Recent changes in Alaro dynamics

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profiting also from the work of J. Mašek, R. Brožková, I. Bašták-Ďurán and N. Pristov

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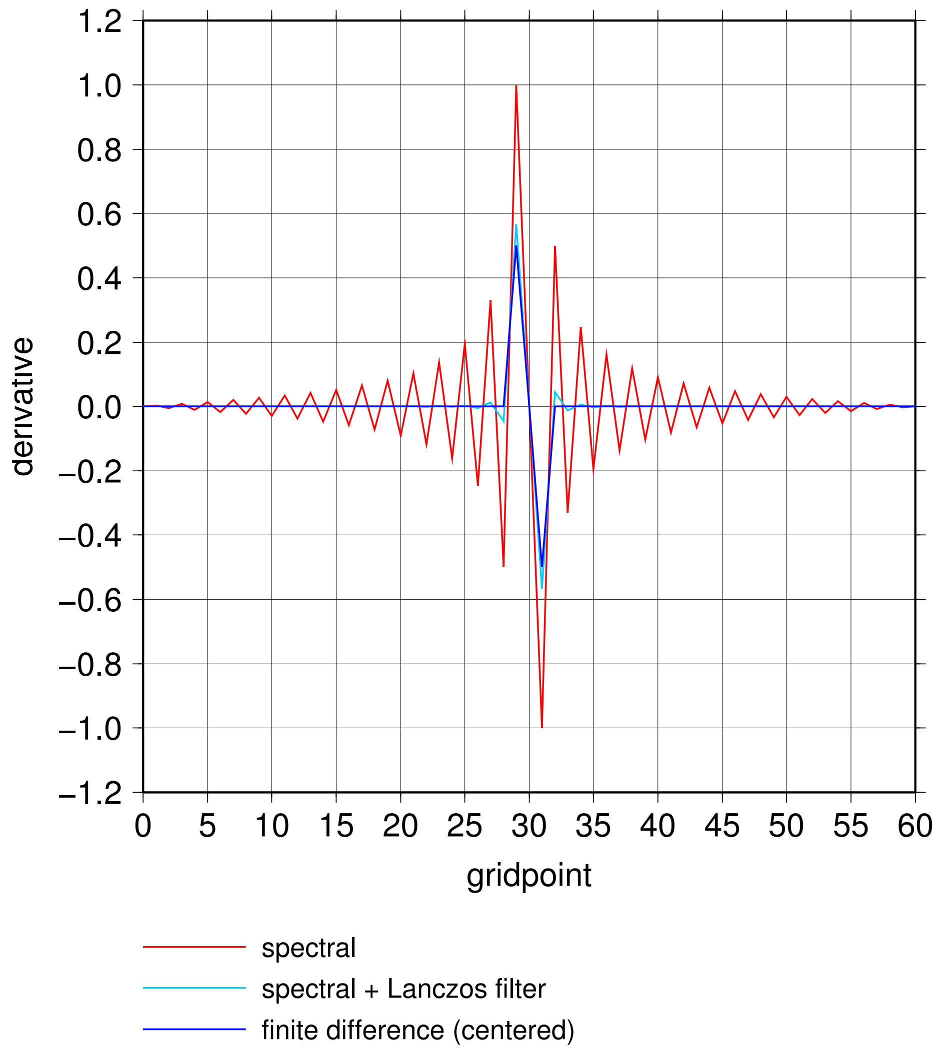
Introduction

- Increasing number of Alaro applications are reaching scales of 4-5 km with at least 60 vertical levels (Au, Be, Cz, No, Se, Slo, ...).
- Improved forecast skills at those scales are mainly related to increasing sophistication of physical package.
- Still, the model dynamics ought to be optimized/verified for delivering the best possible results also at those scales.
    - Strategic questions: Can we remain spectral? Do we already need NH dynamics? Is the 1D physics still sufficient? ...
    - Looking for improvement: Sophistication vs. simplicity, problems detection (and suppression), most appropriate setup ...

Spectral representation

Derivative of hat function



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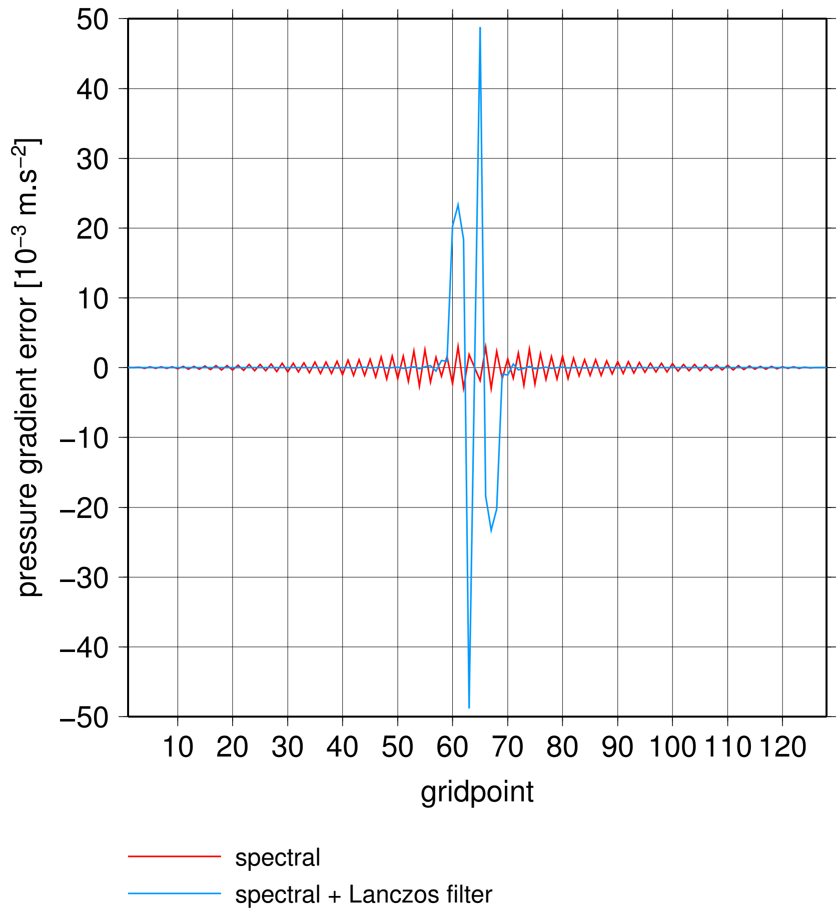
Spectral representation

Surprisingly the PG term ($\nabla\phi + RT\nabla(\ln p)$) error is becoming $\approx$10 times higher when those "nice" derivatives are used:

(triangular mountain 8 km wide, 4 km high, $\Delta x = 1$km, polytropic atm.)



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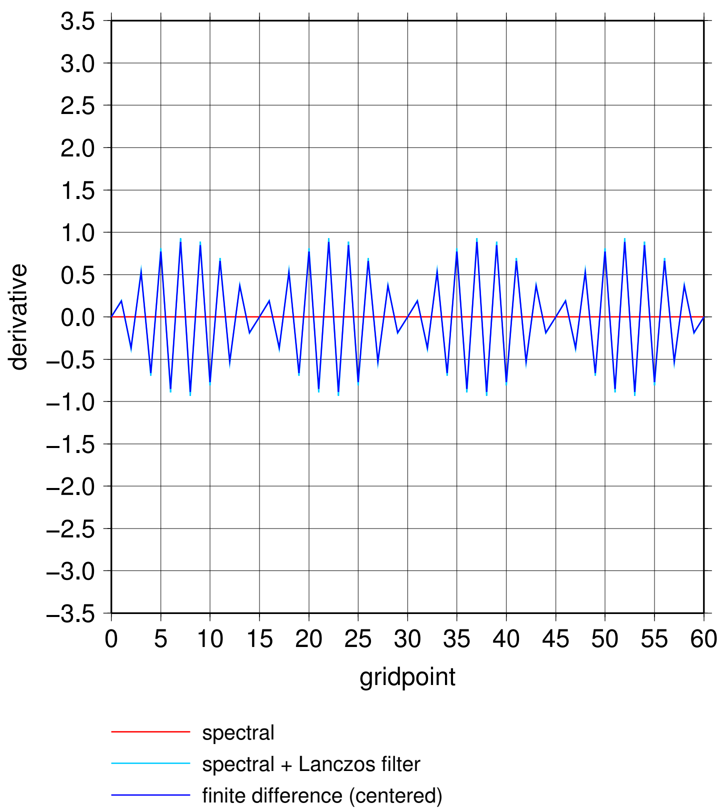
Spectral representation

