Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

LACE : News in dynamics 2018

Petra Smolíková
thanks to Jozef Vivoda, Martina Tudor, Ján Mašek, Oldřich Španiel
and other colleagues

DHMZ ZAMG ROMANIA ANM OMSZ SHMU

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 – direct solver for Helmholtz equation, vertical/horizontal direction separation
- 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

Outline

1. FE used in the vertical discretization of ALADIN-NH
2. Tuning of horizontal diffusion for HR
3. Dynamic definition of the iterative time scheme
4. Vertical motion variable
5. Single precision for the dynamical core
6. Coupling strategies

1. FE used in the vertical discretization of ALADIN-NH

- working implementation in CY45T1
- paper published in MWR

(J.Vivoda)

2. Tuning of horizontal diffusion for HR

Several components: SLHD (Semi-Lagrangian Horizontal Diffusion) = non-linear flow dependent numerical diffusion

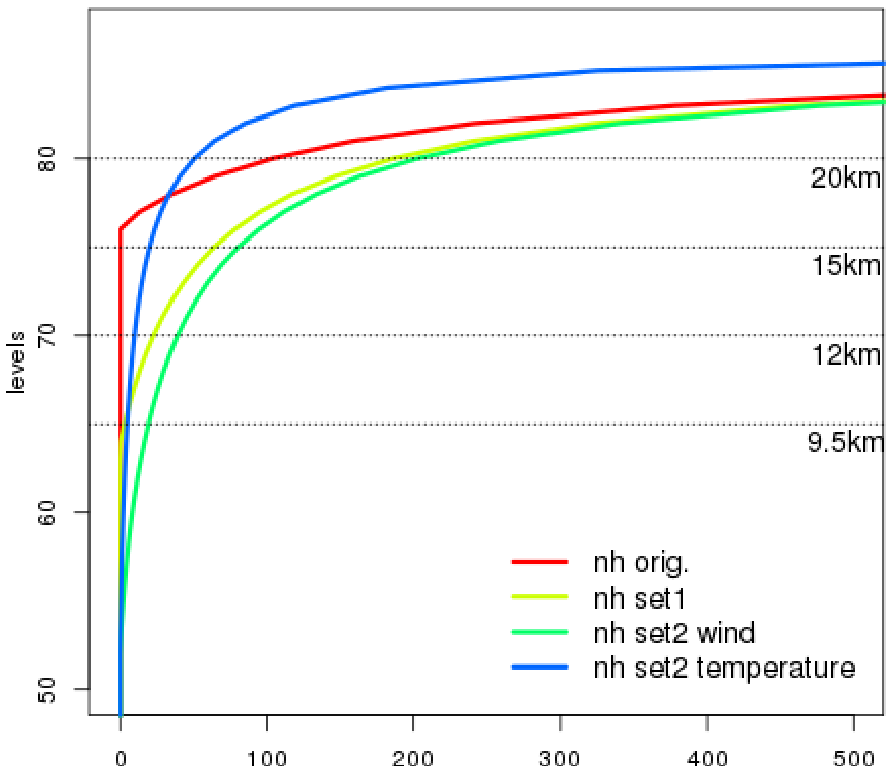
+ reduced spectral diffusion (upper part)

+ supporting spectral diffusion

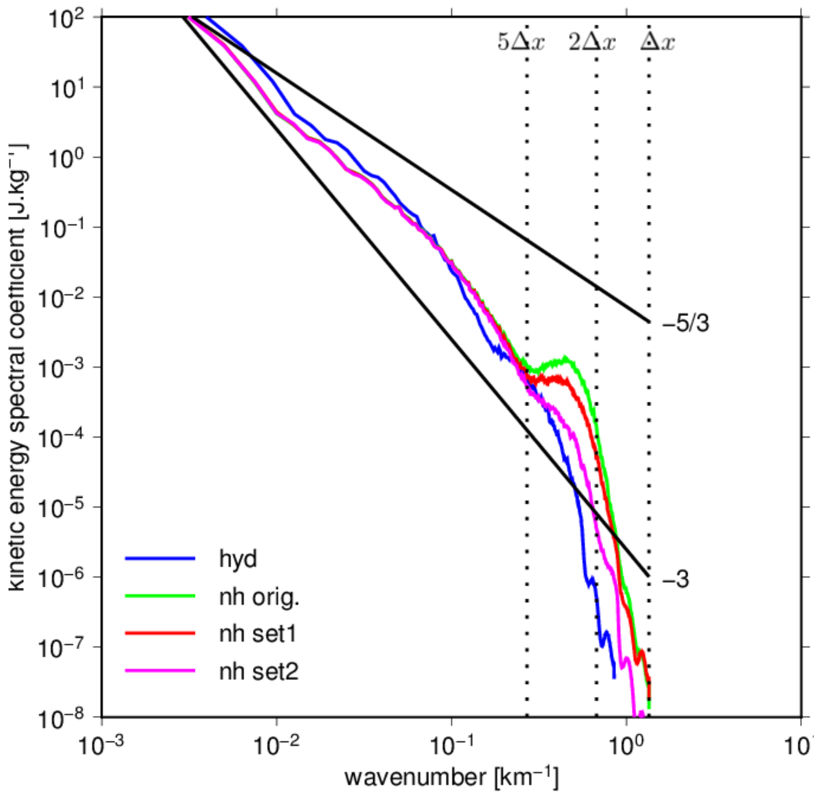
- tuning for operational application of CHMI at 2.325km:
- reduced spectral diffusion on T,Div
- extended to lower part of the domain

