Dynamics & Coupling

2006-2007 progress report

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CHMI

VFE scheme for NH dynamics

Work of: E. Larrieau Rosina (Sk) and J. Vivoda (Sk)

- VFE scheme successfully implemented into the HY model (Untch and Hortal, 2004)

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- VFE scheme successfully implemented into the HY model (Untch and Hortal, 2004) $\Rightarrow$ extension into NH dynamics with HY model as a limit case
- The only non-local operations in the vertical are integrations in HY dynamics (SL version). In NH dynamics also derivatives play crucial role (structure equation contains vertical laplacian).

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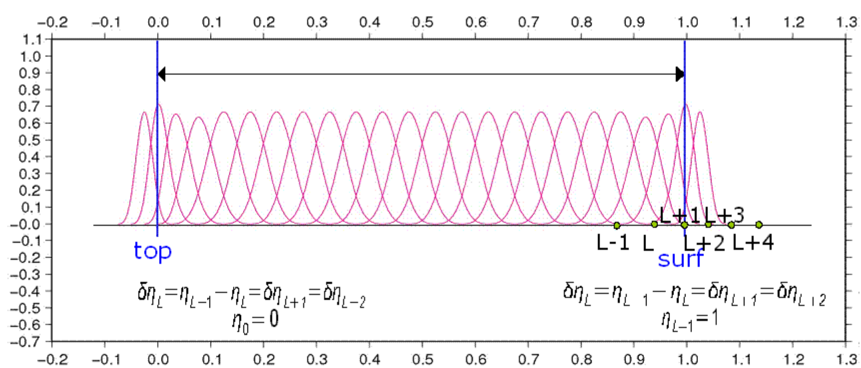
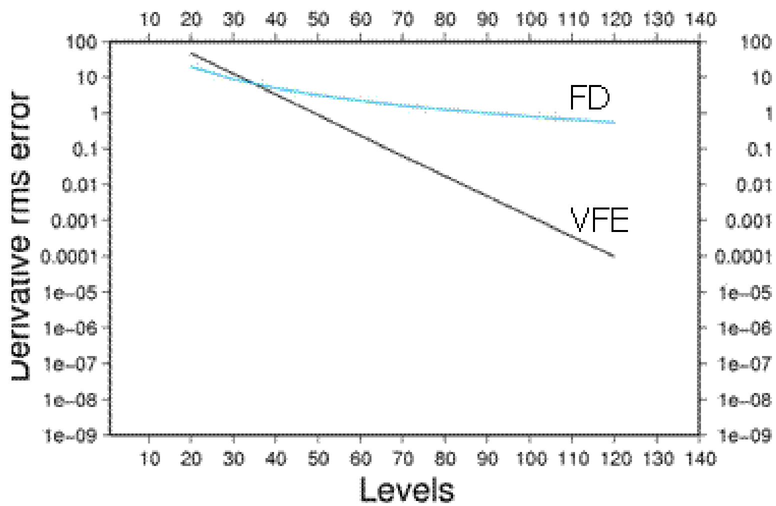
- The only non-local operations in the vertical are integrations in HY dynamics (SL version). In NH dynamics also derivatives play crucial role (structure equation contains vertical laplacian).
- FE derivative operator based on the same basis function as used by Untch and Hortal.

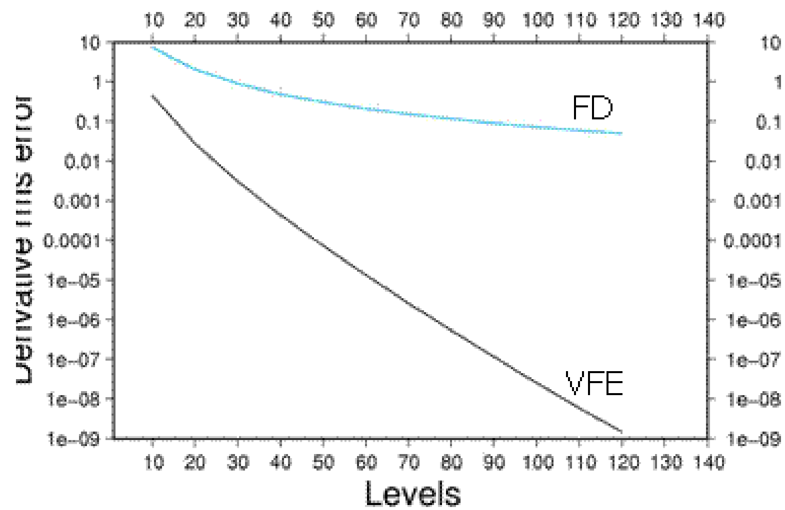


VFE scheme for NH dynamics

FE derivative operator accuracy with respect to BCs

Test function: $f(\eta) = \sin(6\pi\eta)$





$$f(\eta = 0) = f_1$$

$$f'(\eta = 0) = 0$$

$$f(\eta = 1) = f_L$$

$$f'(\eta = 1) = 0$$

$$f(\eta = 0) = \frac{\delta\eta_1 - \delta\eta_0}{\delta\eta_1} f_1 - \frac{\delta\eta_0}{\delta\eta_1} f_2$$

