Regional Cooperation for
Limited Area Modeling in Central Europe

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Dynamics in RC LACE

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thanks to Alexandra Craciun, Jozef Vivoda
and other colleagues

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Outline

- Vertical velocity in NH [Jozef Vivoda]
- The trajectory search algorithm [Alexandra Craciun]
- SLHD for operational application at 2.3km [Czech team]

Fabrice Voitus proposal on the last ALADIN/HIRLAM Workshop: to impose homogeneous BBC treatment in NL model $\mathcal{M}$ and in linear model $\mathcal{L}*$

Currently:

BBC in LIN model

$$
\begin{aligned}
gw_S &= 0 \\
\frac{dgw_S}{dt} &= 0
\end{aligned}
$$

BBC in NL model

$$
\begin{aligned}
gw_S &= V_S \cdot \nabla\Phi_S \\
\frac{dgw_S}{dt} &= \frac{dV_S}{dt} \cdot \nabla\Phi_S + V_S \cdot \nabla\left(V_S \cdot \nabla\Phi_S\right)
\end{aligned}
$$

with

$$
V_S = V_{NLEV}
$$

Vertical velocity in NH

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We define ”modified vertical velocity variable w_{mod}” as

w_{mod} definition

$$g w_{mod} = g w + Y$$

Several options for Y definition

$$Y = -V \cdot \nabla \Phi$$
$$Y = -V \cdot \nabla \Phi_S$$
$$Y = -V_S \cdot \nabla \Phi_S$$

BBC becomes

$$g(w_{mod})_S = g w_S - V_S \cdot \nabla \Phi_S$$
$$\frac{d g (w_{mod})_S}{dt} = \frac{d g w_S}{dt} - \frac{d V_S}{dt} \cdot \nabla \Phi_S - V_S \cdot \nabla \left(V_S \cdot \nabla \Phi_S \right)$$

BBC in LIN and NL models

$$g(w_{mod})_S = 0$$
$$\frac{d g (w_{mod})_S}{dt} = 0$$

Vertical velocity in NH

We define "modified vertical velocity variable w_{mod}" as

w_{mod} definition

$$g w_{mod} = g w + Y$$

Several options for Y definition

$$Y \quad \begin{aligned} Y_5 &= -V \cdot \nabla \Phi \\ Y_6 &= -V \cdot \nabla \Phi_S \\ Y_7 &= -V_S \cdot \nabla \Phi_S \end{aligned}$$

BBC becomes

$$g(w_{mod})_S = g w_S - V_S \cdot \nabla \Phi_S$$

$$\frac{dg(w_{mod})_S}{dt} = \frac{dg w_S}{dt} - \frac{dV_S}{dt} \cdot \nabla \Phi_S - V_S \cdot \nabla \left(V_S \cdot \nabla \Phi_S \right)$$

BBC in LIN and NL models

$$g(w_{mod})_S = 0$$

$$\frac{dg(w_{mod})_S}{dt} = 0$$

Vertical velocity in NH

For vertical divergence we have

Original d definition

$$d = -\frac{\varrho}{m}\frac{\partial gw}{\partial \eta} + \underbrace{\frac{\varrho}{m}\frac{\partial V}{\partial \eta}\nabla\Phi}_{X}$$

modified to

Modified d definition

$$d_{mod} = -\frac{\varrho}{m}\frac{\partial gw_{mod}}{\partial \eta} + \underbrace{\frac{\varrho}{m}\frac{\partial Y}{\partial \eta} + \frac{\varrho}{m}\frac{\partial V}{\partial \eta}\nabla\Phi}_{X_{mod}}$$