2. Tuning of horizontal diffusion for HR

Vertical profile of
the diffusion coefficient



Kinetic energy spectrum at
200hPa



3. Dynamic definition of the iterative time scheme

- weights are calculating depending on the spectral norms of the pressure departure
- the time scheme is chosen in each GP and each vertical level depending on the weight
- presented at last EWGLAM
- implemented in CY46T1

(J.Vivoda)

4. Vertical motion variable (J.Vivoda)

In ALADIN/HIRLAM system prognostic equation for vertical velocity *w* is replaced by prognostic equation for **vertical divergence *d***:

$$d = g\frac{\partial w}{\partial \phi}$$

$$\begin{aligned}
\dot{d} &= \mathcal{L}(p) + d(d+X) + Z \\
\mathcal{L}(p) &= -g^2 \frac{\partial}{\partial \phi}\left(\frac{\partial \widetilde{p}}{\partial \pi}\right) \\
X &= -\frac{\partial V}{\partial \phi} \cdot \nabla \phi \\
Z &= -\frac{\partial V}{\partial \phi} \cdot \nabla (gw)
\end{aligned}$$

4. Vertical motion variable

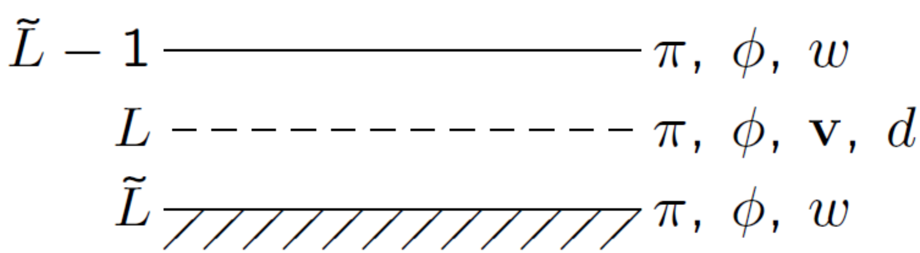
- **vertical velocity w** can be diagnosed as:

