Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

Dynamics in LACE

Petra Smolíková
thanks to many colleagues

Outline

1. **VFE NH**

   Design of vertical finite elements scheme for NH version of the model

2. **SL scheme**

   Application of ENO technique to SL interpolations

3. **1D2D turbulence scheme**

   Scientific validation and high resolution tests

4. **LBC coupling strategy**

   Rapid changes in surface pressure field

5. **Problems**

   SLHD x numerical diffusion design and tuning

Dynamical core of ALADIN/HIRLAM system

- fully compressible Euler equations (NH) or hydrostatic primitive equations (HPE)
- space discretization in horizontal: Fourier spectral method
- mass based vertical coordinate using Laprise hydrostatic pressure
- semi-implicit time scheme
- semi-Lagrangian advection
- prognostic variables differ in grid-point space and in spectral space for stability and accuracy reasons; they are transformed every time step (w <-> d)

Finite element method in the vertical of ALADIN NH

- based on Untch & Hortal (2004) method implemented in IFS (ECMWF) for hydrostatic primitive equation system
- in cooperation with HIRLAM colleagues
- uses B-splines with compact support and of general order
- vertical integrals and derivatives are evaluated in FE space, products of variables are evaluated in physical space
- the expected benefit is high precision of Galerkin type method
- the main roadblock is stability of the scheme
- the main hangups are boundary conditions of vertical operators
- there is a working implementation in ALADIN cy40t1

Finite element method in the vertical of ALADIN NH

Work in progress:

1. Clear formulation of boundary conditions
2. Invertible operators for transformations w <-> d
3. Idealized tests with known analytical solution in 2D vertical plane
4. Real simulations

Finite element method in the vertical of ALADIN NH

1. Boundary conditions for vertical operators

2 different method used at input:

- Explicit definition = the data vector is enlarged, BC are built into the projection matrix from GP space to FE space
- Implicit definition = a special set of basis functions chosen which satisfies BC constant in time and space

Conclusion:

- These two methods are not equivalent.
- Implicit method may not be used everywhere.
- Tests are needed to see the impact of the definitions.

Courtesy of Jozef Vivoda

Finite element method in the vertical of ALADIN NH

2. Invertible operators for integral and derivative

- **Transformations** (ones per time step) by vertical operators $\boldsymbol{I},\boldsymbol{D}$

  Derivative $\boldsymbol{D} : w \rightarrow d$ after GP calculations

  Integral $\boldsymbol{I} : d \rightarrow w$ after SP calculations

- To keep the steady state $\frac{\partial w}{\partial t} = 0$ we need **invertibility**

  $$\boldsymbol{I}.\boldsymbol{D}\, f = \boldsymbol{D}.\boldsymbol{I}\, f = f$$

- Looking for operators in the space of B-splines of a given order was unsuccessful, but **we do not have to keep the order** of splines in all the computations !

 Courtesy of Alvaro Subias

Finite element method in the vertical of ALADIN NH

3. Idealized tests

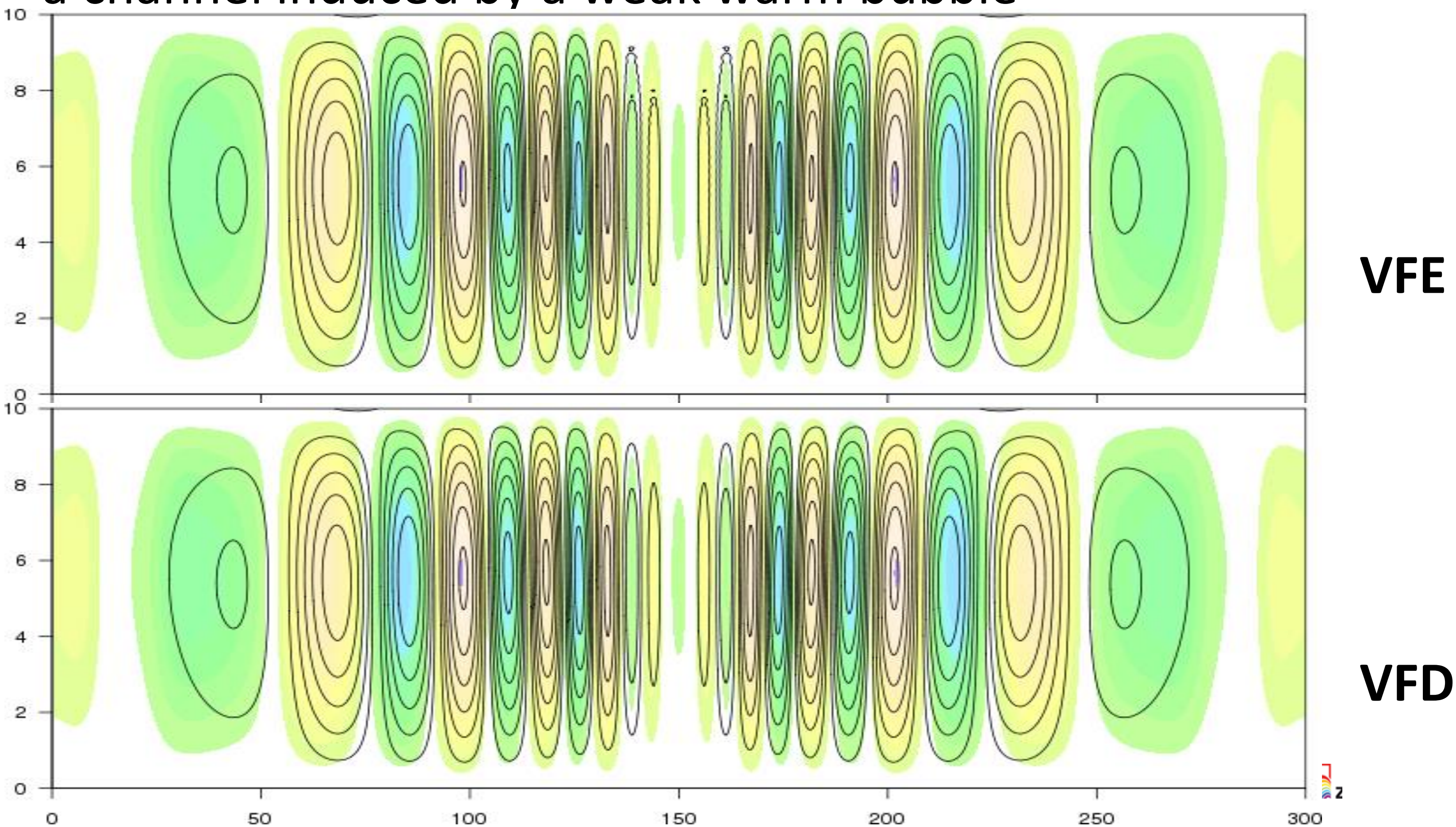
Baldauf-Brdar : the linear expansion of sound and gravity waves in a channel induced by a weak warm bubble

- analytical solution provided
- originally in height based coordinate
- with the boundary conditions: w=0 at top and bottom boundary
- the solution: a set of waves that propagate horizontally
- **in mass based vertical coordinate**: no fixed top boundary => atmosphere can evolve freely and move up and down at the top, we may impose strict sponge conditions, but not to avoid the vertical propagation of waves
- vertical resolution 125m, regular levels in height up to 10km

Finite element method in the vertical of ALADIN NH

3. Idealized tests

Baldauf-Brdar : the linear expansion of sound and gravity waves in a channel induced by a weak warm bubble



