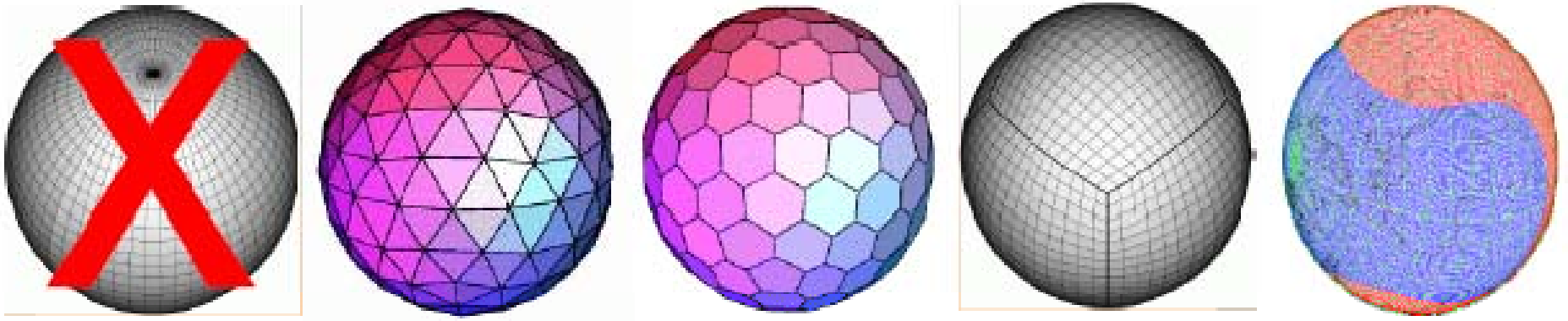
Forecast Centre (Country)	2009	2010	2011	2012	2013	2014
ECMWF (Europe)	T_L799 L91	T_L1279 L91	T_L1279 L140	T_L1279 L140	tbd	tbd
Met Office (UK)	25 km L70	25 km L70	20 km L90	tbd	tbd	tbd
Météo France (France)	T799c2.4 L70	T799c2.4 L70	T1240c2.4 L90	tbd	tbd	tbd
DWD (Germany)	30 km L60	30 km L60	15 km L70	15 km L70	tbd	tbd
HMC (Russia)	T169 L31; 0.72°x0.9° L50	T169 L31; 0.37°x0.45° L50	T339 L63; 0.19˚x0.225˚L60	tbd	tbd	tbd
NCEP (USA)	T382 L64 (7.5) T190 L64 (16)	T878 L91 (7.5) T574 L91 (16)	25 km L90	25 km L90	25 km L90	25 km L90
CMC (Canada)	(0.45°x0.3°) L80	(0.45°x0.3°) L80	(0.45x0.3°) L80	(0.45°x0.3°) L80	(0.3°x0.2°) L90	(0.3°x0.3°) L90
CPTEC/INPE (Brazil)	20 km L96	20 km L96	20 km L96	10 km L96	10 km L128	tbd
JMA (Japan)	T_L959 L60	T_L959 L60	T_L959 L60	tbd	tbd	tbd
CMA (China)	T_L639 L60 GRAPES 50 km L31	T_L639 L60 GRAPES 50 km L31	T_L639 L60 GRAPES 50 km L31	GRAPES 25 km L31	GRAPES 26 km L31	tbd
KMA (Korea)	T426 L40	40 km L50	25 km L70	25 km L70	25 km L90	tbd
BoM (Australia)	ACCESS ~80 km L50	~40 km L50	25 km L70	25 km L90	tbd	tbd

New dynamical cores of atmospheric models

- High parallel efficiency, locality of data
- A grid on the sphere with quasiconstant resolution
- Computational efficiency of numerical algorithm (sufficiently long time-step)
- Nonhydrostatic formulation (includes sound waves)