$$gw = gw_s + \int_{\phi_s}^{\phi} d \; d\phi'$$

- with **free slip bottom boundary condition**

$$gw_s = V_s \cdot \nabla \phi_s$$

- air velocity at the surface is parallel to it, air remains at the surface



4. Vertical motion variable

Bénard ea. (2005): stability enhanced for

$$d4 = d + X = d - \frac{\partial V}{\partial \phi} \cdot \nabla \phi$$

Prognostic equation becomes

$$\dot{d}4 = \dot{d} + \dot{X}$$

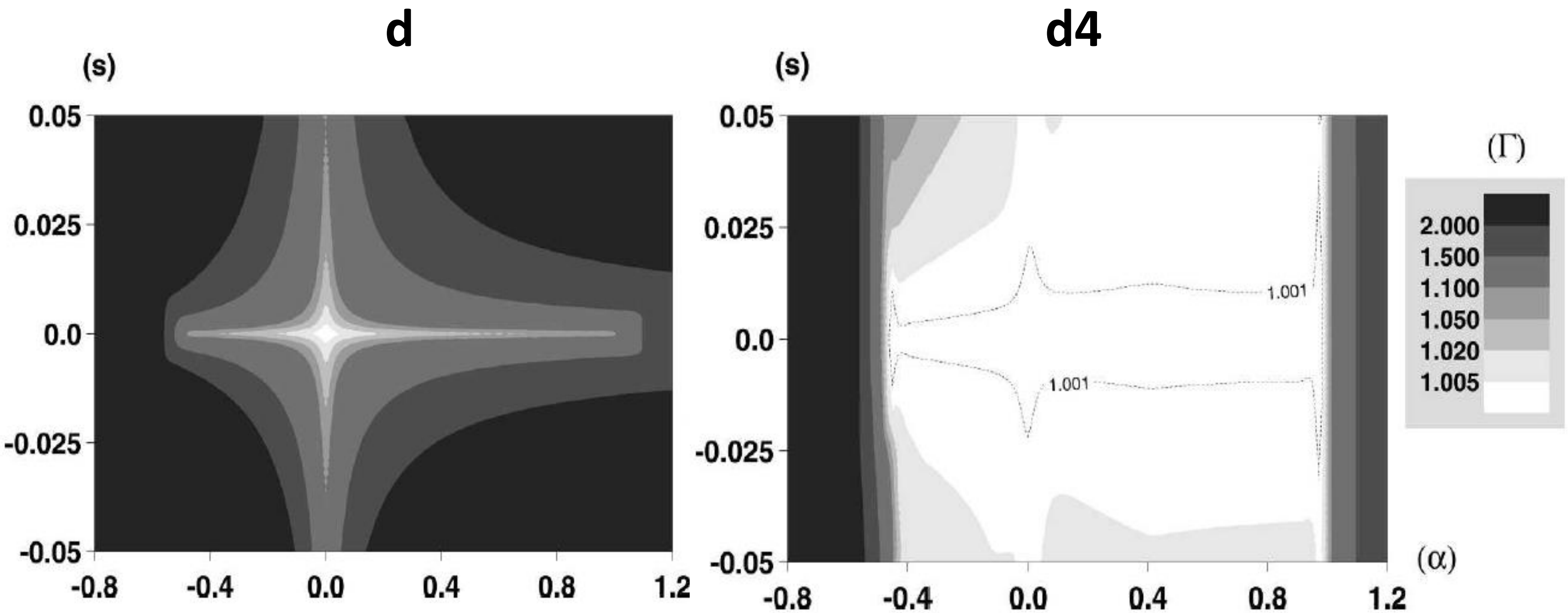
diagnosed from known values

$$\dot{X} \approx \frac{X_F^0 - X_0^-}{\Delta t}$$

or $$\dot{X} \approx \frac{\widetilde{X}_F^+ - X_O^0}{\Delta t}$$

4. Vertical motion variable

Stability analysis of the 3TL SI EE system with

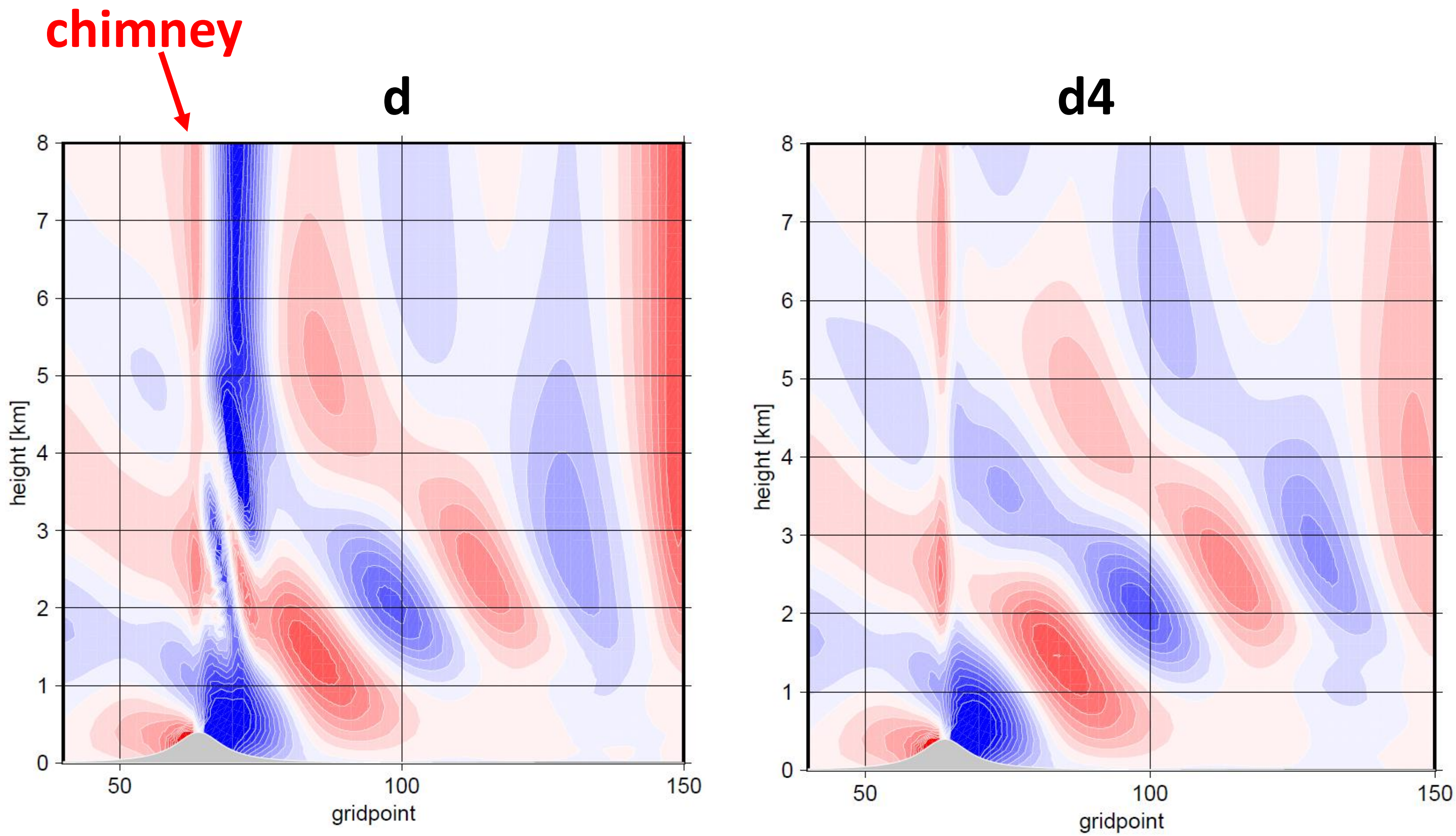


(vertical coordinate σ, Δt=100s, slope s, nonlinearity parameter α)

(courtesy of P.Bénard)

4. Vertical motion variable

Test case: Nonlinear nonhydrostatic flow over bell-shaped orography



4. Vertical motion variable

- Discretization of the vertical Laplacian term

$$\mathscr{L}(p) = -g^2 \frac{\partial}{\partial \phi}\left(\frac{\partial \tilde{p}}{\partial \pi}\right)$$

- At the last layer

$$[\mathscr{L}(p)]_L = \frac{1}{\delta_L}\left[\left(\frac{\partial \tilde{p}}{\partial \pi}\right)_{\hat{L}-1} - \left(\frac{\partial \tilde{p}}{\partial \pi}\right)_s\right]$$

$$g^2\left(\frac{\partial \tilde{p}}{\partial \pi}\right)_s = g\dot{w}_s$$

- Originally

$$g\dot{w}_s = \dot{V}_s \cdot \nabla \phi_s + V_s \cdot \nabla (V_s \cdot \nabla \phi_s)$$