Vertical velocity in NH

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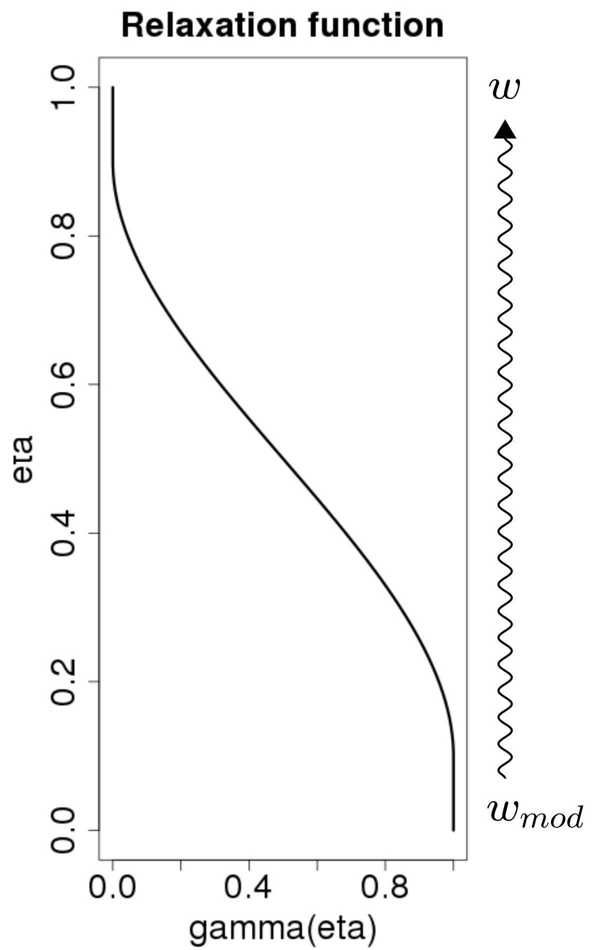
We gained the simple BBC but we got in troubles on the top.

Solution [Fabrice Voitus]: to retain modified vertical velocity at the bottom and to relax towards original w close to the top. We propose smooth relaxation function γ.



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Vertical velocity in NH

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Time evolution

Original w

$$\frac{dgw}{dt} = g^2 \frac{1}{m} \frac{\partial(p-\pi)}{\partial\eta}$$

Modified w

$$\frac{dgw_{mod}}{dt} = \frac{dgw}{dt} + \frac{dY}{dt}$$

Similarly as for vertical divergence

Original d

$$\frac{dd}{dt} = g^2 \frac{\varrho}{m} \frac{\partial}{\partial\eta} \left[\frac{1}{m} \frac{\partial(p-\pi)}{\partial\eta} \right] - g \frac{\varrho}{m} \frac{\partial V}{\partial\eta} \cdot \nabla w + d(d+X)$$

Modified d

$$\frac{dd_4}{dt} = \frac{dd}{dt} + \frac{dX}{dt}$$

$$\frac{dd_{mod}}{dt} = \frac{dd}{dt} + \frac{dX_{mod}}{dt}$$

Modification of w does not change d definition, nor its evolution, just the definition of X is modified.

Vertical velocity in NH

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Y-tendency may be treated explicitly

$$\frac{dY_5}{dt} = -\frac{dV}{dt}\cdot\nabla\Phi - \underbrace{V\cdot\nabla\left[gw - V\cdot\nabla\phi - \dot{\eta}\frac{\partial\Phi}{\partial\eta}\right] + \dot{\eta}\frac{\partial(V\cdot\nabla\Phi)}{\partial\eta}}_{\text{too complicated}} - \mathscr{J}$$

$$\frac{dY_6}{dt} = -\frac{dV}{dt}\cdot\nabla\Phi_S - \mathscr{J}_S$$

$$\frac{dY_7}{dt} = -\frac{dV_S}{dt}\cdot\nabla\Phi_S - \mathscr{J}_{SS}$$

or in the SL manner along the SL trajectory

$$\frac{dY}{dt} = \frac{Y_F^+ - Y_O^0}{\Delta t}$$

Vertical velocity in NH

First, X and X_{mod} are calculated

$$X = \frac{\partial V}{\partial \Phi} \cdot \nabla \Phi$$

$$X^{5}_{mod} = V \cdot \frac{\partial (\nabla \Phi)}{\partial \Phi}$$

$$X^{6}_{mod} = \frac{\partial V}{\partial \Phi} \cdot (\nabla \Phi - \nabla \Phi_S)$$