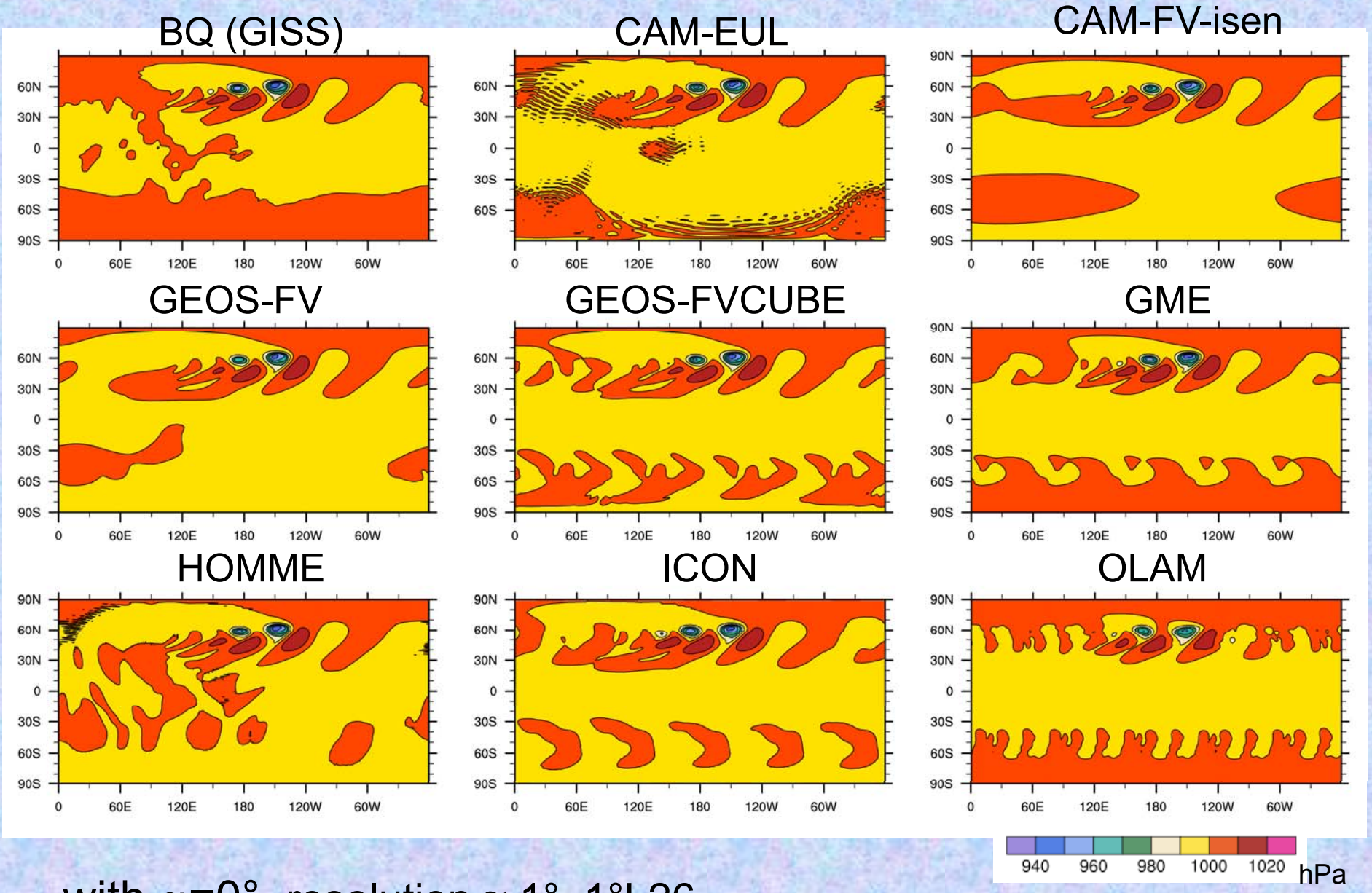
Choice of the grid

- Traditional lat-lon grids have condensed meridians near the poles (from presentation by W.Skamarock, NCAR)



lat-long grid | icosahedral grid (triangles) | icosahedral grid (hexagons) | cubed sphere | Yin-Yang grid