4. Vertical motion variable

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4. Vertical motion variable

Diagnostic BBC:

problematic surface term is expressed in semi-Lagrangian way

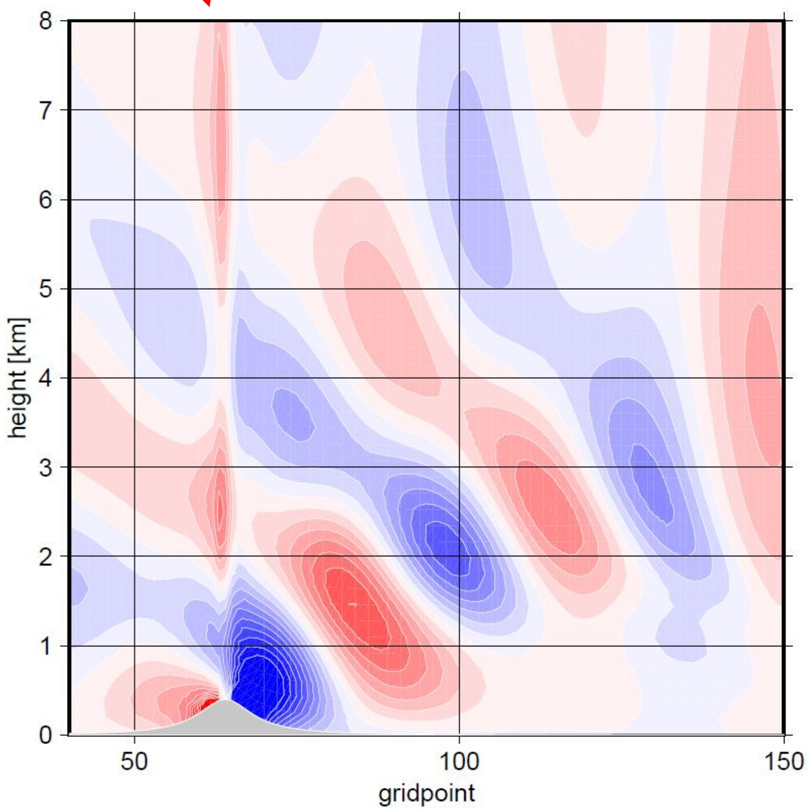
$$g\dot{w}_s = \frac{(g\dot{w}_s)_F^+ - (g\dot{w}_s)_O^0}{\Delta t}$$

4. Vertical motion variable

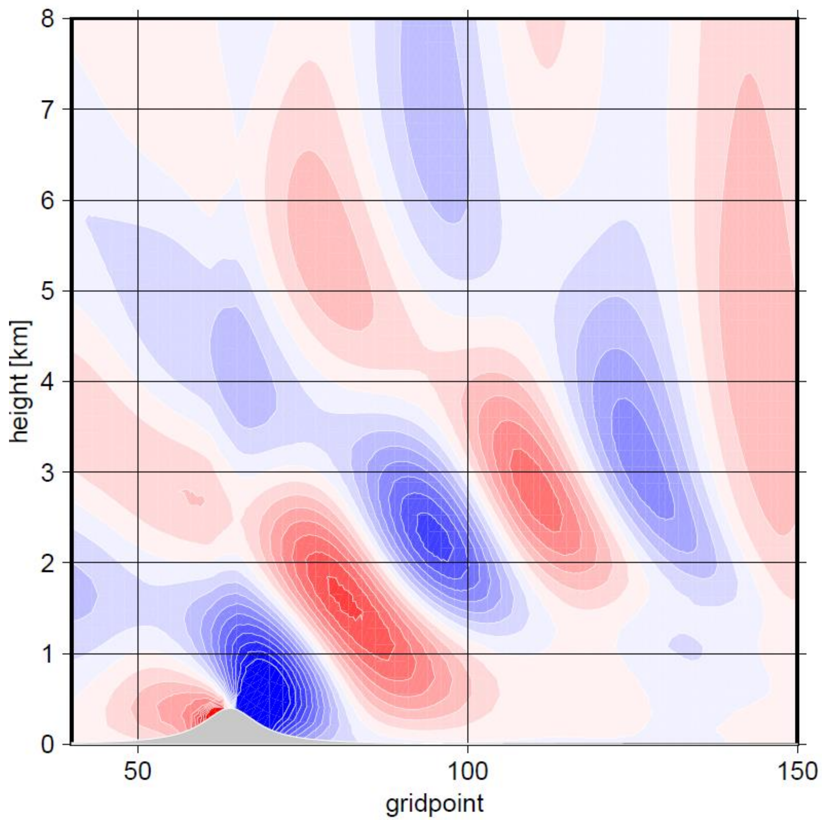
Test case: Nonlinear nonhydrostatic flow over bell-shaped orography

chimney

d4



d4 + diagnostic bbc



4. Vertical motion variable

Stability of the linear system => **vertical divergence d/d4** is used in spectral space