Finite element method in the vertical of ALADIN NH

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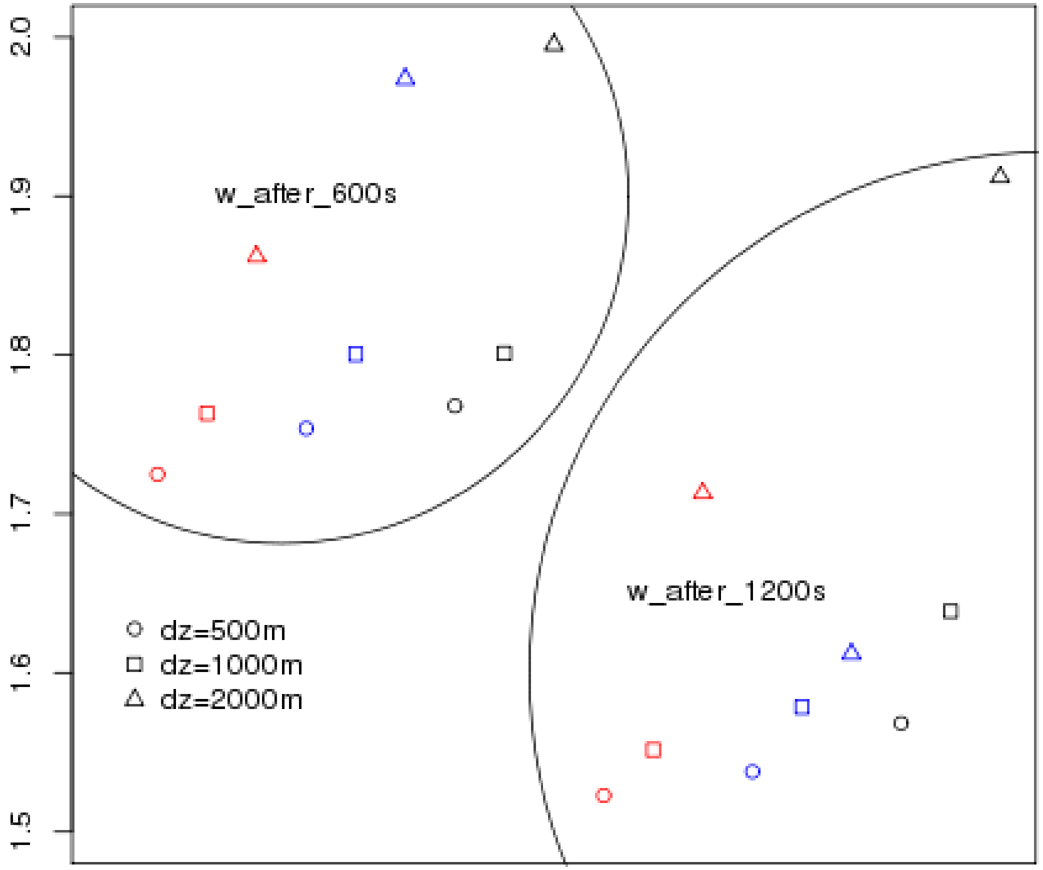
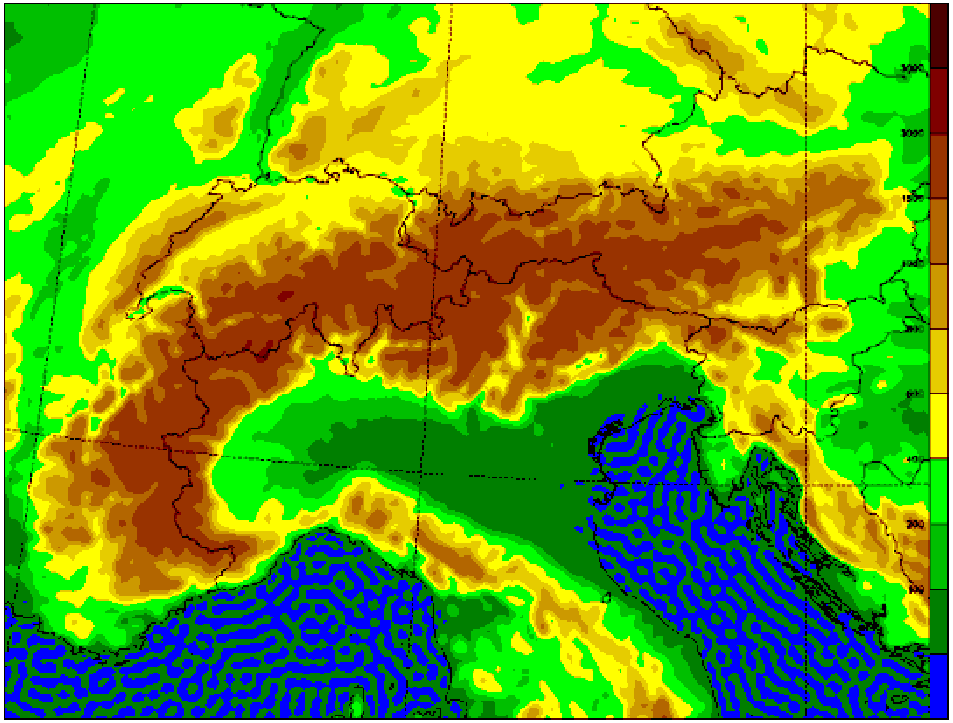


Relative ℓ_2-error for w.

red FE
blue FE approx
black FD

Finite element method in the vertical of ALADIN NH

3. Real simulations: domain over Alpain region, 1.25km resolution, 87 vertical levels, 2tl PC + LGWADV, 2 series – January 2014 and July 2014, once per day from 00UTC + 24hours, timestep = 50s; ALARO-0 physics



Finite element method in the vertical of ALADIN NH

3. Real simulations

Results:

1. VFE scheme with proper setting of parameters and vertical levels is as **stable** as VFD scheme in 1.25km resolution.

2. It is difficult to find any benefit from FE used in vertical discretization concerning **objective scores**.

3. The **precipitation field** is modified by FE in such a way that there is bigger number of grid points without rain (cumulated precipitations for 1 hour < 0.1mm) and bigger number of grid points with high values of cumulated precipitations (>30mm/hour). Consequently, there is smaller number of grid points with modest rain between 0.1 and 30mm.

ENO technique in SL interpolations

ENO (Essentially Non-Oscilatory)/WENO (Weighted ENO)

Motivation: to explore alternative interpolators which are

- less overshooting then Lagrange polynomials close to discontinuities
- more accurate than their quasi-monotonic versions

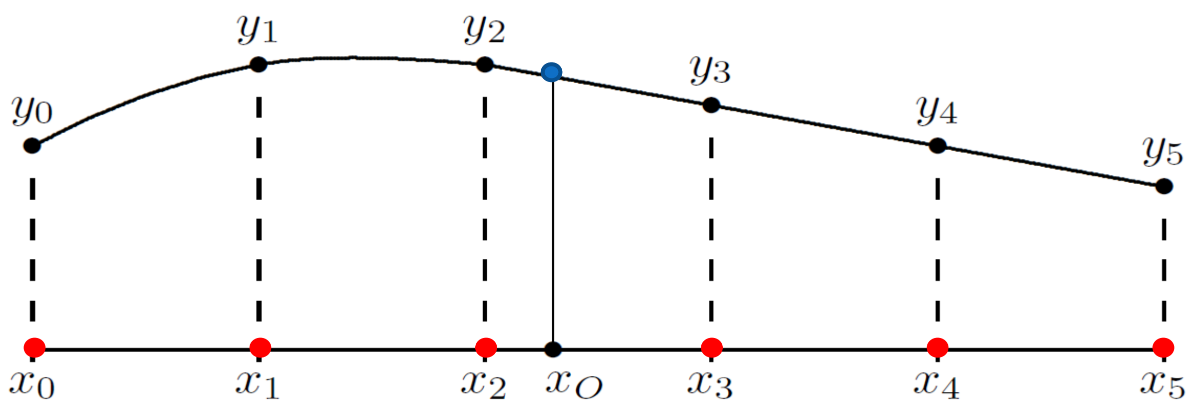
$\Rightarrow$ interpolation depending on the smoothness of the interpolated field