Aliasing error dominates the PG term accuracy

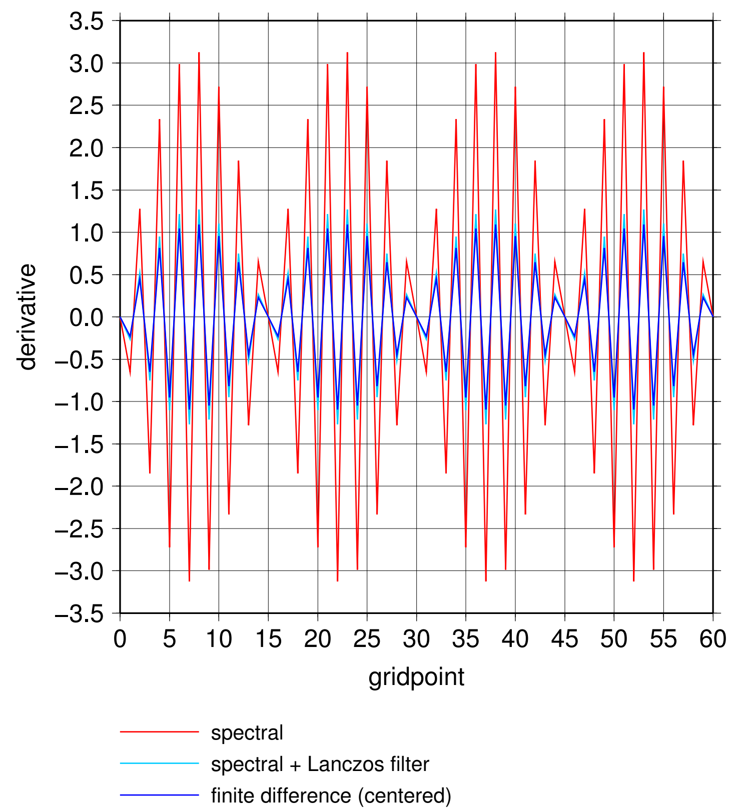
Deviation 2f.df/dx – d(f^2)/dx from Leibnitz rule for 4.29Δx wave

$N_{points} = 60$, $N_{trunc} = 29$, $N_{waves} = 14$



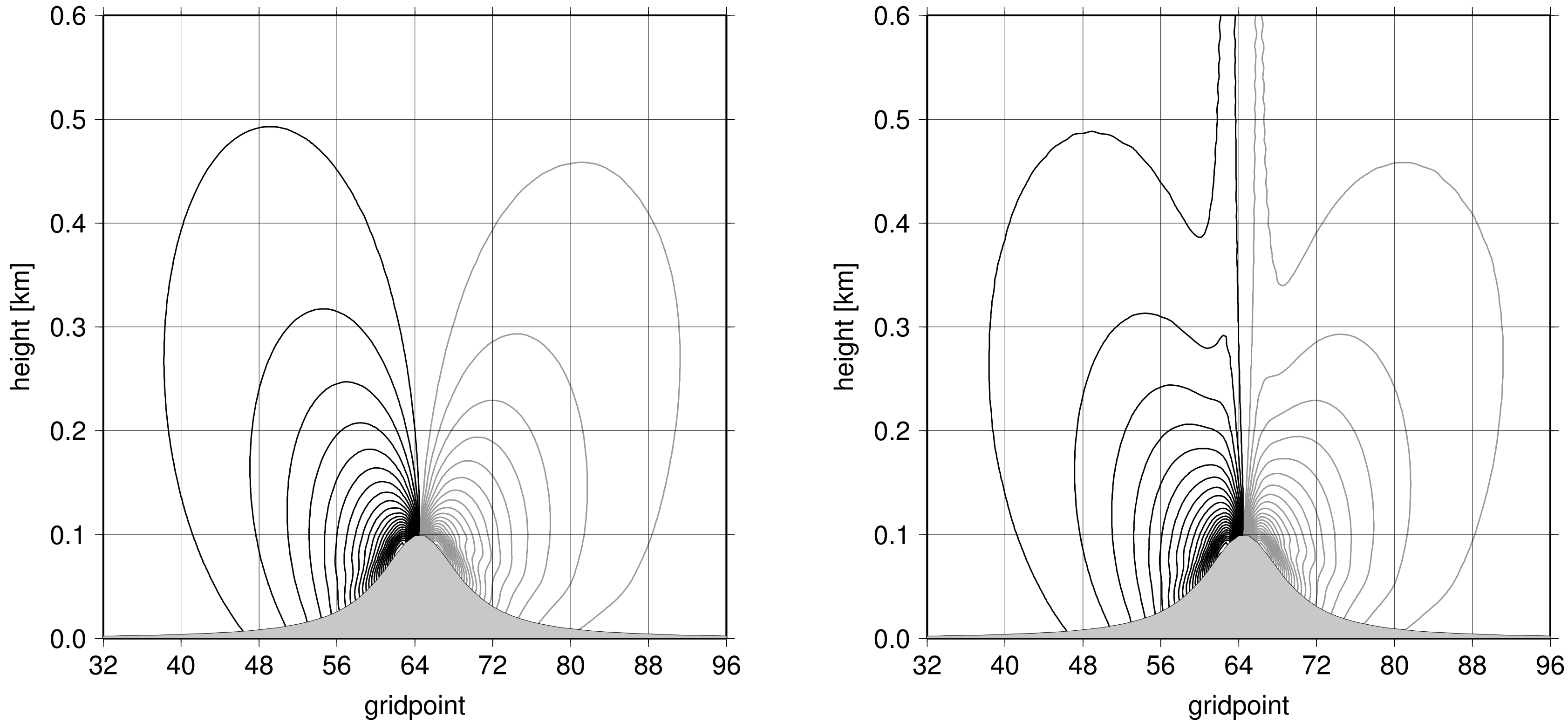
Deviation 2f.df/dx – d(f^2)/dx from Leibnitz rule for 3.75Δx wave

$N_{points} = 60$, $N_{trunc} = 29$, $N_{waves} = 16$



Spectral representation

Potential flow, NH dynamics, $\Delta x = \Delta z =$ 20m



vertical velocity diagnosed from reference model (left) and the same obtained with GP-like derivatives (right) $\Rightarrow$ Gibbs doesn't seem to be the limiting factor for spectral modeling

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Spectral representation II.

Does this apply to the reality?

- Spectral representation of q_v used in Alaro
- With linear truncation the field should not be disturbed by spectral fit, only derivatives can be affected by Gibbs
- Direct implication mainly to convection

$\Rightarrow$ Introduced NCOMP_CVGQ=3 enabling GP treatment of q_v by evaluating the horizontal part of the moisture convergence term $\vec{u} \cdot \nabla q_v$ with pseudo-staggered 4th order GP formula:

$$u_i \frac{\partial q}{\partial x_i} = \frac{1}{4} \left[(u_l + u_{l-1}) \frac{(27(q_l - q_{l-1}) - (q_{l+1} - q_{l-2}))}{24 \Delta x_i} + (u_l + u_{l+1}) \frac{(27(q_{l+1} - q_l) - (q_{l+2} - q_{l-1}))}{24 \Delta x_i} \right], \quad i = 1, 2$$

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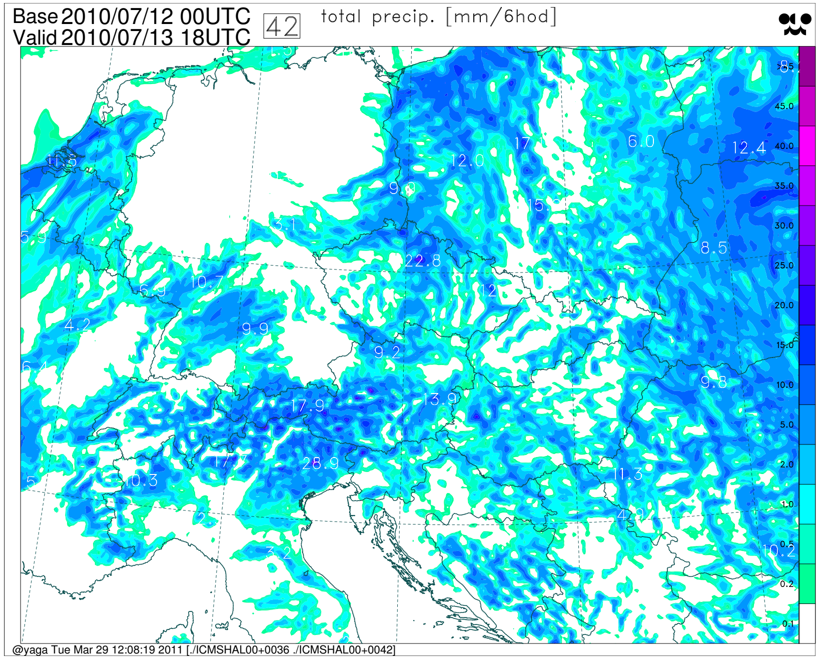
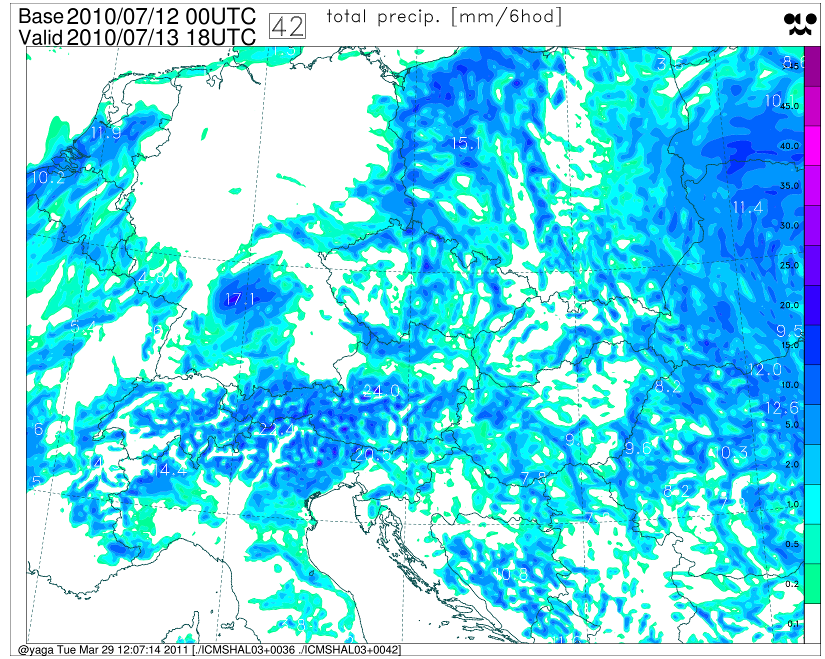
Spectral representation II.