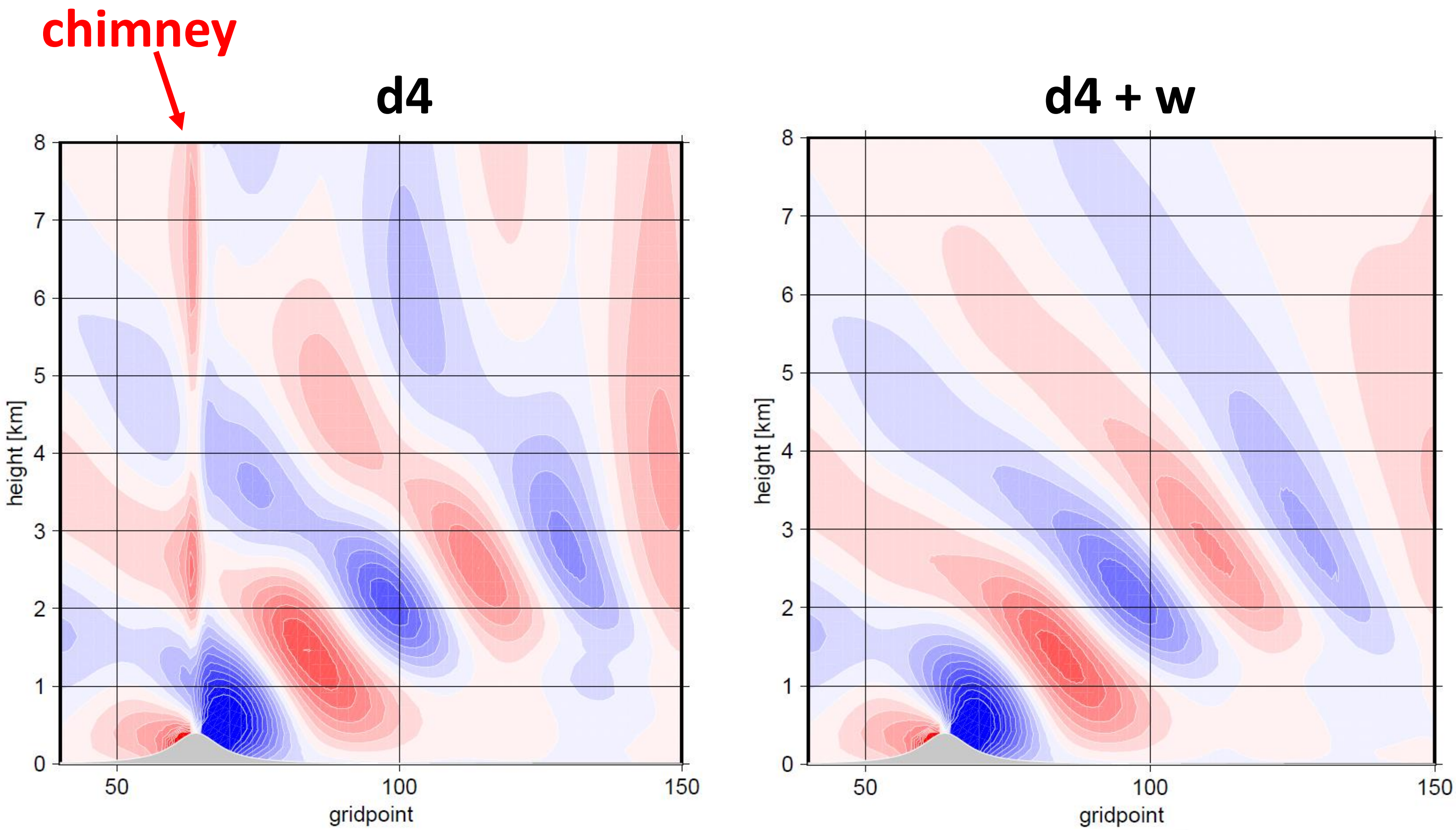
X

Accuracy of the non-linear system => **vertical velocity w** is used in GP space

- Basic idea: no need to evaluate BBC for the vertical Laplacian
- Non-trivial part of the job is preparation of RHS for Helmholtz solver, because operators acting on *w* must be transformed into operators acting on *d* (transformation is non-linear).
- Problem is solved by using the fact that transformation between explicit guesses is very close to transformation between final quantities.

4. Vertical motion variable

Test case: Nonlinear nonhydrostatic flow over bell-shaped orography



4. Vertical motion variable

We see that :

- BBC must be done consistently with model dynamics otherwise problems appear.
- It is very easy to overlook some inconsistencies in time and space discretized equations.
- On the other hand it is very hard to say a priori which discretization details are innocent and which are harmful.
- Correct BBC treatment in spectral model can be technically difficult.
- Simple BBC can be beneficial.

4. Vertical motion variable

Rigid BC for *w*: $$g w_s = V_s \cdot \nabla \phi_s$$

with $$V_s = V_L$$

Prognostic equation: $$g \dot{w}_s = \dot{V}_s \cdot \nabla \phi_s + V_s \cdot \nabla (V_s \cdot \nabla \phi_s)$$

New idea (Voitus, 2018): define vertical velocity *W* in such a way that

$$g W_s = 0$$

$$g \dot{W}_s = 0$$

Now, the full model and linear model are the same.

4. Vertical motion variable

Two definitions came from this condition:

$$gW5 = gw - V \cdot \nabla\phi$$

$$gW6 = gw - V \cdot \nabla\phi_s$$

Vertical divergence is always transformed in the same way:

$$d = -\frac{p}{RT}\frac{\partial gW}{\partial \pi} + X$$

Differs just the division between *W* and *X*:

$$X5 = \frac{V \cdot \nabla \left(\frac{\partial \phi}{\partial \eta}\right)}{\frac{\partial \phi}{\partial \eta}}$$

$$X6 = \frac{\partial V}{\partial \phi} \cdot (\nabla\phi_s - \nabla\phi)$$

4. Vertical motion variable

Prognostic equation $g\dot{W} = g\dot{w} + \dot{Y}$ **diagnosed from known values**