Previous work: already tested for quadratic interpolators in 2D and 3D, results show that quadratic ENO/WENO is too smoothing

The aim: to implement cubic ENO interpolations in SL scheme – technically demanding, the stencil for SL 3D interpolation has to be extended from 32 points to 120 points

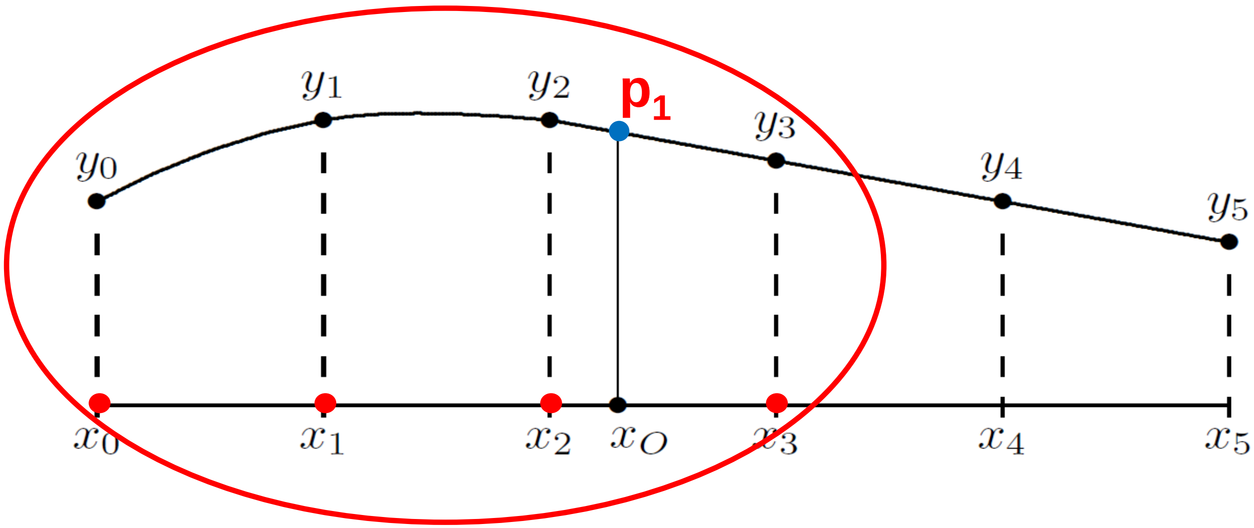
ENO technique in SL interpolations

Third order interpolation scheme (cubic) needs 4 points to find ●,
⇒ **6 points** needed for ENO/WENO interpolation



ENO technique in SL interpolations

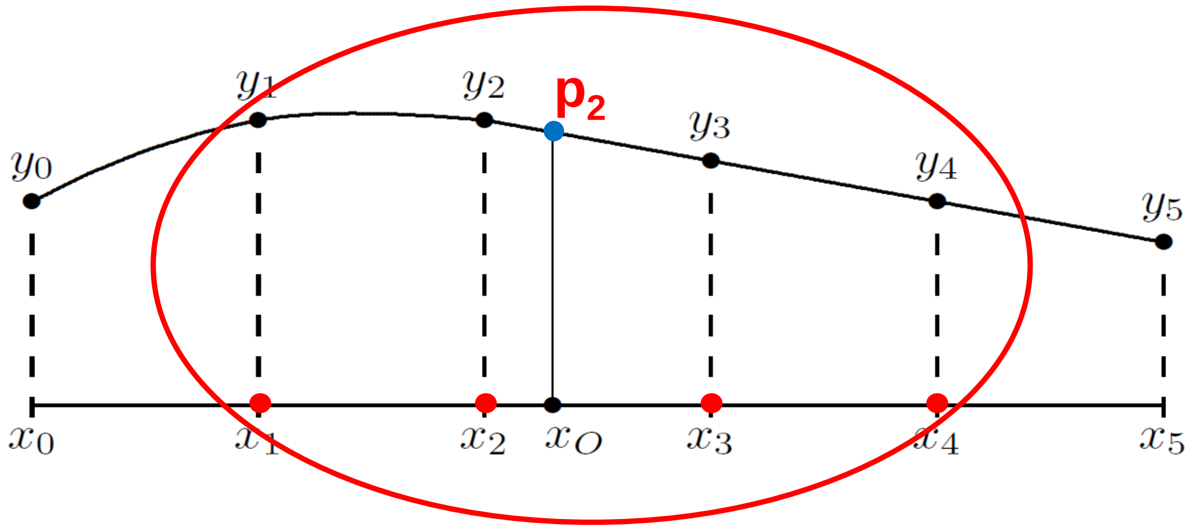
Third order interpolation scheme (cubic) needs 4 points to find ● :



Stencil 1 =>
interpolated value p_1

ENO technique in SL interpolations

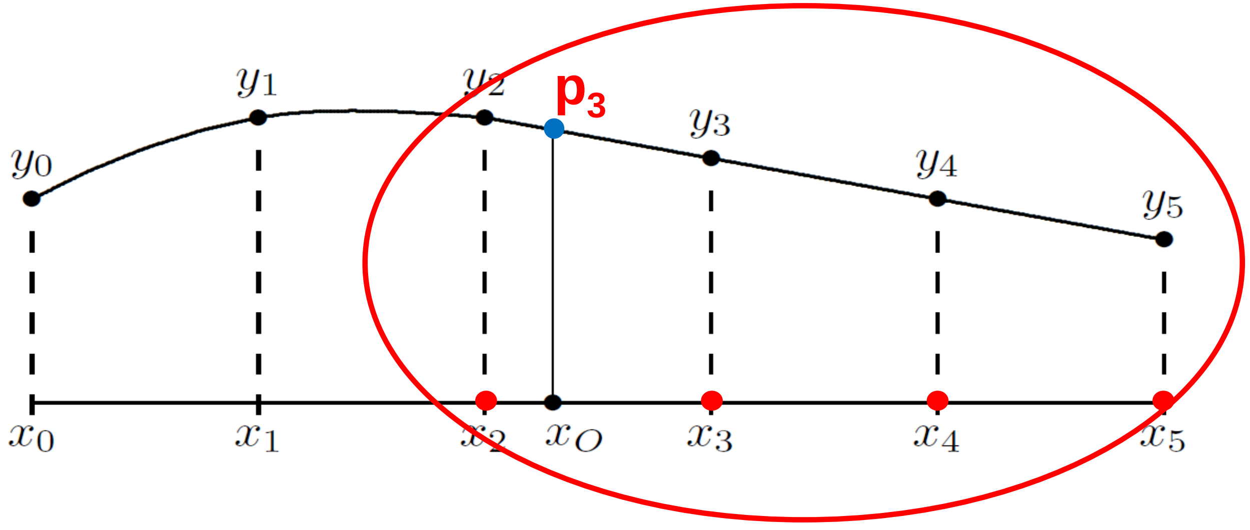
Third order interpolation scheme (cubic) needs 4 points to find ● :