Aladin/CE, Δx = 4.7 km



NCOMP_CVGQ=0



NCOMP_CVGQ=3

- No significant difference in terms of structure
- GP slightly worse in terms of scores
- Worse consistence between 4.7 km and 9 km runs
- GP more expensive (comms, memory conflicts) or memory consuming (multiplied 5*5 points stencil)

Spectral representation III.

Conclusion for spectral space

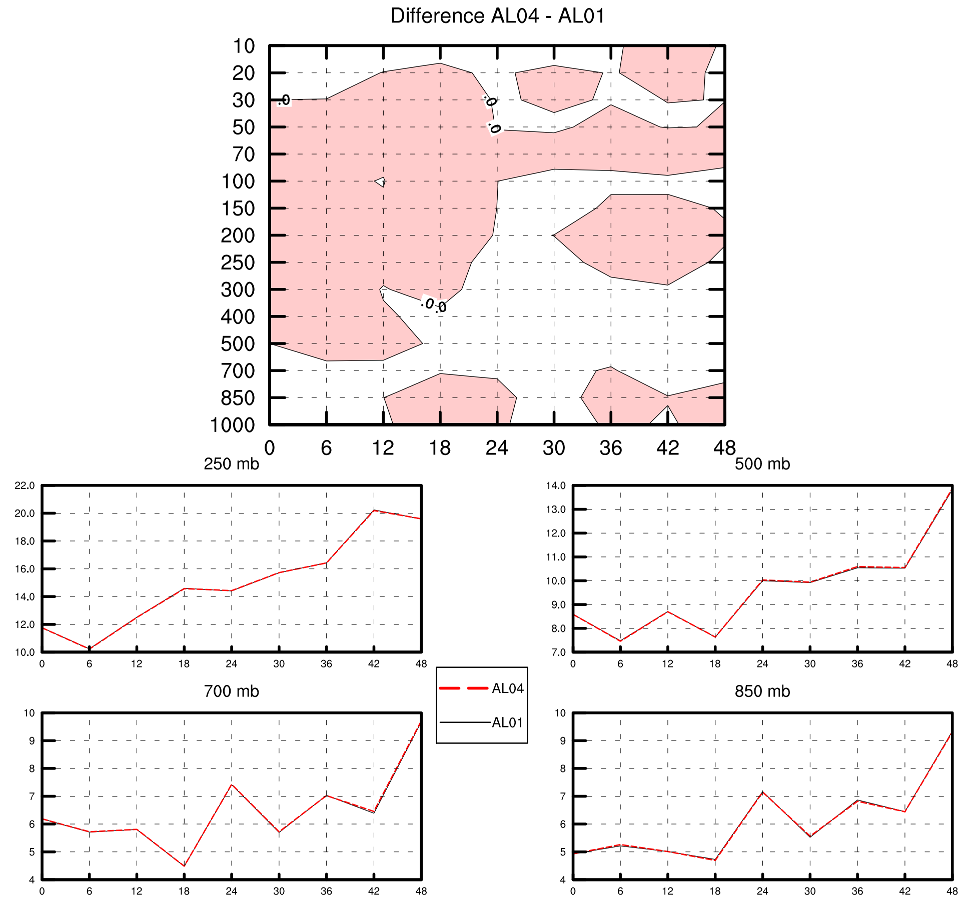
- There's no trace to gain anything from abandoning spectral fields representation at horizontal scales of 4-5 km.
- In reverse the GP methods (FD, 4th order) seems to offer no comparable accuracy to the spectral method.
- Until FFT scales, spectral formulation offers also the most efficient option (no memory conflicts, no comms).

NH dynamics at 4-5 km

- LACE project (development, validation,...)
- parallel test at 9 km/L43:
  - most of the benefit comes from the vertical discretization (NDLNPR)
  - LGWADV=.F./.T. offers comparable results in terms of scores
  - ICI (P/C) offers improvement of scores (0 it. < 1 it. < 3 it. <...)
  - there's no profit from NH with respect to hydrostatic (simplicity vs. accuracy)
- parallel test at 4.7 km/L87:
  - same conclusion holds as for 9 km
  - not much to gain from NH (strong rain in mountain, wind10m), scores are perfectly neutral
  - ICI scheme detrimental for scores (for both NH and hyd.) (problem of phys/dyn interface or SI?)

Evaluation of NH dyn. (4.7km, L87)

geopotential (rmse) NH-HYD



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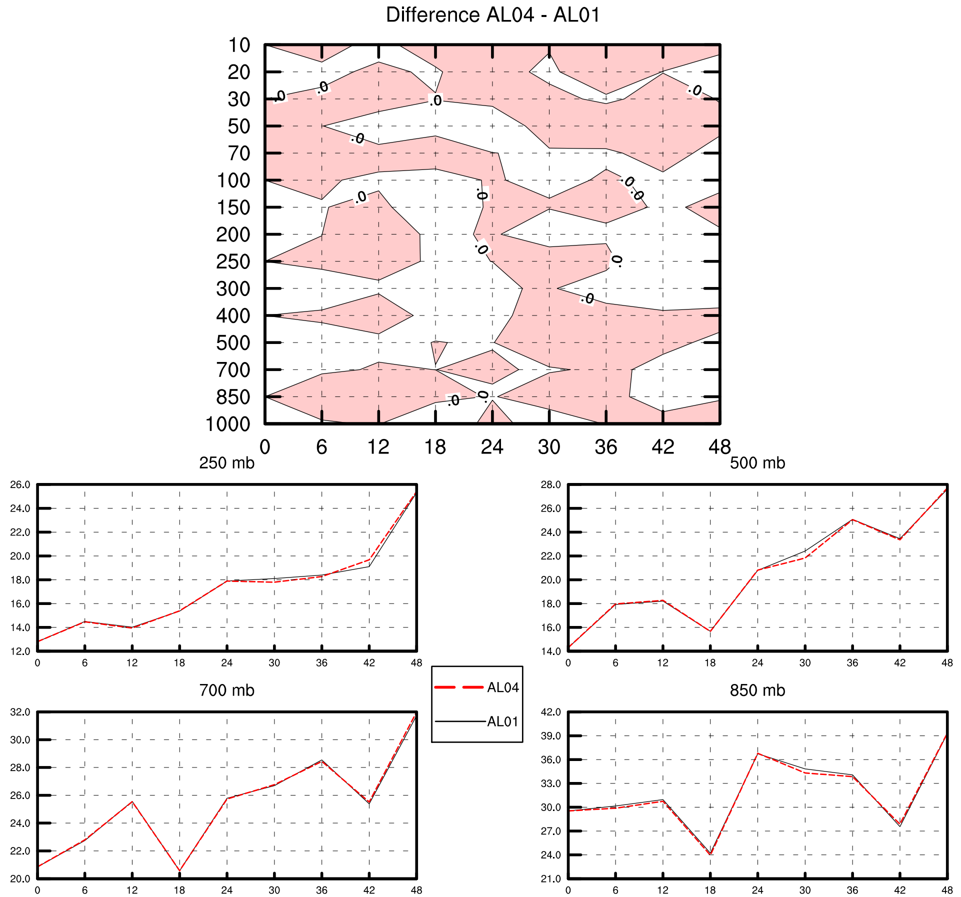
Evaluation of NH dyn. (4.7km, L87)

wind direction (rmse) NH-HYD



Summary for NH dynamics at 4-5 km

- In the most favorable case the additional cost of NH is around +8% (SI) – +49% (ICI)
- For this extra cost, there's no spectacular effect brought by NH
- So far we haven't observed any particular case where the hydrostatic dynamics offers significantly worse forecast (at the scales of 4-5 km)
- Pragmatic approach is to invest those extra CPU to other scheme bringing more benefit for similar cost (VFE $\approx$ +15%, TOUCANS $\approx$ +6-8%,...)
- Indeed as we are very close to start profit from NH an attention is payed to this model code (VFE-NH; LGWADV,LSETTLS=.T.,.T.)