Second order accurate SL-approximation :

$$\frac{Y_F^{+} - Y_O^{0}}{\Delta t} = \left(-\alpha + \frac{3}{2}\right) Y_F^{0} + \left(\alpha - \frac{1}{2}\right) Y_F^{-} + \left(\alpha - \frac{1}{2}\right) Y_O^{0} + \left(-\alpha - \frac{1}{2}\right) Y_O^{-} + \mathcal{O}(\Delta t^2)$$

$$\alpha = \frac{1}{2} : \frac{Y_F^{+} - Y_O^{0}}{\Delta t} = \frac{Y_F^{0} - Y_O^{-}}{\Delta t}$$

4. Vertical motion variable

Stability analysis of the SL scheme

Time evolution of *f* is divided in a prognostic and diagnostic part

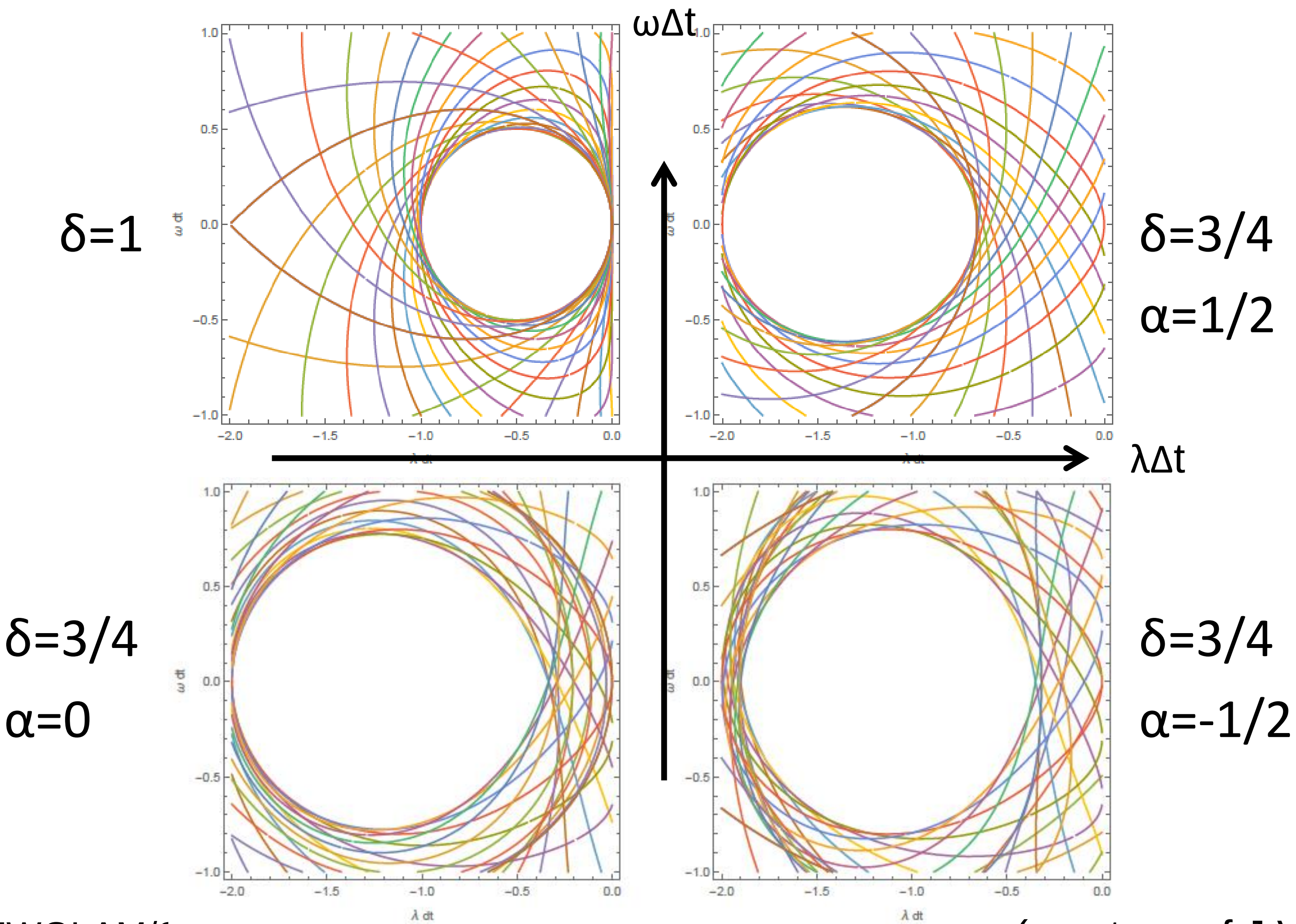
$$\frac{df}{dt} = \delta\left(\lambda + i\omega\right) f + \left(1-\delta\right)\frac{df}{dt}$$

= prototype for *d* or *gW* prognostic equations, diagnostic part represents the evolution of *X*,*Y*-terms.