Stencil 2 => interpolated value p_2

ENO technique in SL interpolations

Third order interpolation scheme (cubic) needs 4 points to find ● :



Stencil 3 =>
interpolated value p_3

ENO technique in SL interpolations

p_1, p_2, p_3 … interpolated values on three stencils

Final interpolated value
$y = w_1 p_1 + w_2 p_2 + w_3 p_3$, where w_1, w_2, w_3 are weights with

$$w_1 + w_2 + w_3 = 1$$

ENO chooses the smoothest solution ($S_i = min(S_1,S_2,S_3) \Rightarrow w_i = 1$)
WENO weighted combination based on smoothness

ENO technique in SL interpolations

In 3D :

6 vertical levels

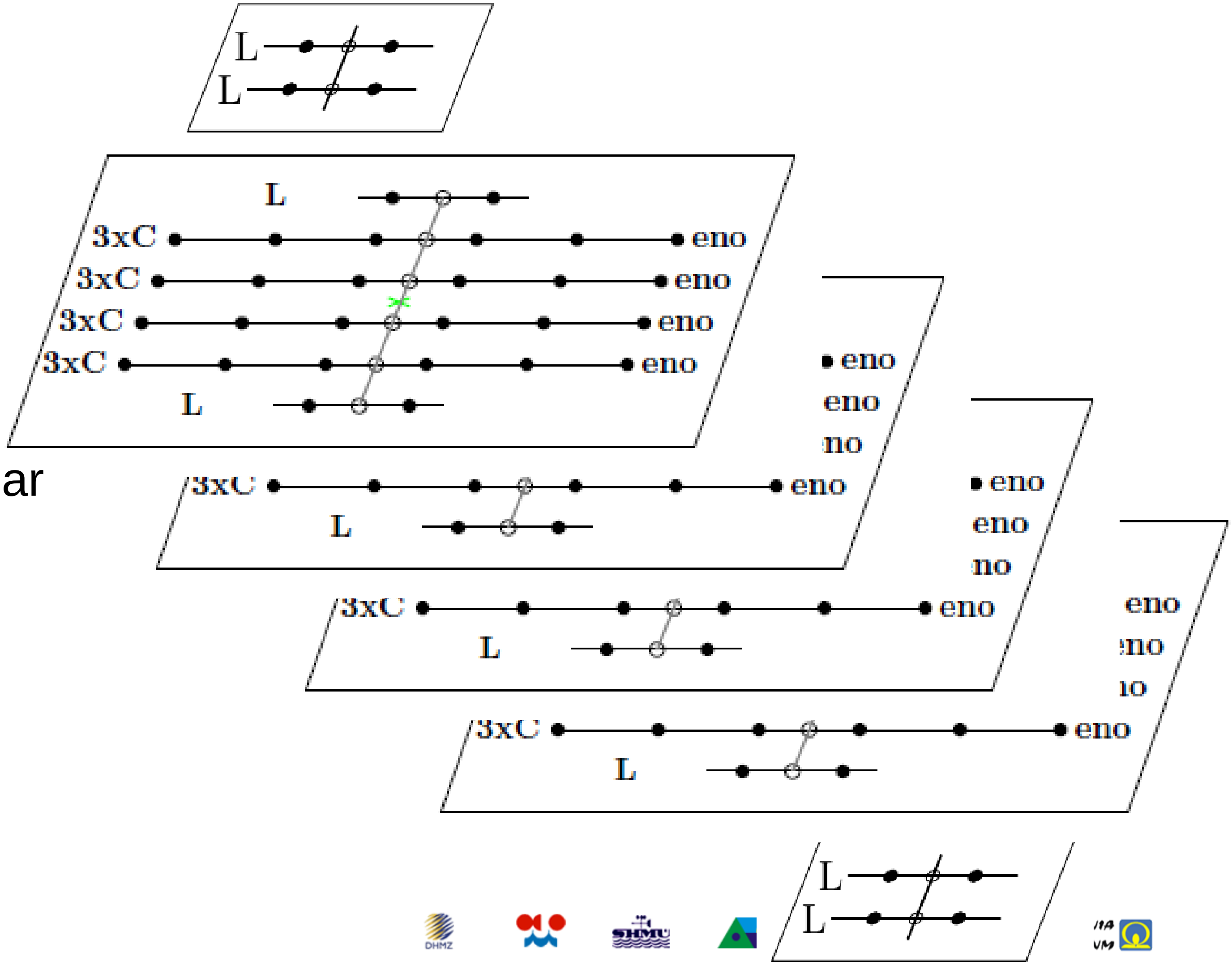
3 linear interpolations in top and bottom level