Physics - dynamics interaction

- Approaching the higher resolutions, physics should be increasingly regarded as a 3D process.
- Before going to truly 3D physics there are still some intermediate solutions increasing the horizontal awareness of physical processes:
  - prognostic character for physical quantities being transported as 3D quantity eventually also diffused by SLHD (5+2 prognostic arrays for convection, 3 prognostic sustained water phases, 2 prognostic falling precipitations, TKE),
  - option N[x]LAG=4,%LPHYLIN to treat physical tendencies in the same way as NL tendency from dynamics
  - possibility to apply quasi-horizontal diffusion through SL interpolation (NSPLTHOI=1) to physical tendencies only
- Work in progress for 2nd order accurate coupling of physics to dynamics (Hirlam, LACE)

New options to phys/dyn coupling

$$\Psi_F^+ = \left(1 - \tfrac{\Delta t}{2}\mathcal{L}\right)^{-1} \left[\underbrace{\left(1 + \frac{\Delta t}{2}\mathcal{L}\right)\Psi_O^0}_{I_{H,D}} + \underbrace{\Delta t \mathcal{F}_O^0}_{I_F} + \underbrace{\frac{\Delta t}{2}\mathcal{N}_O^*}_{I_L} + \tfrac{\Delta t}{2}\mathcal{N}_F^* \right]$$

- Default is $I_F = I_{H,D}$ (in IFS: $I_F = I_L$)
- N[x]LAG=4 (GMV), LPHYLIN=.T. (GFL): $I_F = I_L$
  - no additional cost for GMV (redistribution between existing quantities), some small overhead for GFLs
  - ideal starting point for 3D turbulence
  - no signal in terms of scores (some impact to wind and moisture)
- NSPLTHOI=1: $I_F = I_{D2}$
  - smoother physical fields (distinctively different)
  - additional cost by extra interpolation per prognostic field
  - not yet extensively tested in terms of scores (optimal tuning for the diffusion has to be defined, NSPLTHOI=2: $I_F = I_{D3}$?)

What about 3D turbulence?

- NWP world is far from scales allowing isotropic and consistent 3D approaches $\Rightarrow$ need for additional approximations
- Our approach assumes $\nabla K_H(x,y,z,t) \approx 0$. Then the horizontal terms of turbulence can be expressed as:

$$\frac{\partial \Psi}{\partial t} + ... = -K_H \frac{\partial^2 \Psi}{\partial x^2} - K_H \frac{\partial^2 \Psi}{\partial y^2} - \frac{\partial}{\partial z}\left(K_V \frac{\partial \Psi}{\partial z}\right) - K_{Num}\mathcal{D}(\Psi)$$

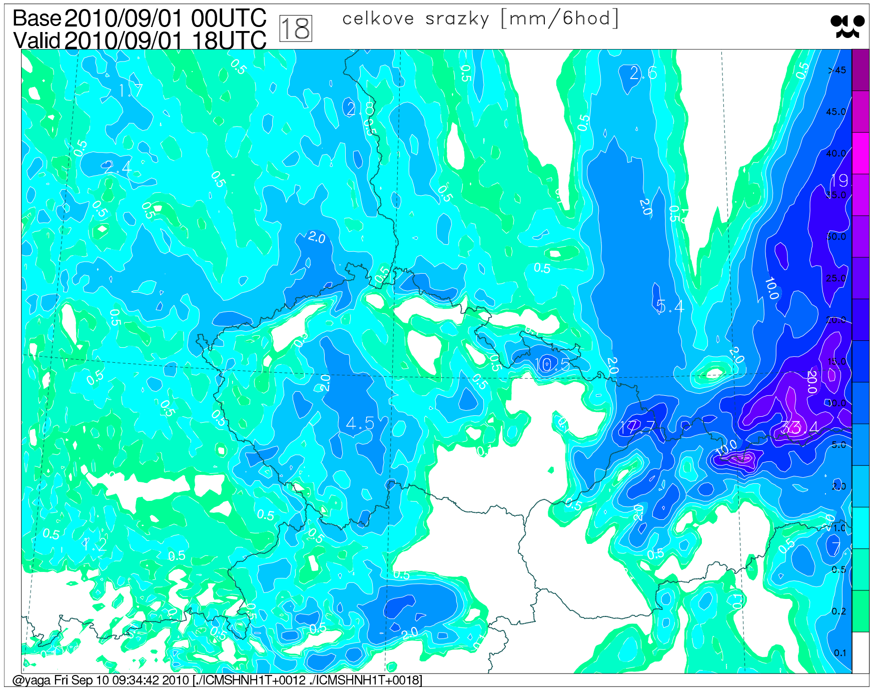
- Term $-K_H \Delta_H \Psi$ is evaluated by GP Laplacian available through the SL interpolation weights
- K_V and K_H are derived in consistent way with TOUCANS (emulating QNSE):

$$\begin{aligned} K_{m,V} &= L_K C_K \sqrt{e}\chi_3(Ri) \\ K_{h,V} &= L_K C_K C_3 \sqrt{e}\phi_3(Ri) \end{aligned} \Rightarrow \begin{aligned} K_{m,H} &= L_K^H C_K \sqrt{e}\chi_H(Ri) \\ K_{h,H} &= L_K^H C_K C_3 \sqrt{e}\phi_H(Ri) \end{aligned}$$

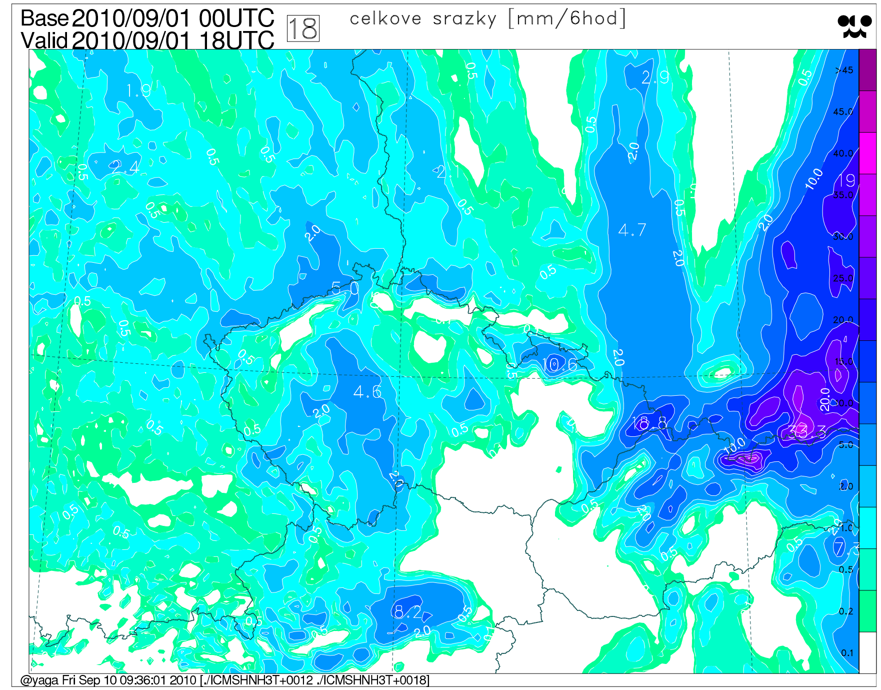
- Closure based on 3D TKE equation
- Computationally affordable (+1.8% of CPU, 14.8% of extra memory)
- No additional stability restriction

3D turbulence at 4-5 km

ALADIN/CE, Δx = 4.7 km



TOUCANS 1D



TOUCANS 3D

- Is not very surprising that the effect is negligible (scale analysis)
- Transition to "unprofitable scales" is smooth and harmless
- The time of 3D turbulence has still to come...