2TL-time discretization

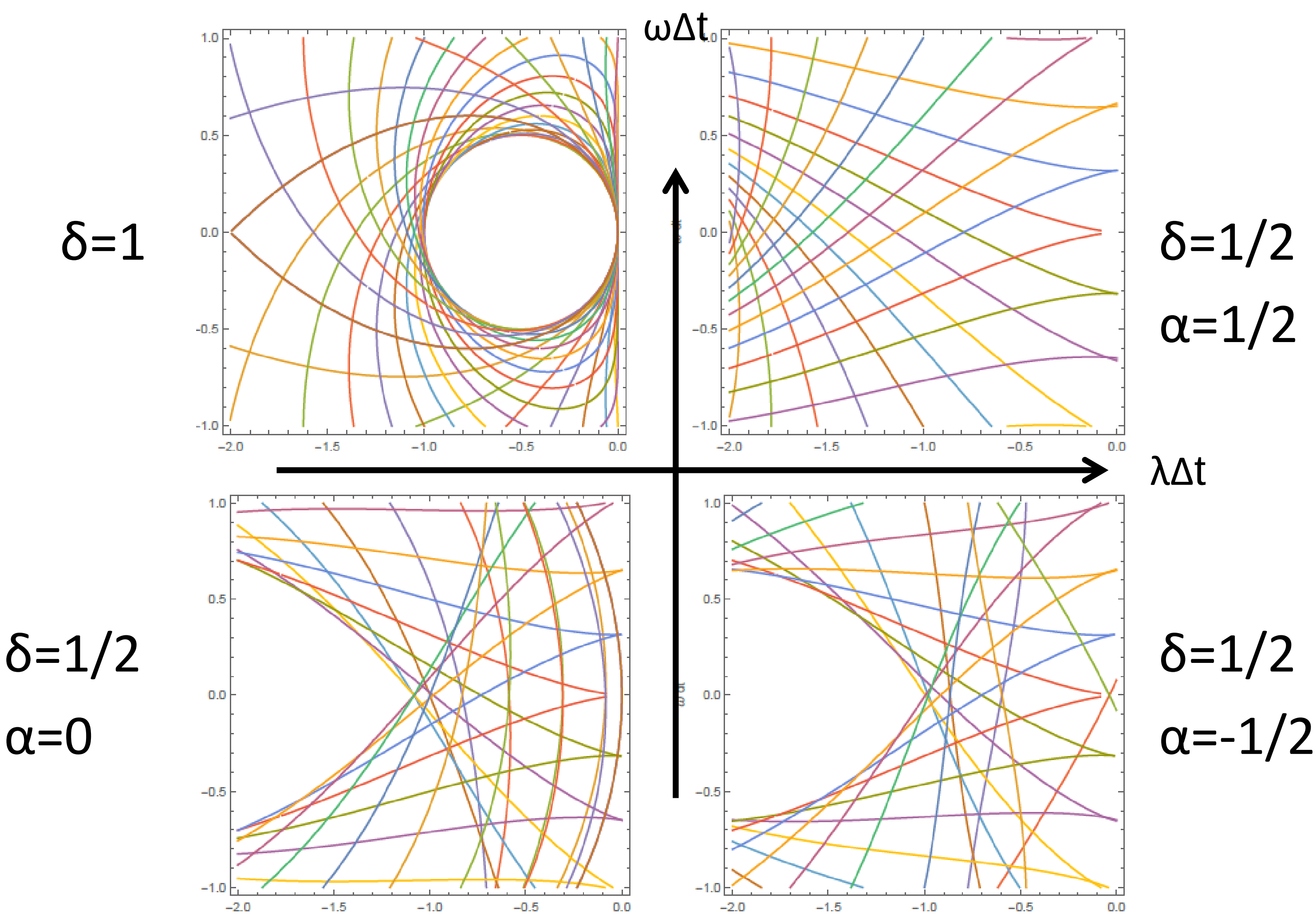
$$\frac{f_F^+ - f_O^0}{\Delta t} = \delta(\lambda + i\omega) f_M^m + (1-\delta)\frac{\widetilde{f_F^+} - f_O^0}{\Delta t}$$

4. Vertical motion variable



(courtesy of J.Vivoda)

4. Vertical motion variable

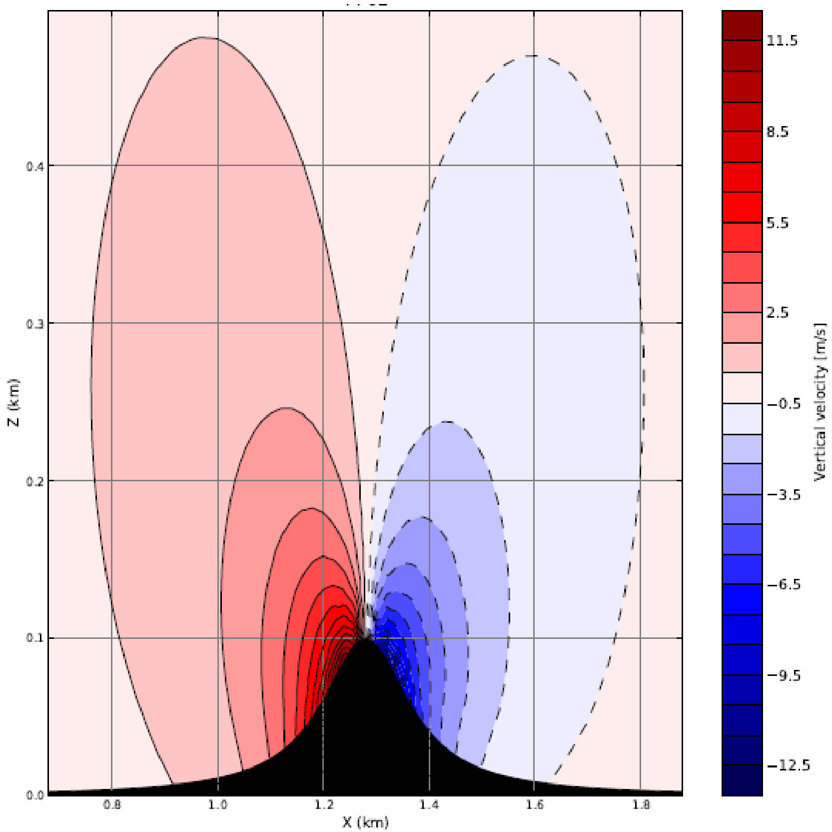


(courtesy of J.Vivoda)