$$X^{7}_{mod} = \frac{\partial V}{\partial \Phi} \cdot \nabla \Phi$$

Then Y is calculated through vertical integration from

$$\frac{\partial Y}{\partial \Phi} = X_{mod} - X$$

using BBC for Y

$$Y_S = -V_S \cdot \nabla \Phi_S$$

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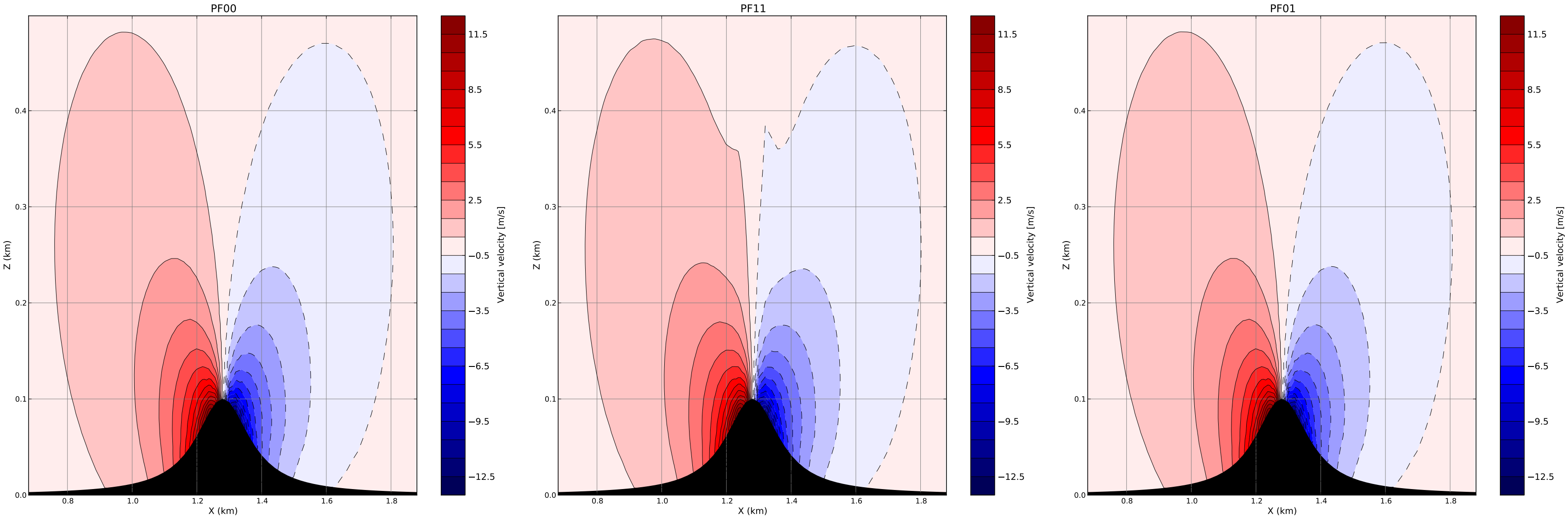
Idealized adiabatic experiments - potential flow



w

w_{mod} **explicit treatment**

w_{mod} **SL treatment**

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Vertical velocity in NH

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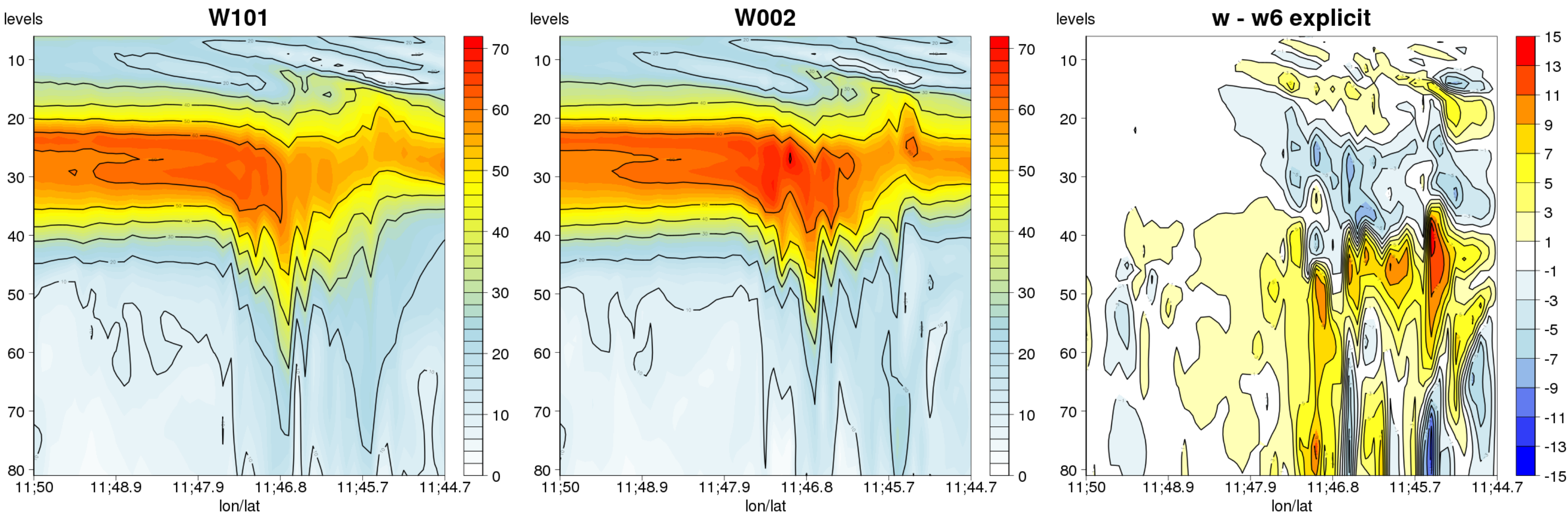
Real simulations - 4.1.2017, strong wind across Alps.
Vertical cross section through the hor. wind speed field:



w $\qquad$ w_{mod} **explicit** $\qquad$ $w - w_{mod}$

We have to find a testbed to study the stability properties of the proposed alternatives.

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For the semi-Lagrangian advection scheme the departure points have to be found for all grid-points. An iterative method is used to solve the trajectory equation

$$\frac{dr}{dt} = V(r,t)$$

based on the stable extrapolation two time level scheme (SETTLS, Hortal, 2002)

$$\begin{aligned} r_{O(1)} &= r_F - \Delta t \cdot V(r_F^0) \\ r_{O(k)} &= r_F - \frac{\Delta t}{2}\left[V(r_F^0) + 2V(r_{O(k-1)}^0) - V(r_{O(k-1)}^-)\right] \end{aligned}$$

Is this iterative procedure convergent for all grid-points? Natural upper bound for the convergence rate is the Lipschitz number (as shown by Diamantakis):

$$\mathscr{L} \equiv \Delta t \left|\left|\frac{\partial V}{\partial r}\right|\right|$$

in horizontal $$\mathscr{L}_H \equiv \Delta t \max\left(\left|\frac{\partial u}{\partial x}\right|, \left|\frac{\partial u}{\partial y}\right|, \left|\frac{\partial v}{\partial x}\right|, \left|\frac{\partial v}{\partial y}\right|\right)$$

in vertical $$\mathscr{L}_V \equiv \Delta t \left|\frac{\partial w}{\partial z}\right|$$

$$\frac{\left|\left|r_{O(k)} - r_{O(k-1)}\right|\right|}{\left|\left|r_{O(k-1)} - r_{O(k-2)}\right|\right|} \leq \mathscr{L}, \mathscr{L}_H, \mathscr{L}_V$$

Then $\mathscr{L}, \mathscr{L}_H, \mathscr{L}_V < 1$ is the convergence criterion.

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In reality even values smaller then 1 may indicate poor convergence.

If having reference solution, we may envisaged various convergence indicators as

- minimum k such that $|O(k) - O(ref)| < R_1$
- $\frac{|O(k)-O(ref)|}{|O(k-1)-O(ref)|} < R_2$ if $|O(k-1) - O(ref)| > \varepsilon$

We calculate these numbers for a case with strong wind over the Alpian region (4.1.2017) and carry out several statistics.