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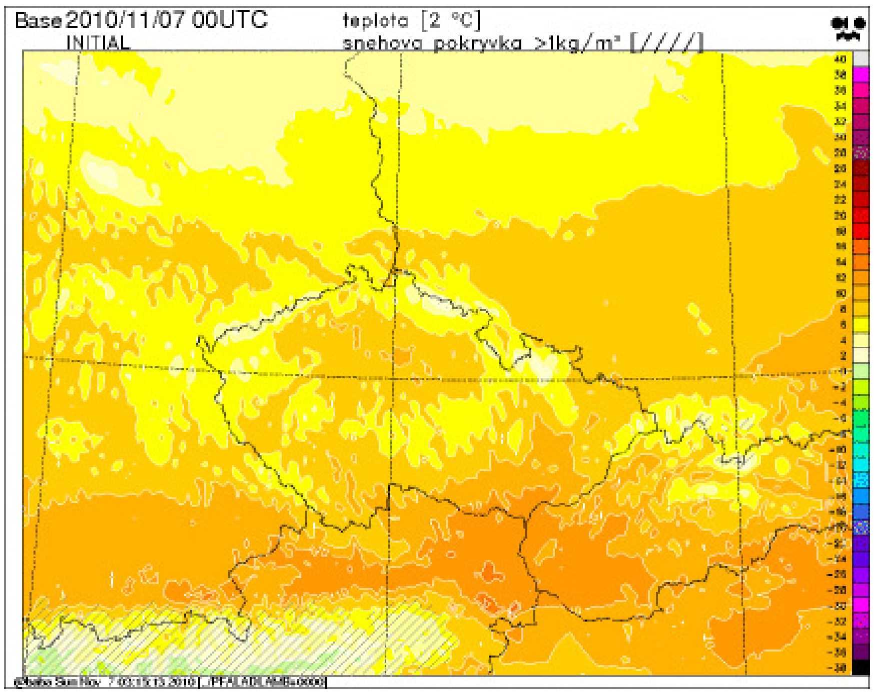
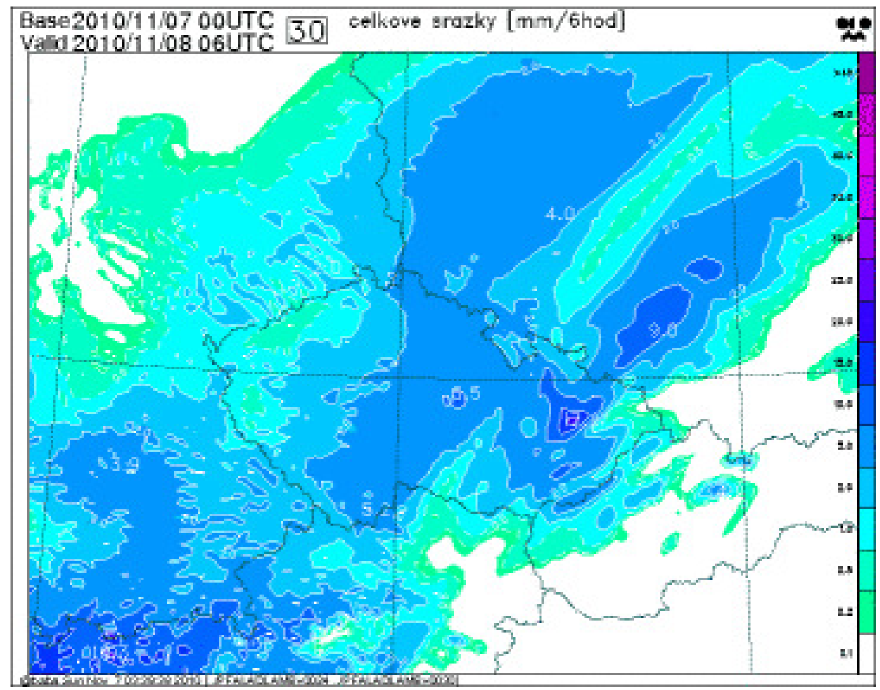
Spectral diffusion on divergence

Sometimes model outputs were tending to be "granular"





Aladin/CE: T2m precipitations

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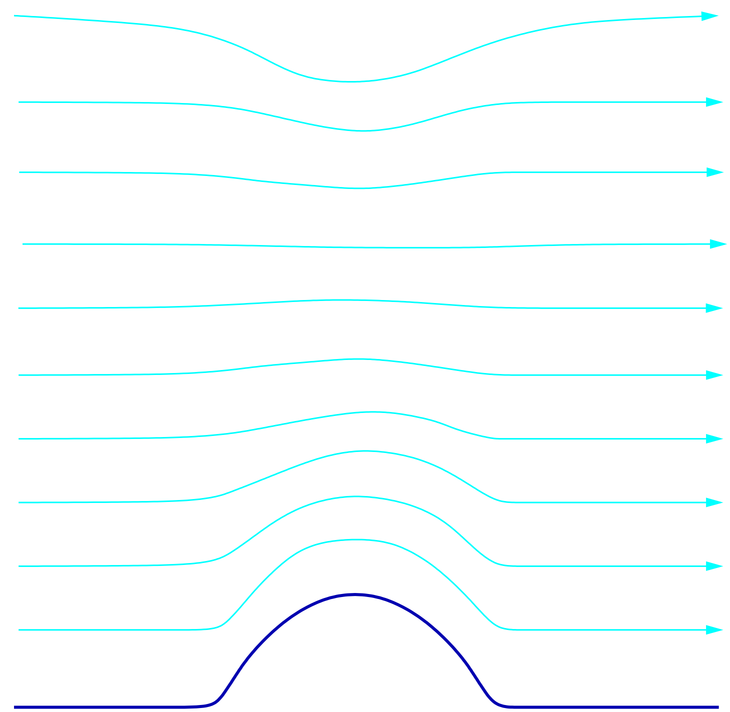
Spectral diffusion on divergence

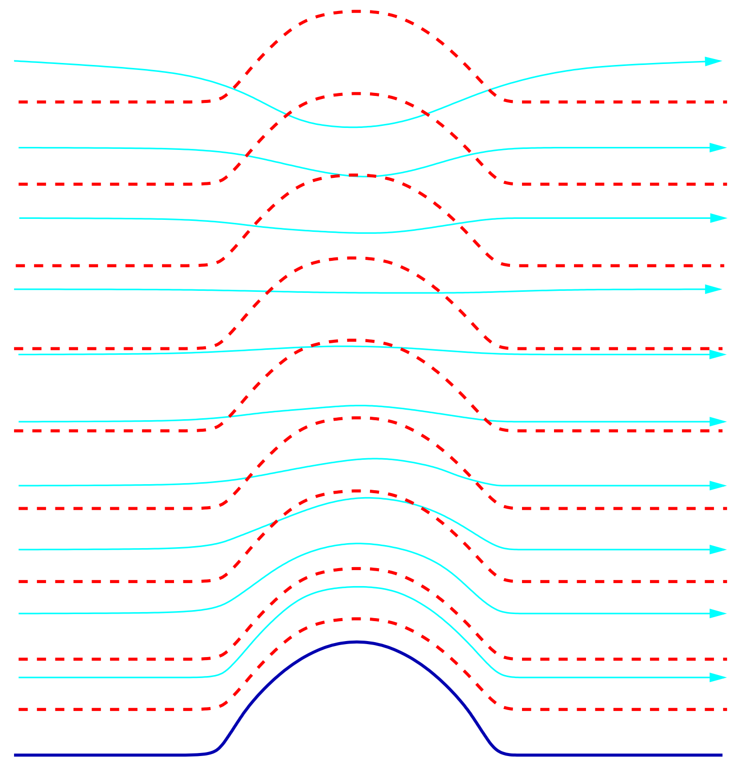
Origin of this phenomena has been traced back to linear diffusion on divergence:



Flow over obstacle in stable stratification

Spectral diffusion on divergence

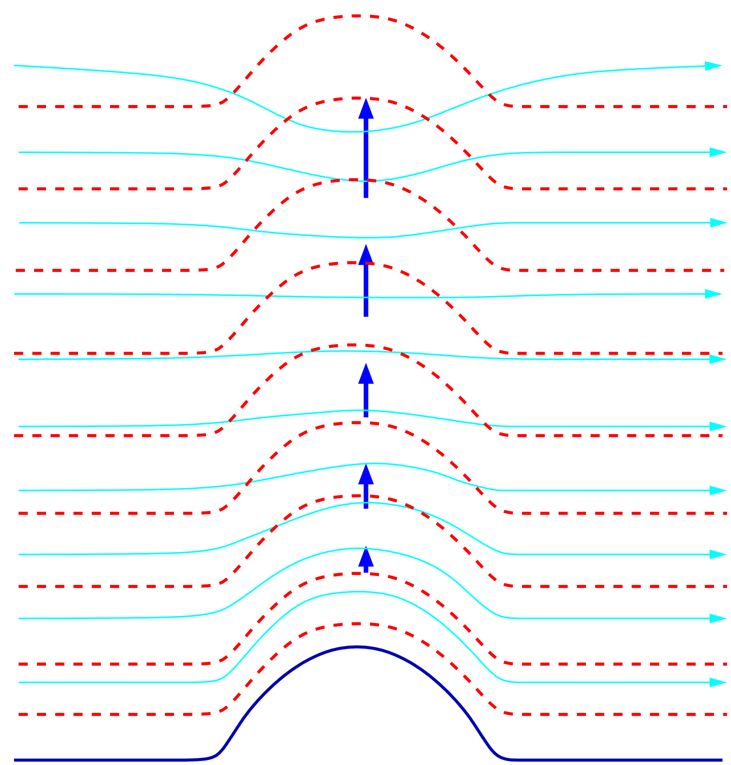
Origin of this phenomena has been traced back to linear diffusion on divergence:



Diffusing divergence imposes an unphysical steady state

Spectral diffusion on divergence

Origin of this phenomena has been traced back to linear diffusion on divergence:



The difference between physical and non-divergent flows leads to noise in vertical velocity

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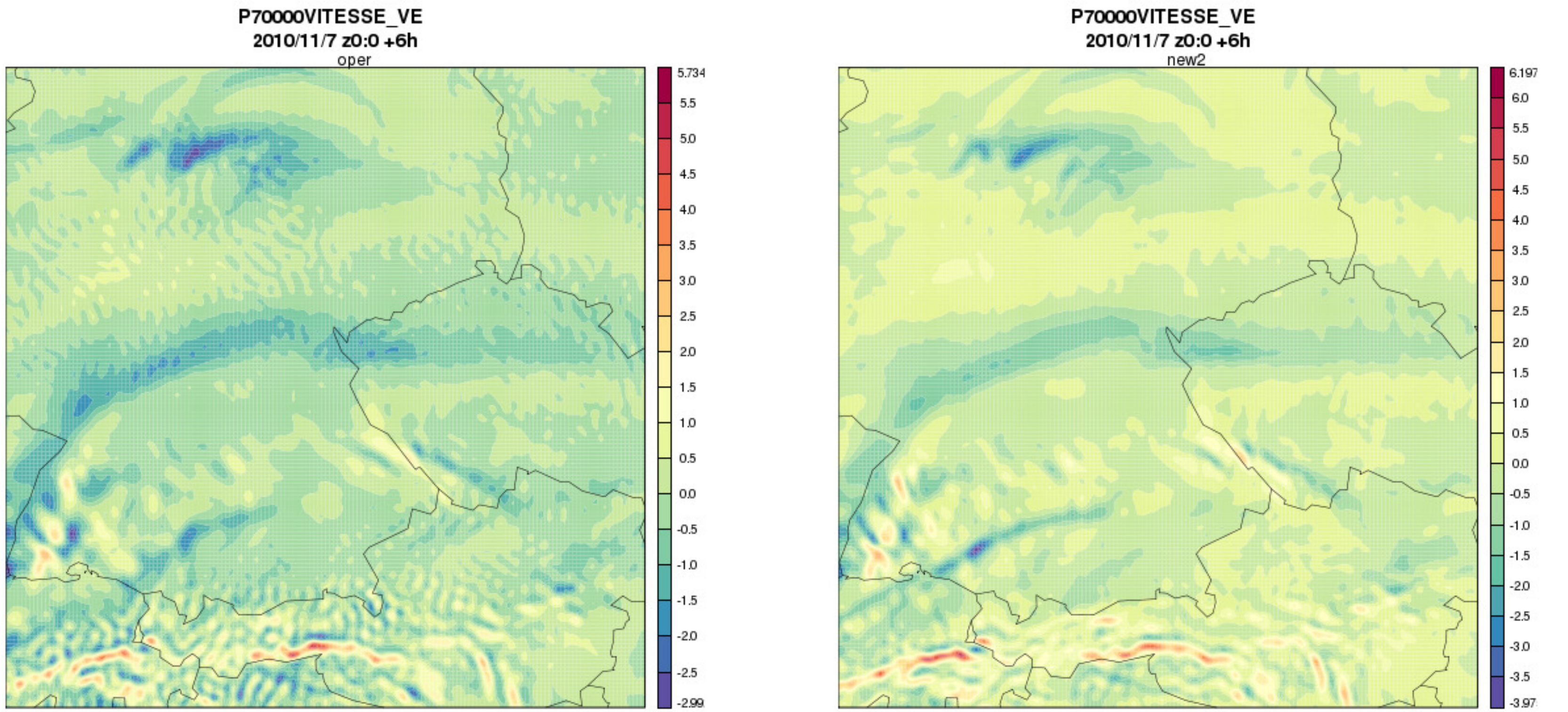
Spectral diffusion on divergence



Solution used in Alaro is based on suppression of spectral diffusion from atmosphere bellow 100 hPa, leaving all the damping for SLHD (and very weak and selective supporting diffusion).

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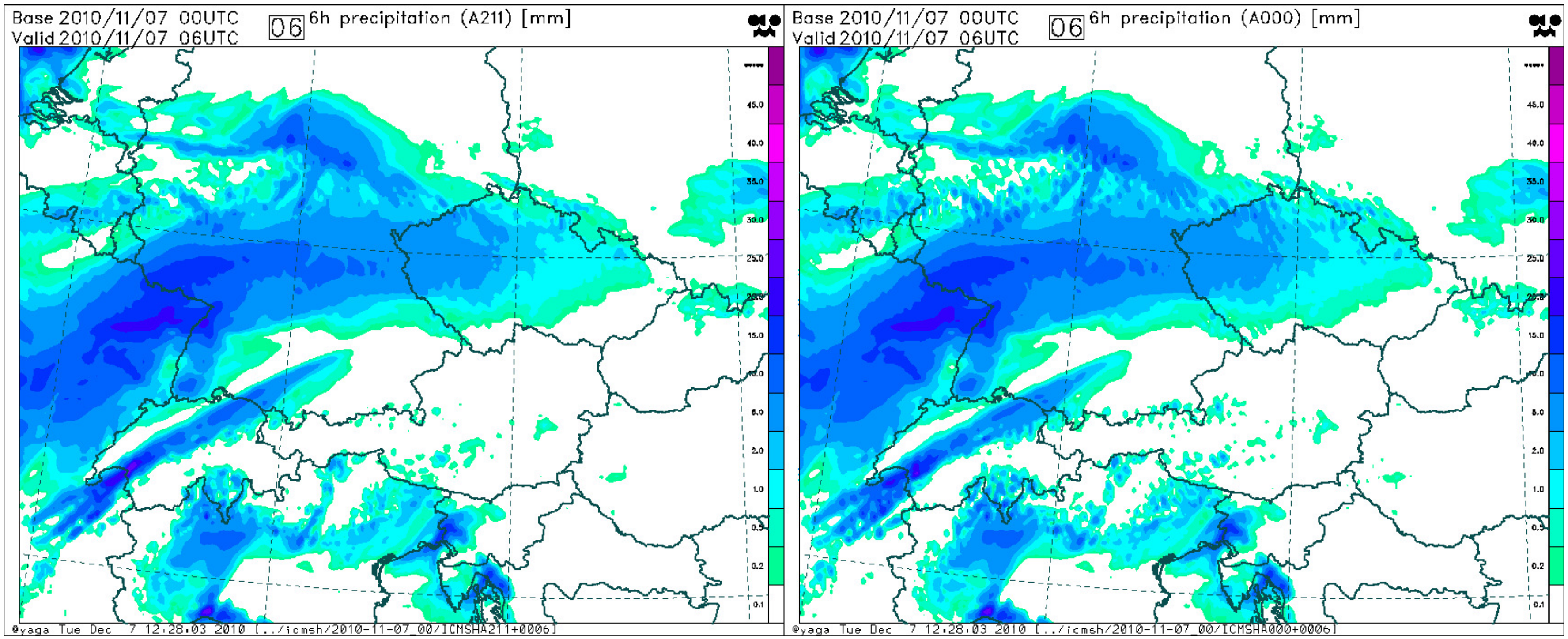
Spectral diffusion on divergence