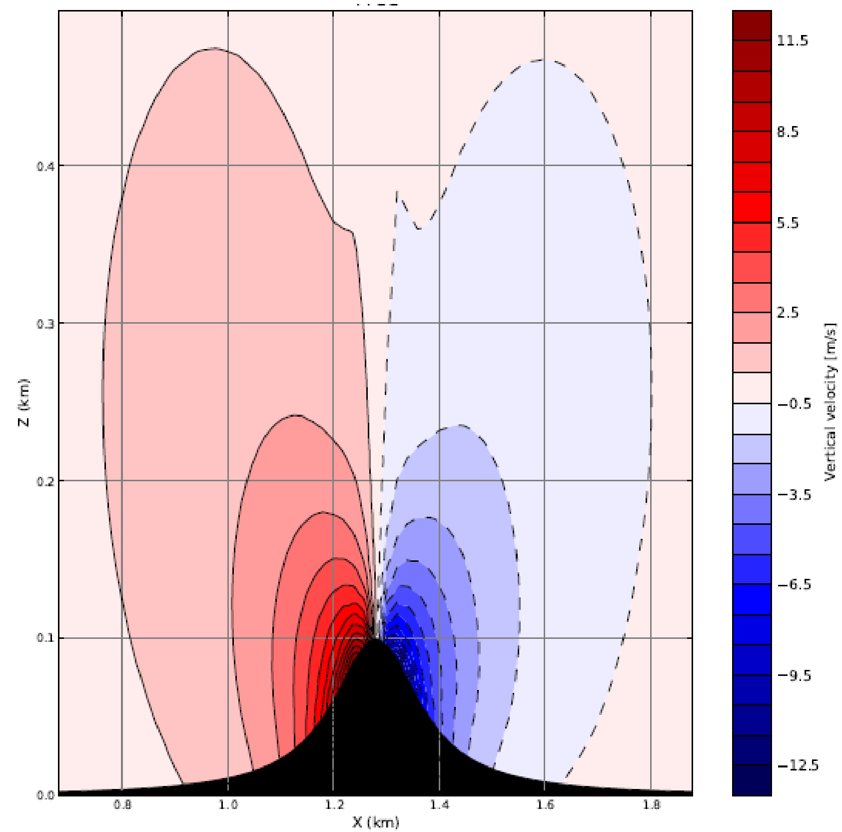
4. Vertical motion variable

2D test case: potential flow

W5



W6



(courtesy of J.Vivoda)

4. Vertical motion variable

Work is in progress.

5. Single precision for the dynamical core

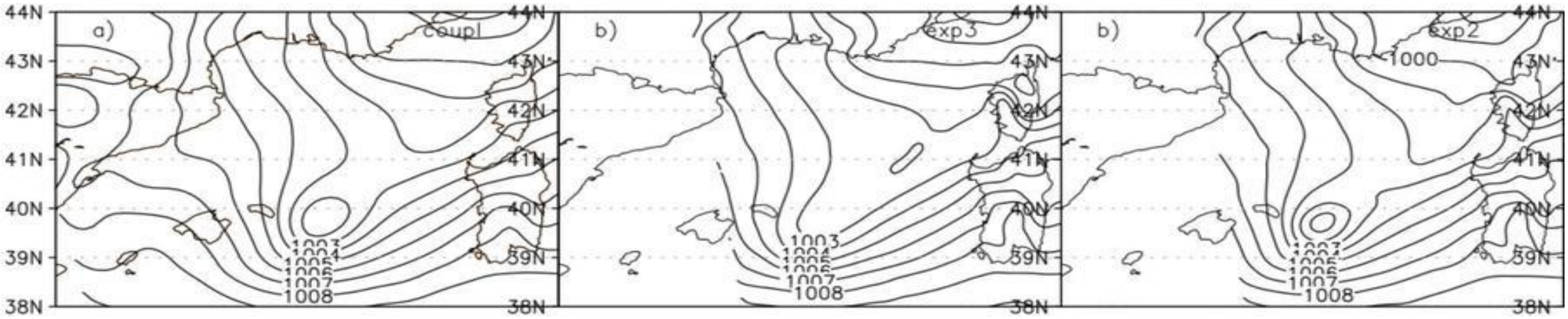
- first tests
- not so convincing results
- we have to learn

(O.Španiel)

6. Coupling strategies (M.Tudor)

Main conclusions may be summarized in 4 points:

- 1) Higher coupling frequency is beneficial for rapidly moving features. It is as well expensive in transfer and storage of the LBC data, of course.



Mean sea level pressure : present in LBC files *captured using 3hours coupling frequency* *1hour coupling frequency*

 (courtesy of M.Tudor)

6. Coupling strategies

Main conclusions may be summarized in 4 points:

- 1) Higher coupling frequency is beneficial for rapidly moving features. It is as well expensive in transfer and storage of the LBC data, of course.
- 2) Different temporal interpolation schemes give similar results.
- 3) Coupling of the surface pressure tendency may have detrimental effect on results.
- 4) Spectral blending is very sensitive to the length of the coupling interval and may produce large errors. Especially, it may not be combined with Boyd's method.


Thank you for your attention!