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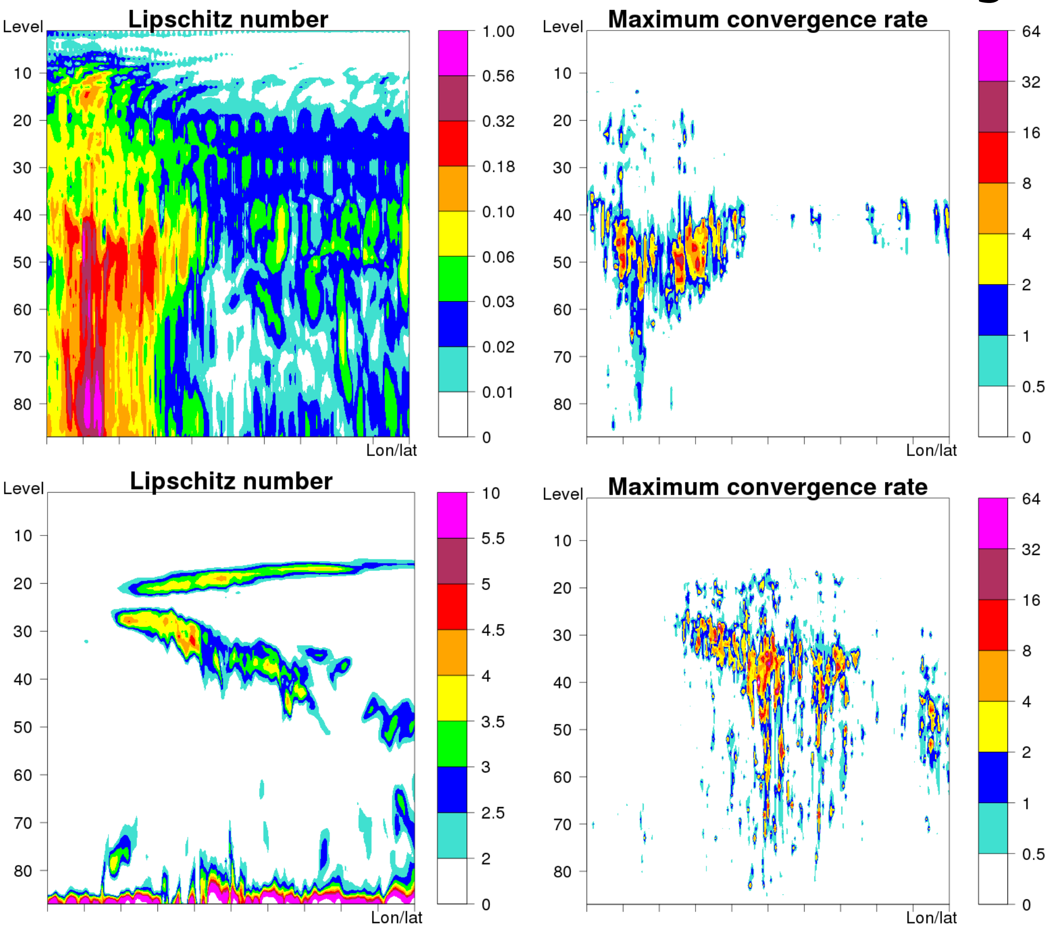
Vertical cross section over mountain region:



in horizontal

in vertical

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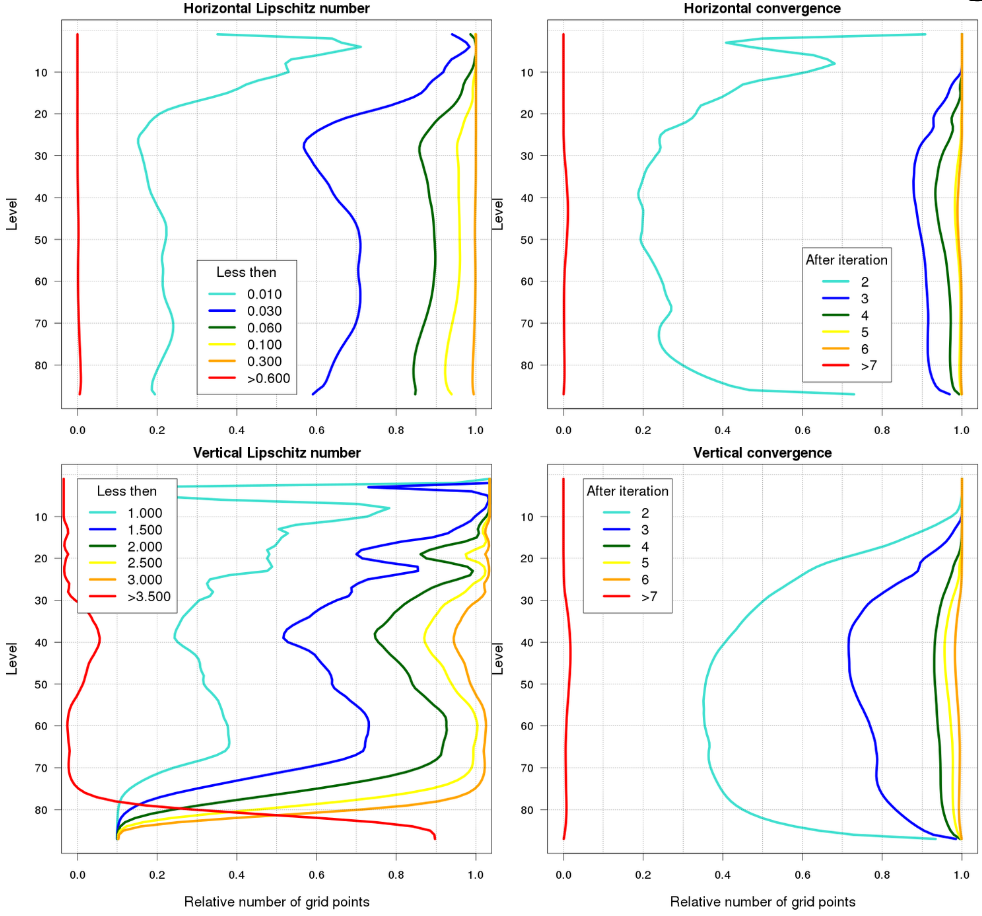
The trajectory search algorithm