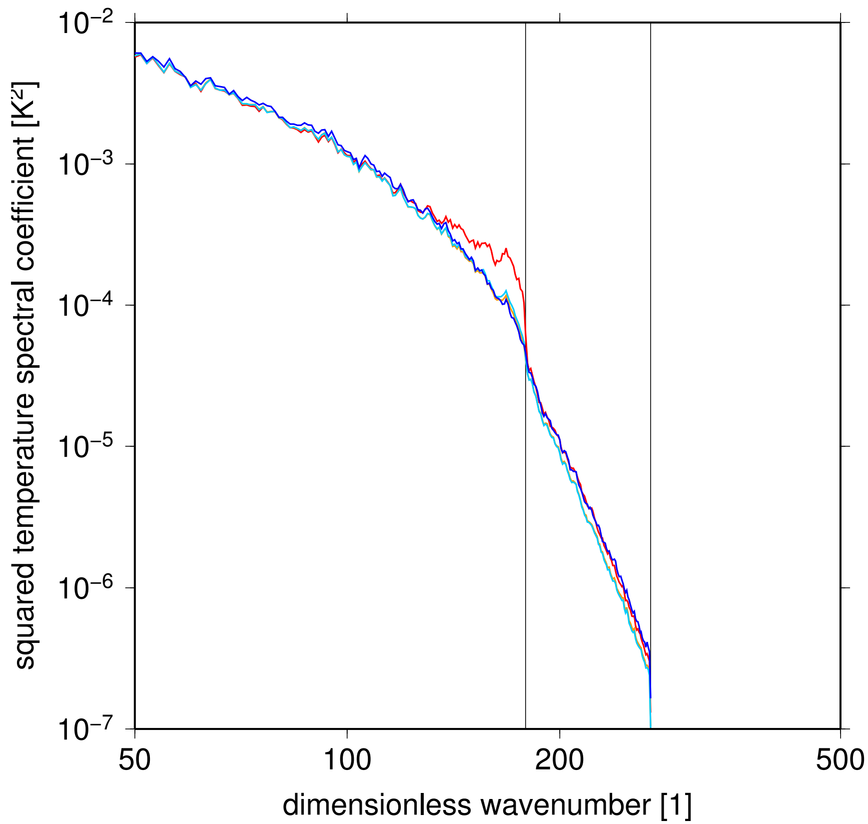


SLEVDH=0.1
RDAMPVORS=10 ⇐
RDAMPDIVS=10

SLEVDH=1
RDAPVORS=5
RDAMPDIVS=1

Spectral diffusion on divergence

Energy spectra of temperature

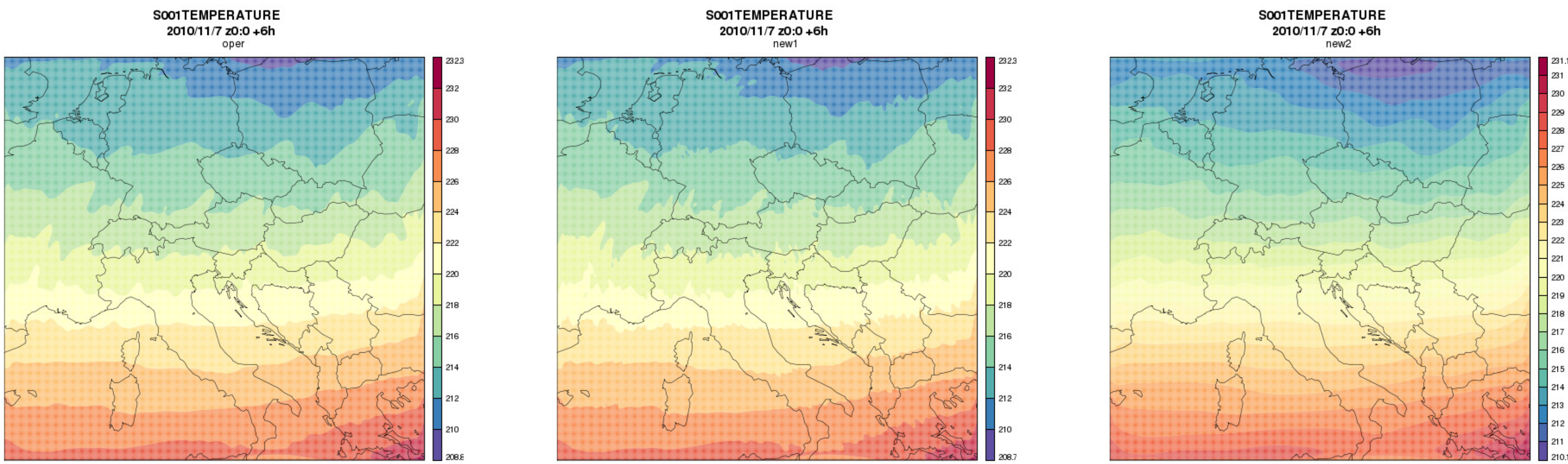


Diffusion (on divergence) generates small scale signal instead of removing it.

Spec. diffusion near the model top

Reduced diffusion order REXPDH=4 $\Rightarrow$ REXPDH=2

S001 temperature for original, reduced and final HD tuning



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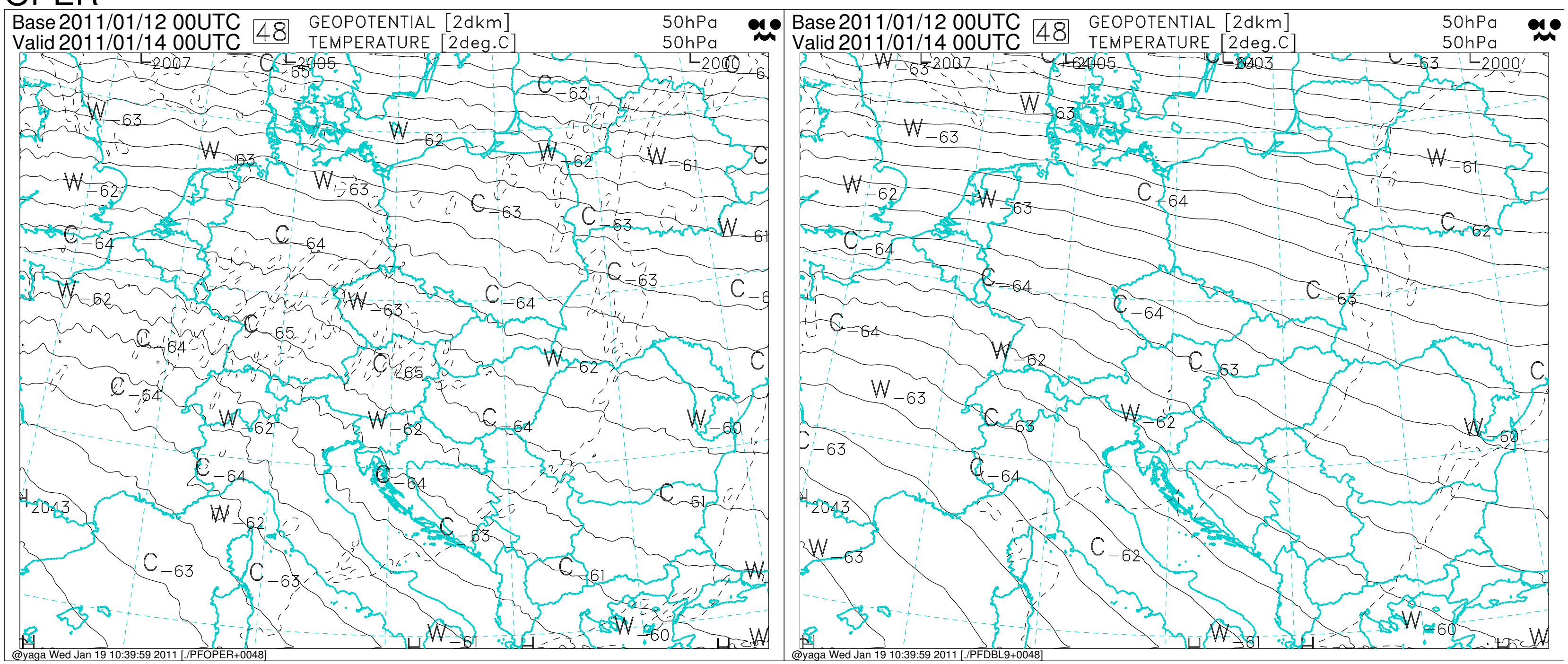
Spec. diffusion near the model top