+

5 eno and 2 linear interpolations in 4 middle levels

+

1 vertical eno interpolation

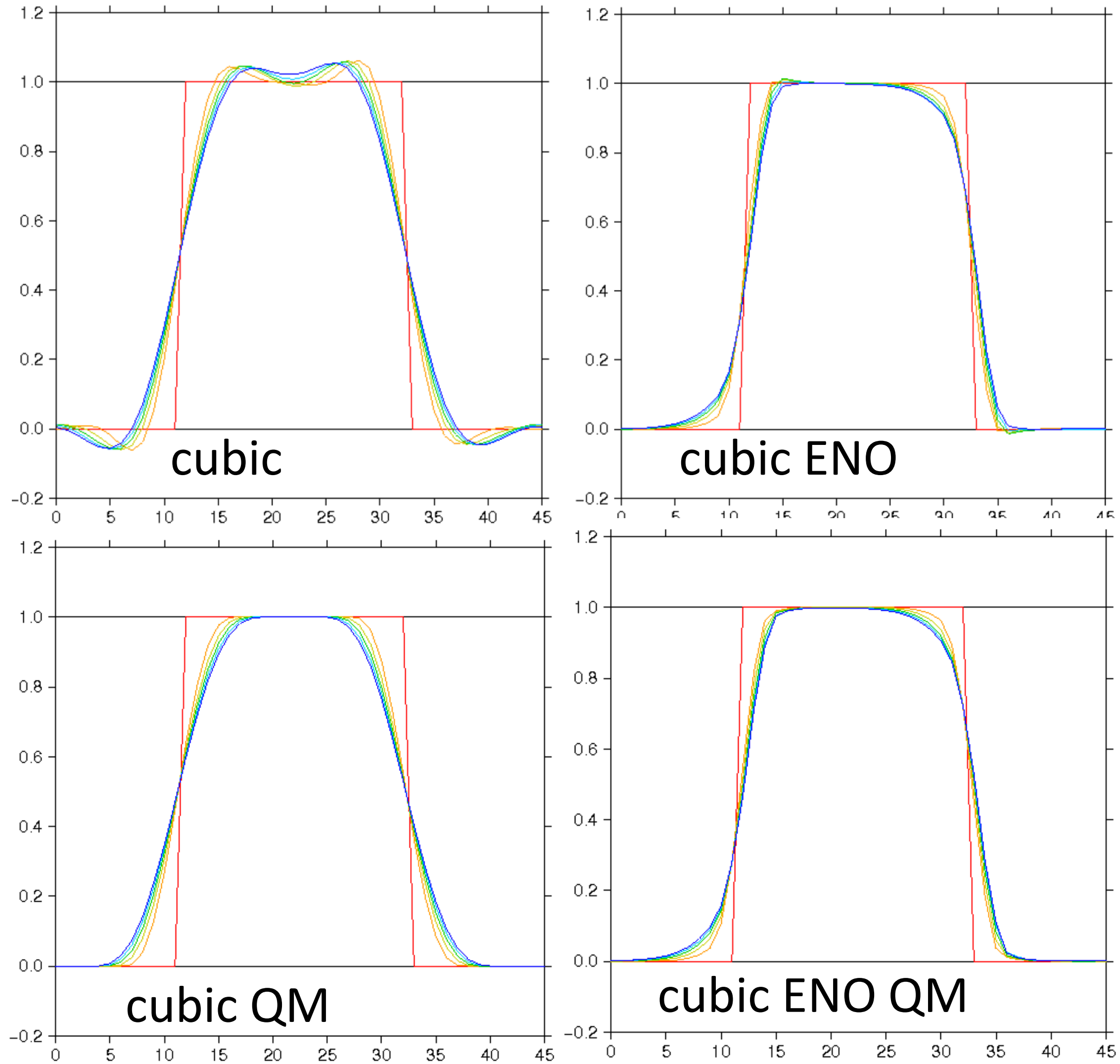


ENO technique in SL interpolations

Toy model:

1D linear advection of rectangular pulse in a periodic domain

QM for ENO is closer to ENO than QM cubic to cubic interpolation => less overshooting with ENO

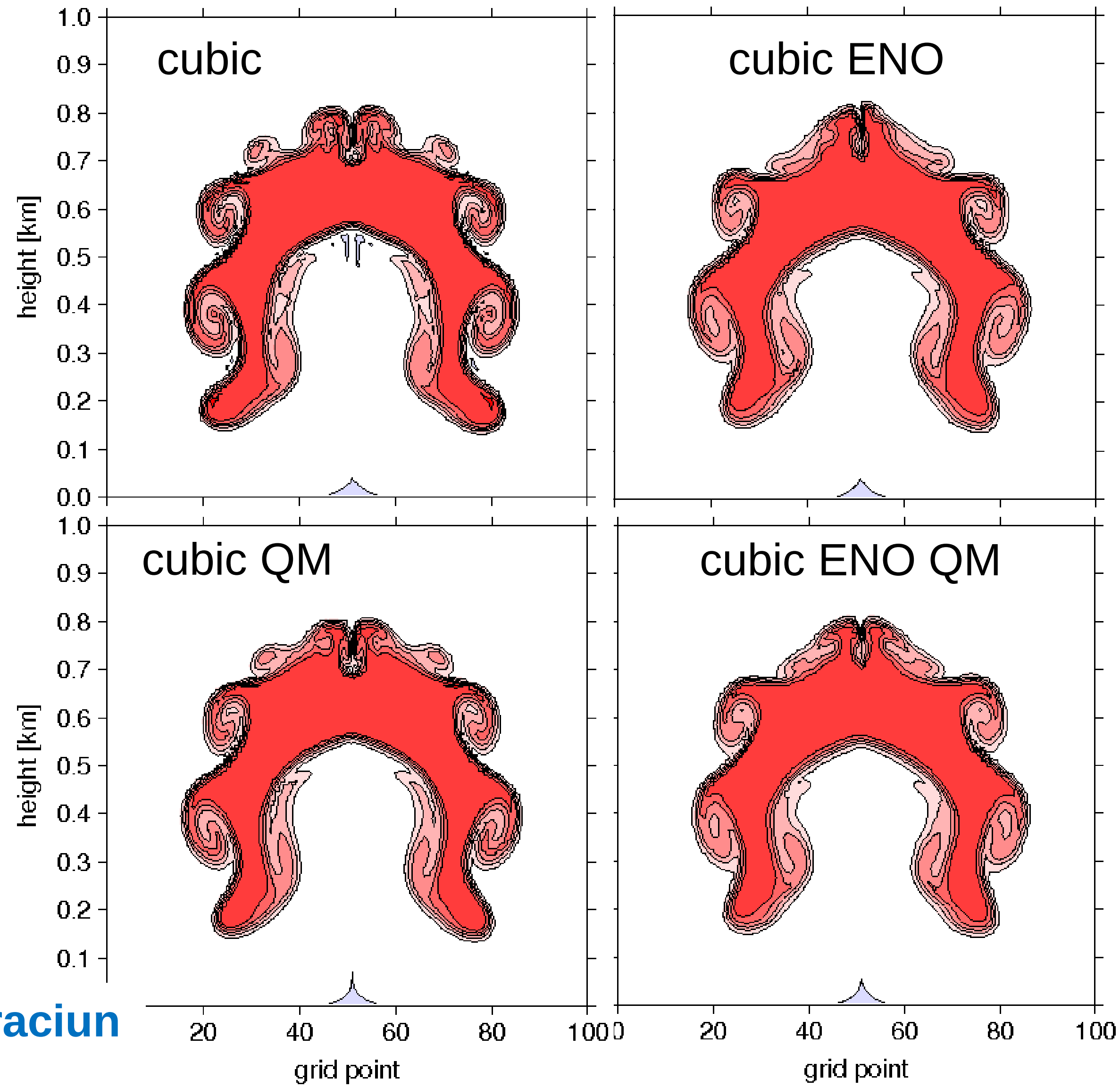


Courtesy of Ján Mašek

ENO technique in SL interpolations

Robert's test in 2D model: warm bubble (+0.5K) in the field of potential temperature (300K) without advection

Difference between S and S QM is smaller for ENO => less overshooting with ENO



Courtesy of Alexandra Craciun

ENO technique in SL interpolations

Conclusions and questions:

- Cubic ENO interpolator seems to be too smoothing, but less overshooting than the cubic Lagrange operator.
- What about cubic WENO ? It is very promising and suitable for linearization (TL code).
- What is the cost of ENO in 3D ?

1D2D turbulence

Motivation:

- usually only vertical components of turbulent fluxes influence the evolution of prognostic variables (vertical components dominant, computations of physics done in vertical column)
- combination of vertical turbulent diffusion and horizontal diffusion needed in high resolutions => 1D2D turbulence scheme