Horizontal statistics for 12 hours of integration:



in horizontal

in vertical

The trajectory search algorithm

We may see that at least for this severe case there are grid points without convergence. How big problem this represents?

Algorithm ITER ON DEMAND:

- calculate departure points in iterative procedure with SETTLS
- if for a given GP the procedure has converged, STOP
- if for a given GP the procedure has diverged, STOP

Can we see the difference between results with conventional and "on demand" algorithms on the objective scores?

NO so far.

The trajectory search algorithm

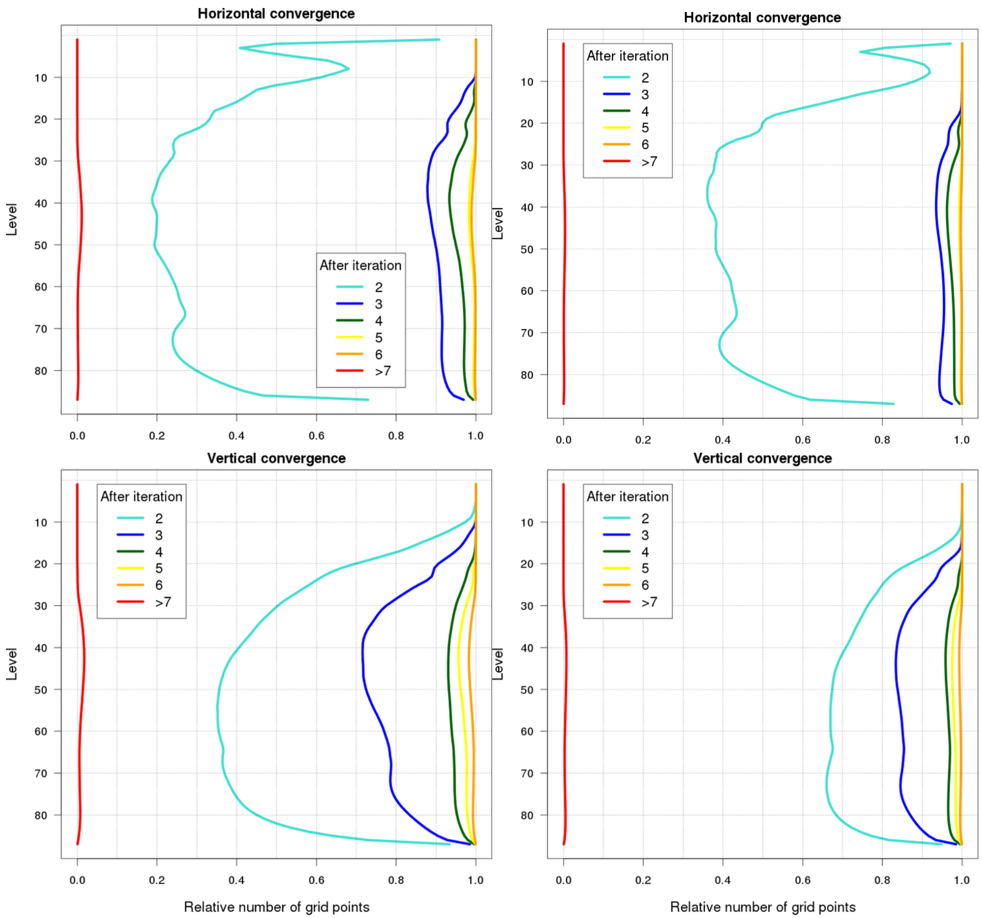
Is the problem strengthened or attenuated with increasing horizontal resolution?