Reduced diffusion order REXPDH=4 $\Rightarrow$ REXPDH=2

Geopotential and temperature at 50 hPa for reduced and new tuning

OPER



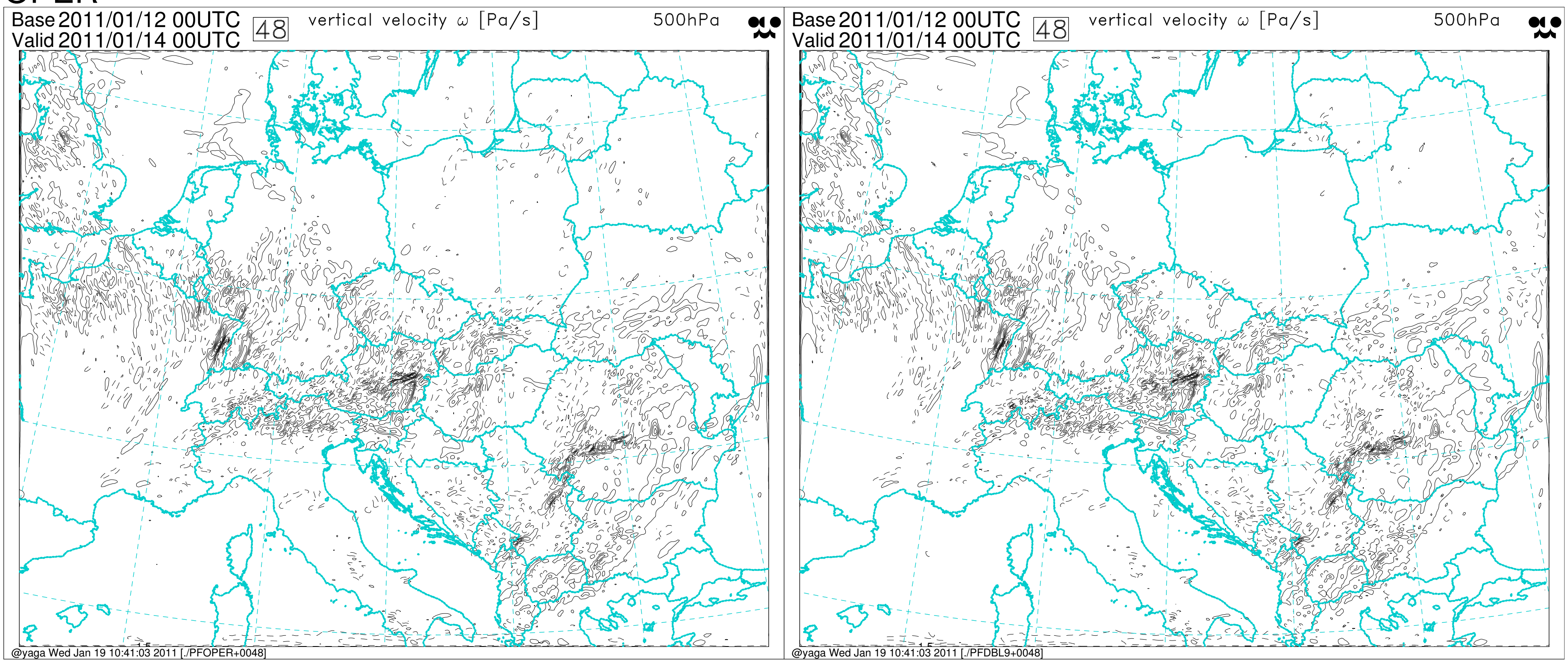
No need for special "tricks" near the model top (stable even for DFI jobs).

Spec. diffusion near the model top

Reduced diffusion order REXPDH=4 ⇒ REXPDH=2

Omega at 500 hPa for reduced and new tuning

OPER



Helps in removing gravity waves reflecting from model top

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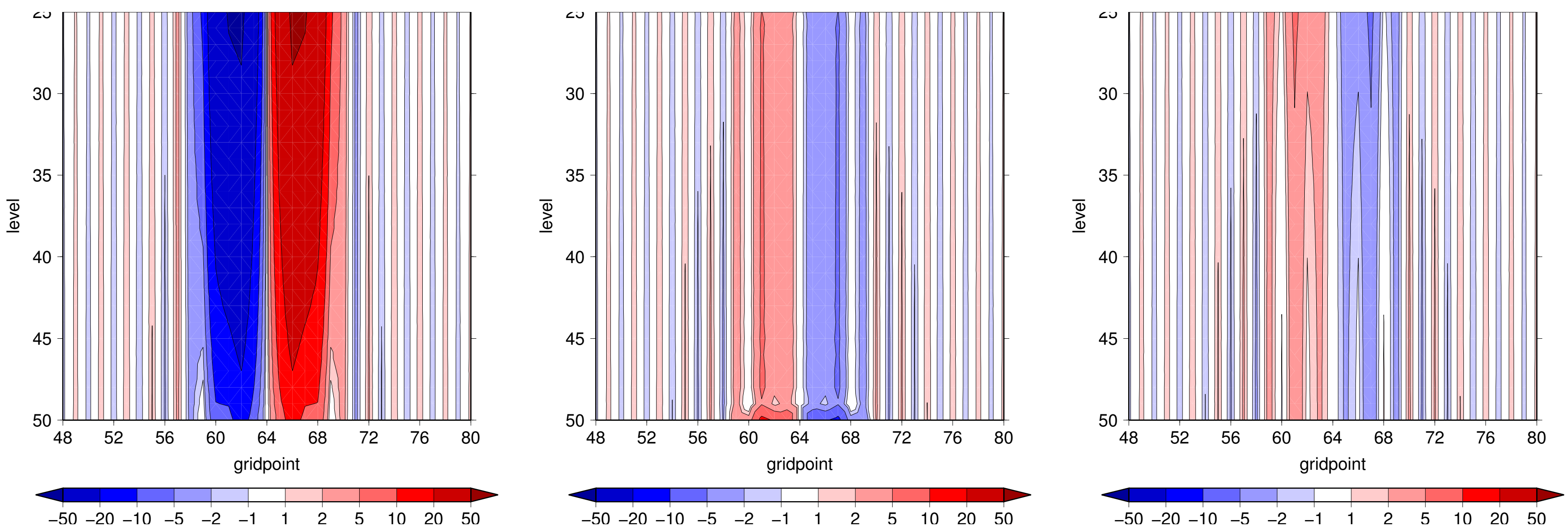
PG term - vertical discretization

Model error of pressure gradient term (triangular mountain, resting state)

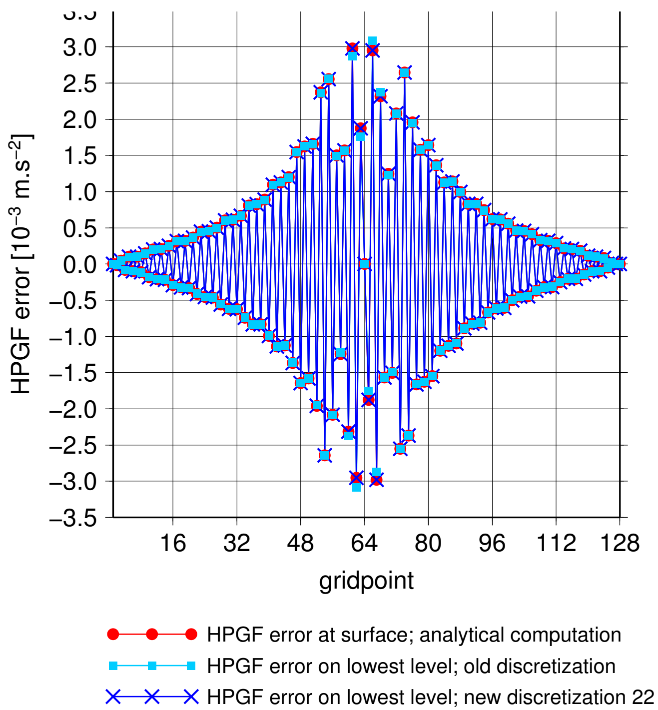


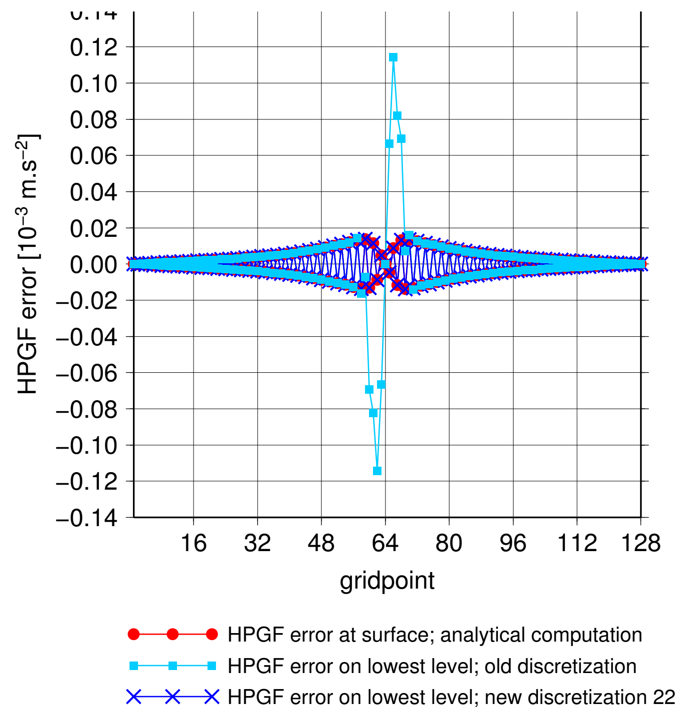
reference | VFE | polytropic var. of T

⇒ There are ways to improve PGF, the most preferable solution seems to move into VFE

PG term - horizontal representation

PGF error for non-filtered and filtered orography





$\Rightarrow$ Orography filtering substantially reduces the PGF error

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Summary

Changes in dynamics following resolution increase (9km/L43 $\rightarrow$ 4.7km/L87)

- Lagrangian cubic SL interpolation replaced by less damping one (SLHDKMIN=-0.6)
- Suppressed spectral diffusion bellow 100 hPa, keeping only SLHD there
- Lowered order of spectral diffusion near the model top
- Filtering of orography (generalization of LSPSMORO option in e923)
- LREGETA=.T. $\Rightarrow$ .F.
- The ultimate target to improve vertical discretization (at high enough resolution) is to move to VFE.