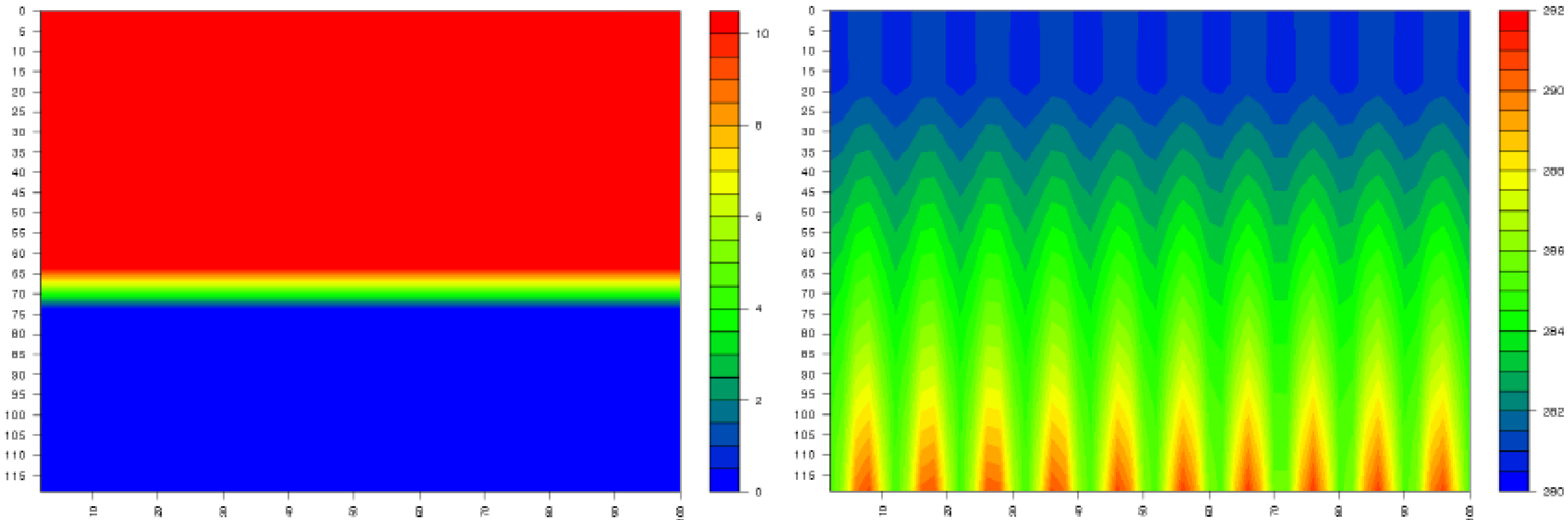
The aim:

- to ensure scientifically correct behavior of the whole 1D2D system of turbulence parametrization
- the vertical part is being developed in TOUCANS while the horizontal part using SLHD structure is being redesigned (new horizontal stability functions)

1D2D turbulence

Scientific validation

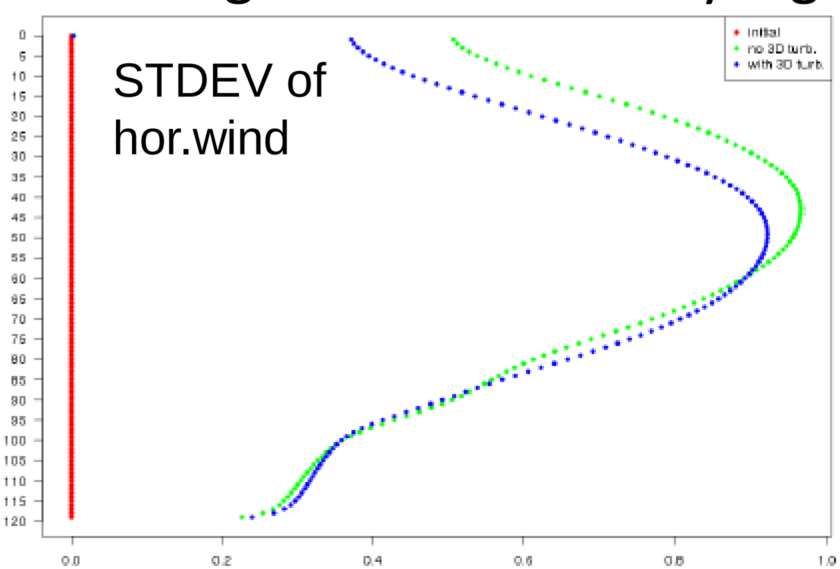
- Tested in CY38t1_op3 with ALARO1 package
- Both components (vertical and horizontal) are up to date
- **2D sensitivity experiments:** idealized initialization through the wind shear and temperature vertical profile

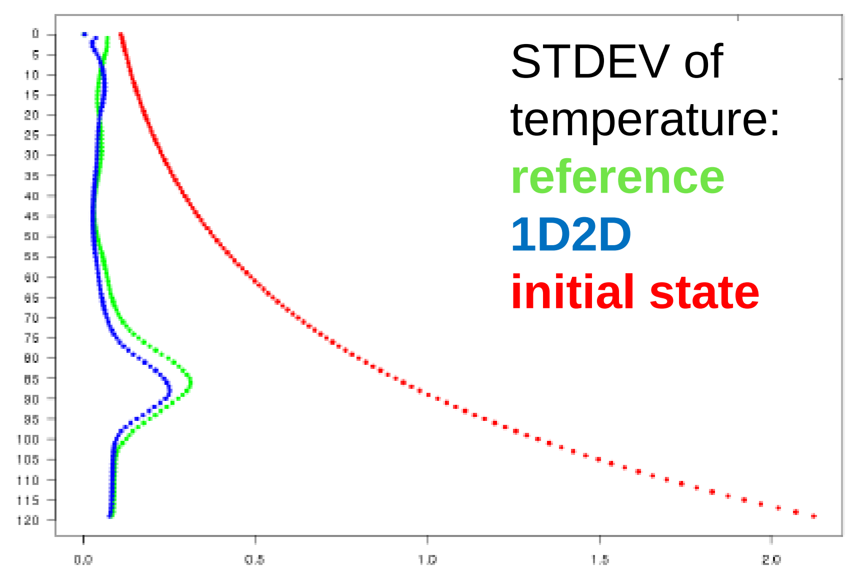


1D2D turbulence

The results:

- 1D2D turbulence parametrization decreases the horizontal variability of the diffused fields
- the influence of 1D2D turbulence parametrization is significant only where the horizontal gradients are steep enough => in sufficiently high horizontal resolutions





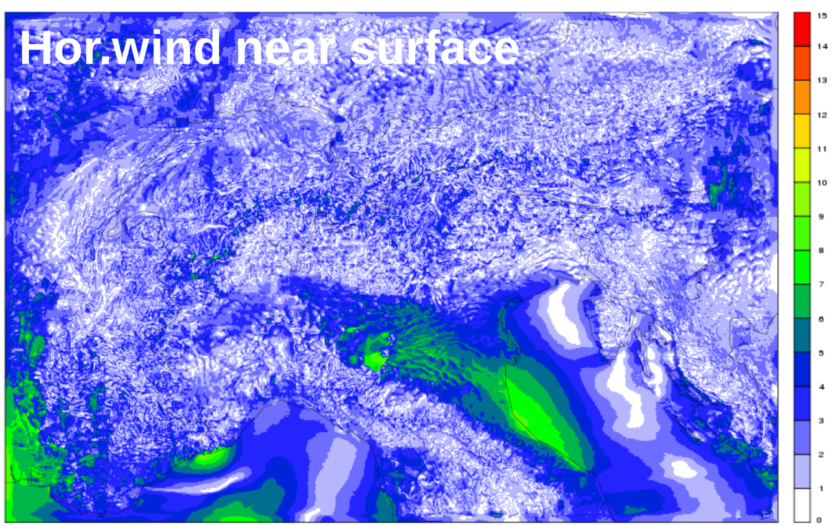
Courtesy of Ivan Bašták-Ďurán

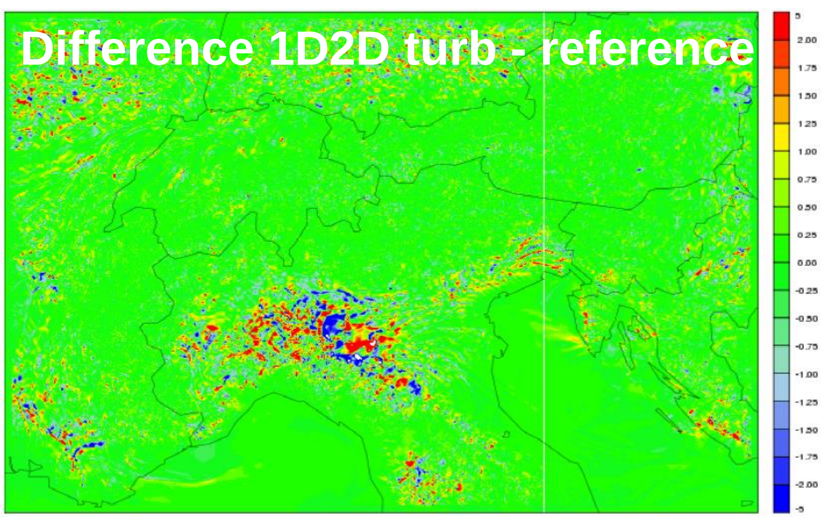
1D2D turbulence

Real simulations: 1.7.2014, Alpine region, 1.25km x 87 vert.levels

The results:

- a significant impact on model forecasts of diffused variables in regions with steep horizontal gradients
- sensitivity to the choice of stability functions and to the choice of the length scale





Courtesy of Ivan Bašták-Ďurán

1D2D turbulence

Future work:

- to repeat the whole task after modifications of TOUCANS part are finished
- to analyse the spectrum of the model fields to see where the 1D2D turbulence is most active in order to determine the horizontal resolution at which the scheme is worth to be switched on
- to find the optimal mixture of SLHD and 1D2D turbulence in dependence on the horizontal model resolution

Rapid changes of surface pressure field in LBC files

Motivation:

- Interpolation in time applied on LBC data may not capture fast propagating storms; a dual modest cyclone structure may replace the propagation of a storm
- increasing resolutions of LAM and leading global models => even hourly available coupling data may not be sufficient in some cases
- more accurate (but computationally expensive) methods for LBC data time interpolation should be used only when needed

⇒ an increasing need of a reliable method **to detect such events** of severe weather conditions which missing in the forecast may cause important damages

Rapid changes of surface pressure field in LBC files

Current status: MCUF as an indicator of rapidly moving pressure disturbances (RMPD) operationally provided in ARPEGE LBCs, but not in IFS LBCs

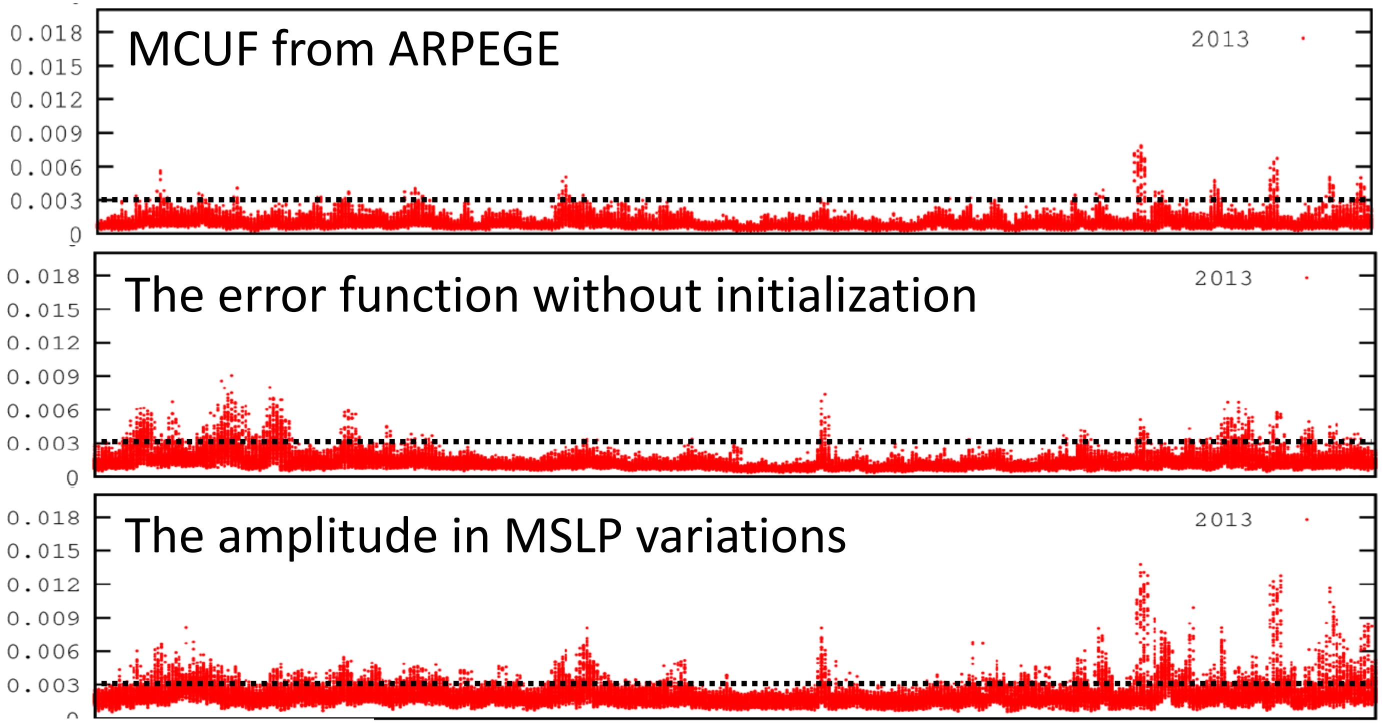
Work in progress:

- An analysis prepared of the MCUF field for the LACE coupling domain for the period 23rd January 2006 - 15th November 2014
- Several methods proposed to detect RMPD **a posteriori** from IFS:
  - by running ALADIN in low resolution on the IFS coupling files
  - by simple computation of the amplitude of variations in mean sea level pressure from three consecutive coupling files
  - by error function which is computed using tendencies estimated by running ALADIN for one time step, using coupling fields without initialization, initialized with DFI or with Scale Selective DFI

Rapid changes of surface pressure field in LBC files

Conclusions:

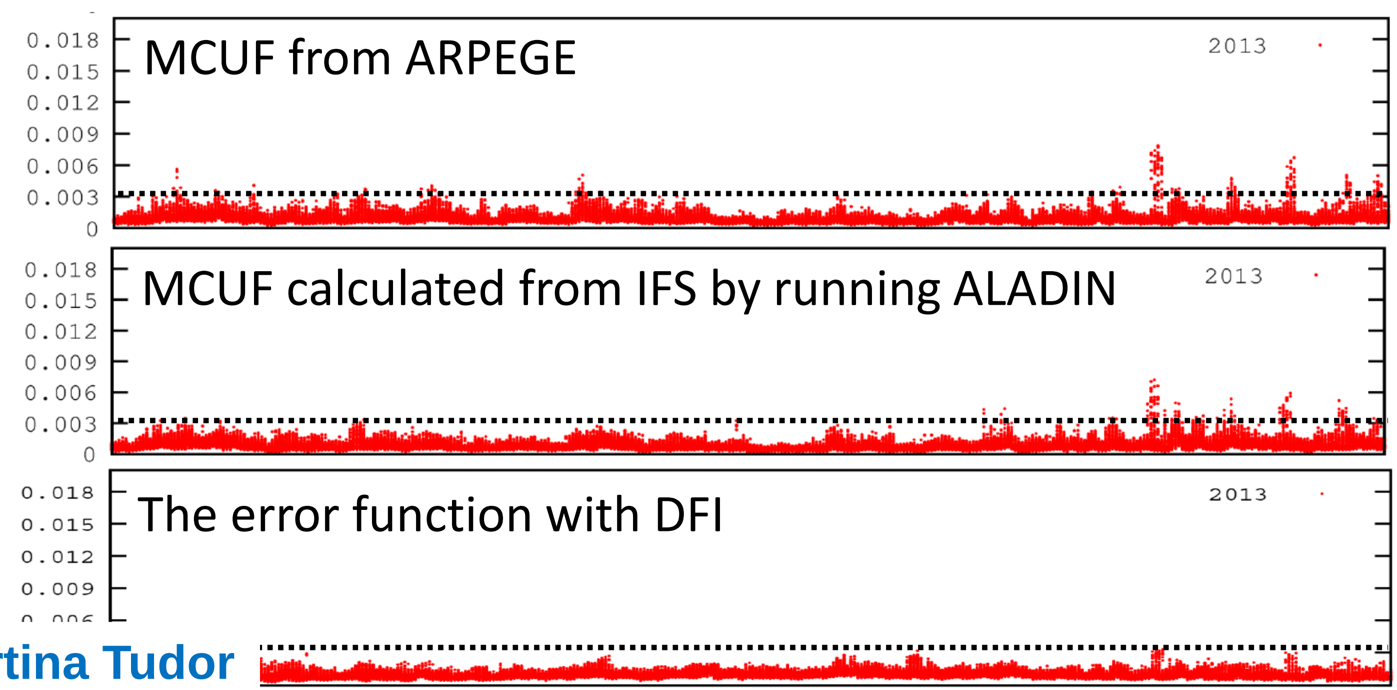
- The error function computed without initialization and the amplitude of mean sea level variations are **cheap and give satisfactory results** (better captured cases close to model boundaries)



Rapid changes of surface pressure field in LBC files

Conclusions:

- Two other proposed methods (MCUF calculation by running ALADIN in low resolution and error function calculated with initialization) **have questionable results** (false peaks from orography, too moderate signal) which do not justify their extra computational cost.



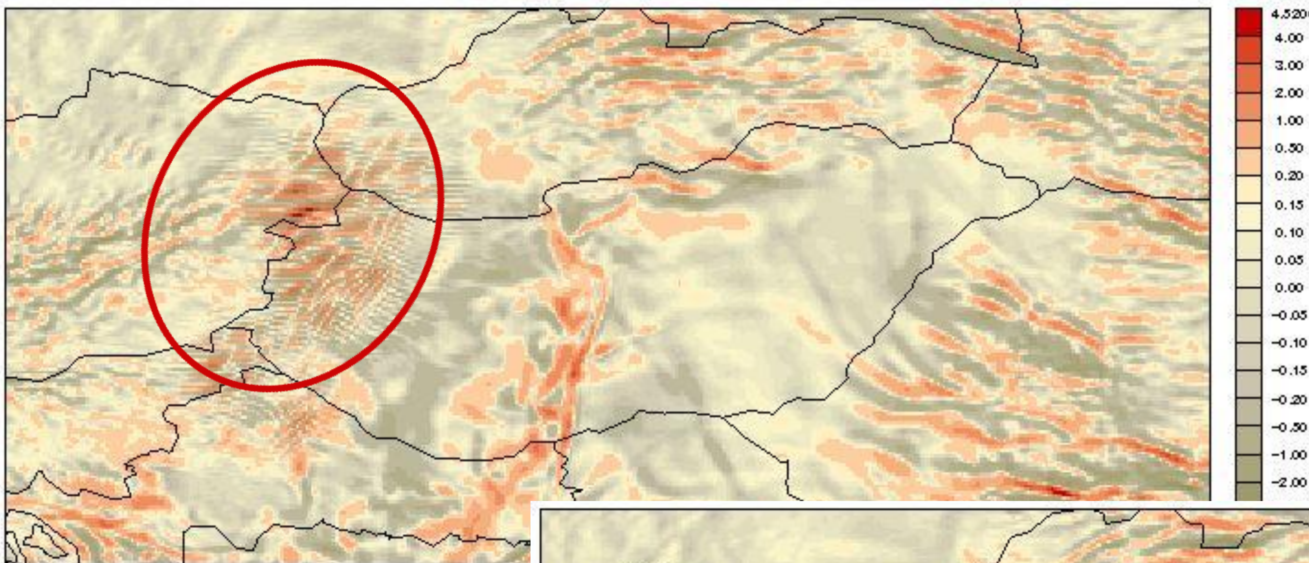
Courtesy of Martina Tudor

Problems: Share between horizontal diffusion (SLHD) and numerical (spectral) diffusion

Lee waves in the hungarian operatinal run, 2km hor.resolution

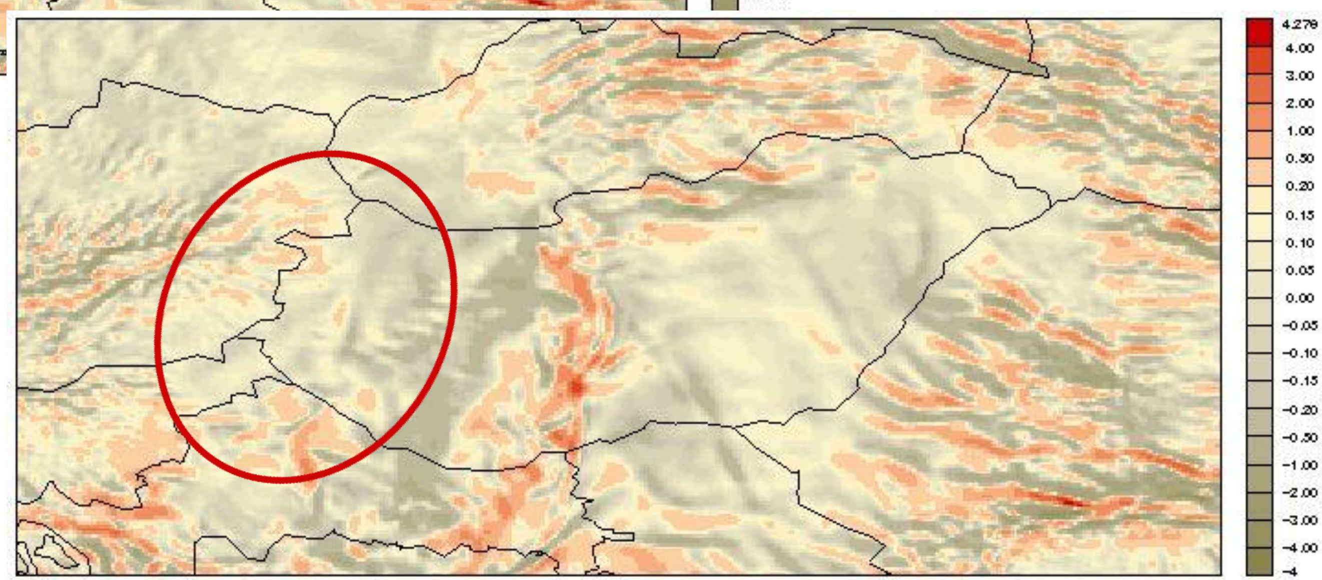
- tuning of SLHD has helped
- an example of needed tuning for SLHD in high resolution experiments

Problems: Share between horizontal diffusion (SLHD) and numerical (spectral) diffusion



w at 700hPa
t + 29 hours

SLHD tuning
+ advection of w



Courtesy of Viktória Homonnai

Thank you for your attention!

Хвала на пажњи !