Two aspects having an opposite effect in higher horizontal resolution

- trajectories are shortened
- slopes are steeper

As the conclusion: The iterative process seems to be more convergent in higher resolution.

The trajectory search algorithm



in horizontal

4km

1km

in vertical

SLHD for application at 2.3km

Preparation for the transition of operations at CHMI from HYD 4.7km to NH 2.3km:

- basic setting - ICI 1 iteration, SETTLS + 4 iterations in the trajectory search algorithm
- horizontal diffusion setting

SLHD (Semi-Lagrangian Horizontal Diffusion, Váňa, 2008) is the nonlinear horizontal diffusion with three basic parts:

- grid-point diffusion dependent on the flow deformation
- reduced spectral diffusion acting on the upper domain
- supporting spectral diffusion

These parts may be tuned with several namelist parameters.

To which variables applied? The strength of each part? More ...

SLHD for application at 2.3km

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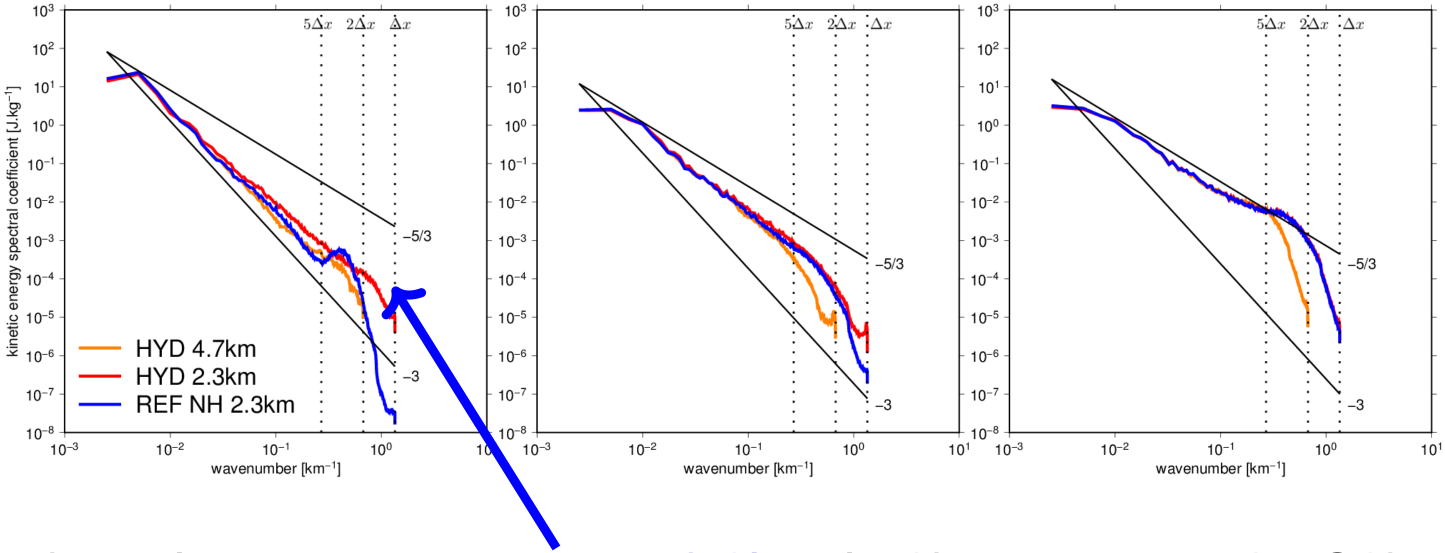
Kinetic energy spectra as the indicator:



There is an energy accumulation in the upper part of the domain, while lower parts seem ok. We have concluded that the reduced spectral diffusion is not acting enough, or not acting in sufficient extent of the atmosphere.