Evolution of p_s, day 9 (Jablonowski test)



with α=0°, resolution ≈ 1°×1°L26

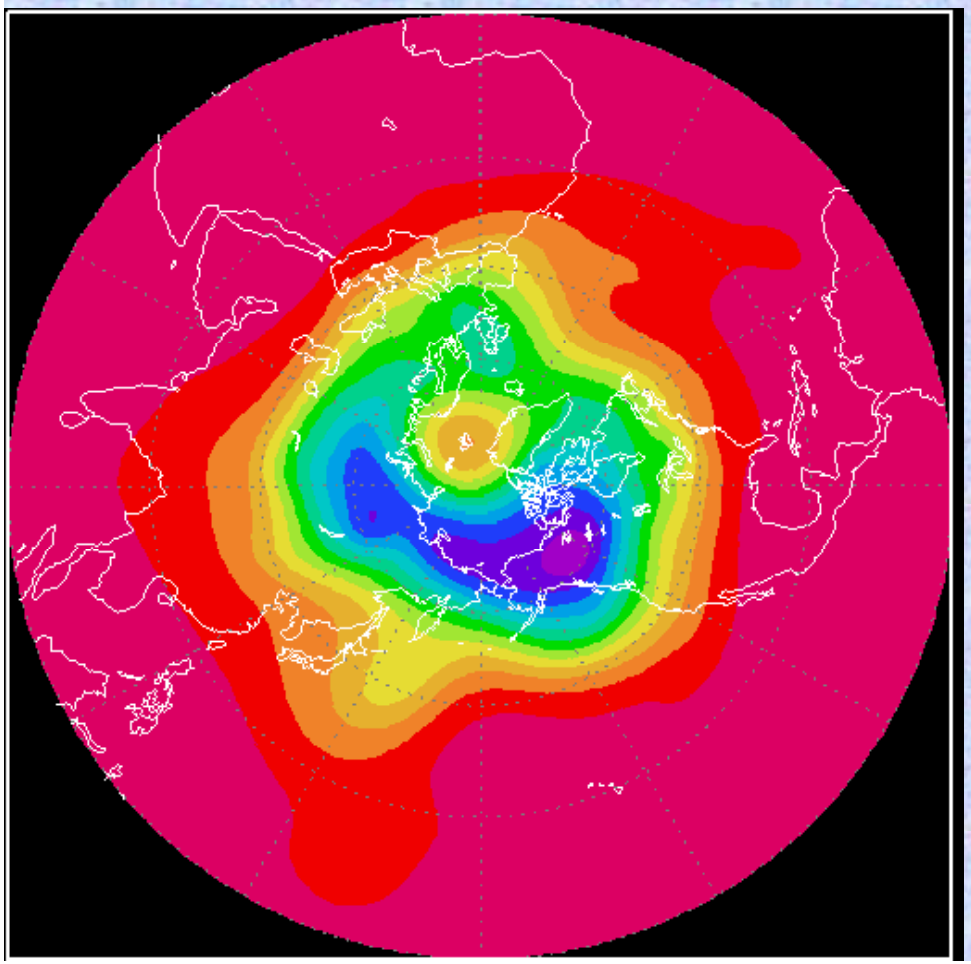
Reduced latitude-longitude grid

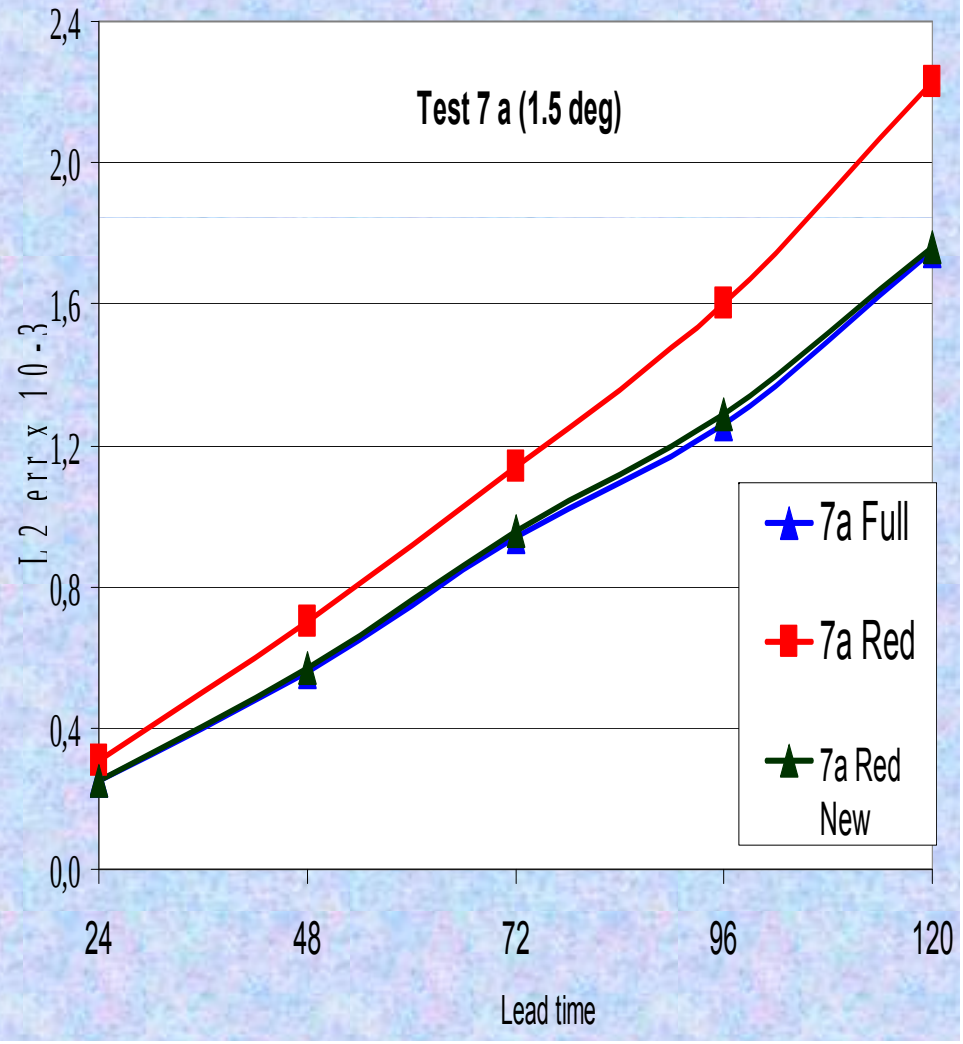
- Routinely used in models based on spectral approach. It is possible to use it in finite-difference/finite volume models with specific formulation
- Advantages

- High-order approximations are easily possible

- Easy to code and parallelize

Shallow-water model





Some directions of development for the global semi-Lagrangian model SL-AV

- Increasing the scalability of the code from ~300 to 5000 processors.
- Replacement of 1D solvers by divide-and conquer algorithms.
- Nonhydrostatic dynamical core.
- Mass-conserving semi-Lagrangian scheme
- More advanced land surface parameterization

(bogs, carbon cycle, multilayer soil, soil hydrology…)

Conclusions

- The works of the last years allowed to increase the accuracy of the SL-AV model, both for medium-range and seasonal version
- Challenges of the nearest decade – development and implementation of global atmospheric models with the horizontal resolution 1-10 km.
- New approaches are required to develop new dynamical cores and parameterizations
- This requires efficient parallel implementation on ~ 10000 processors

Thank you for attention!