SLHD for application at 2.3km

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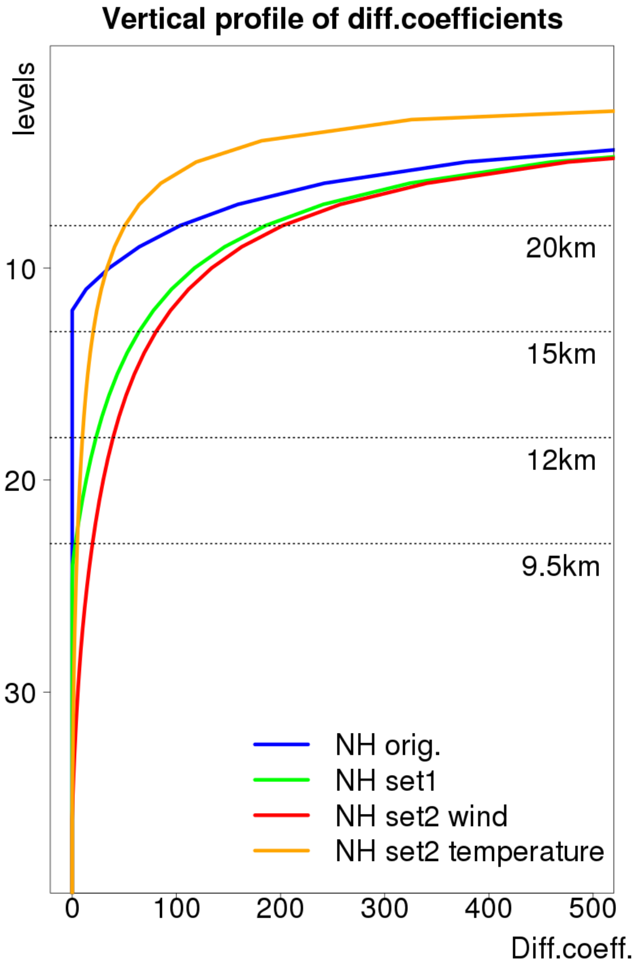

- The reduced spectral diffusion acts in too narrow zone in the upper part of the domain.
- When this zone is extended to lower model levels, the diffusion coefficient become too strong.
- Moreover, it was found beneficial to apply weaker diffusion on temperature then on wind.

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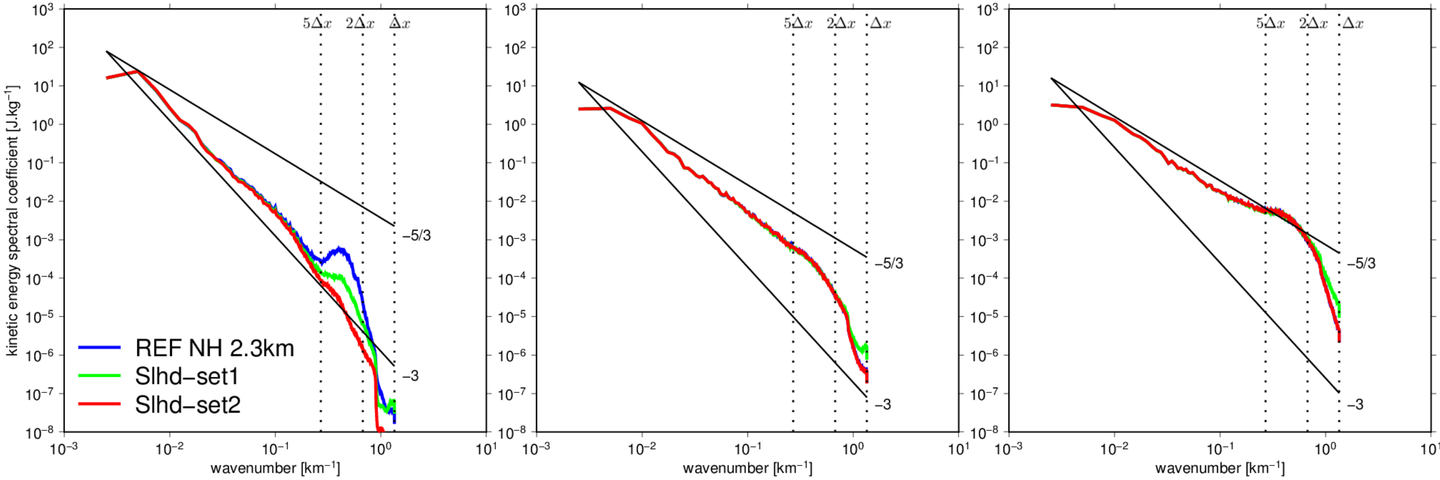
Retuning with the reduced spectral diffusion acting in the extended domain, but with reduced diffusion coefficients.



We get rid of the knob in the kinetic energy spectra and obtain better objective scores.


Gracias por su atención!