$$f'(\eta = 0) = \frac{f_1 - f_2}{\delta\eta_1}$$

$$f(\eta = 1) = \frac{\delta\eta_{L-1} - \delta\eta_L}{\delta\eta_{L-1}} f_L - \frac{\delta\eta_L}{\delta\eta_{L-1}} f_{L-1}$$

$$f'(\eta = 1) = \frac{f_L - f_{L-1}}{\delta\eta_{L-1}}$$

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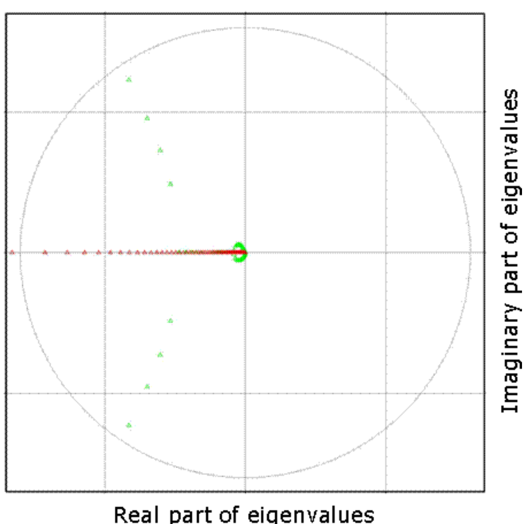
VFE scheme for NH dynamics

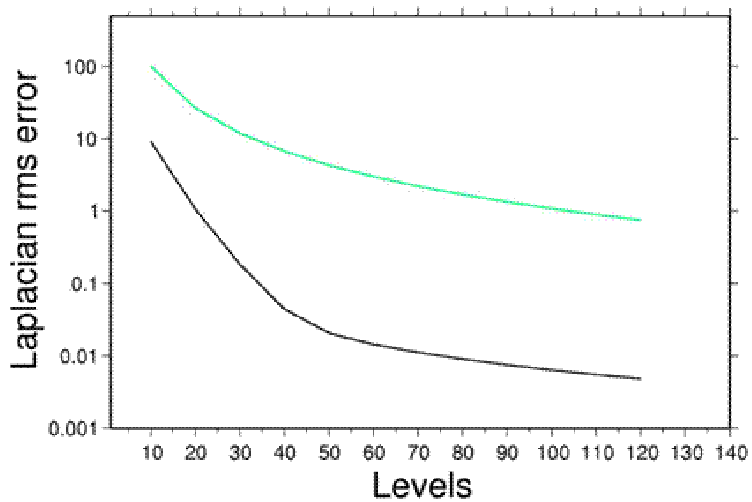
Laplacian term FE treatment

In linear and non-linear model the laplacian is explicit and has the same form (thanks to fact that the vertical divergence related prognostic variable is used):

V1: $LP = \frac{\pi}{m}\frac{\partial}{\partial \eta}\left(\frac{1}{m}\frac{\partial \pi P}{\partial \eta}\right)$ V2: $LP = \frac{\pi}{m}\frac{\partial}{\partial \eta}\left(\frac{\pi^2}{m}\right)\frac{\partial P}{\partial \eta} + \left(\frac{\pi}{m}\right)^2\frac{\partial}{\partial \eta}\left(\frac{\partial P}{\partial \eta}\right)$

boundary conditions the same as in FD





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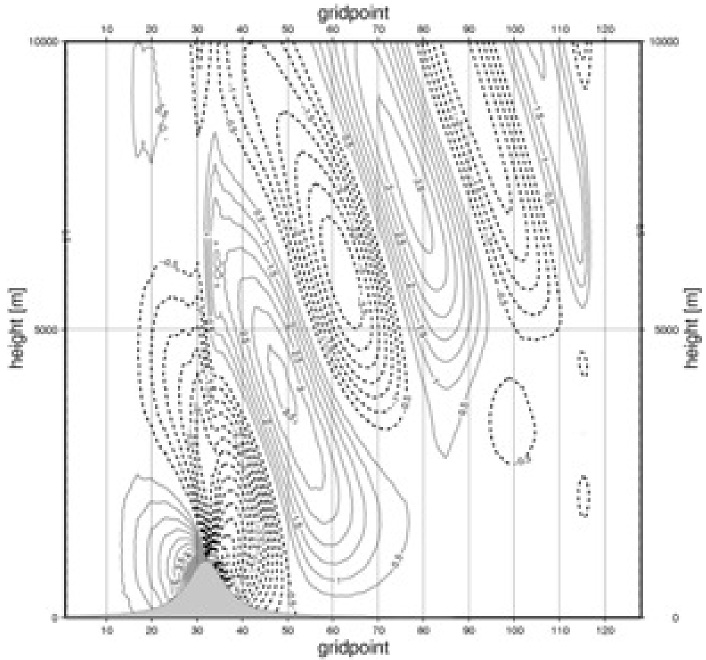
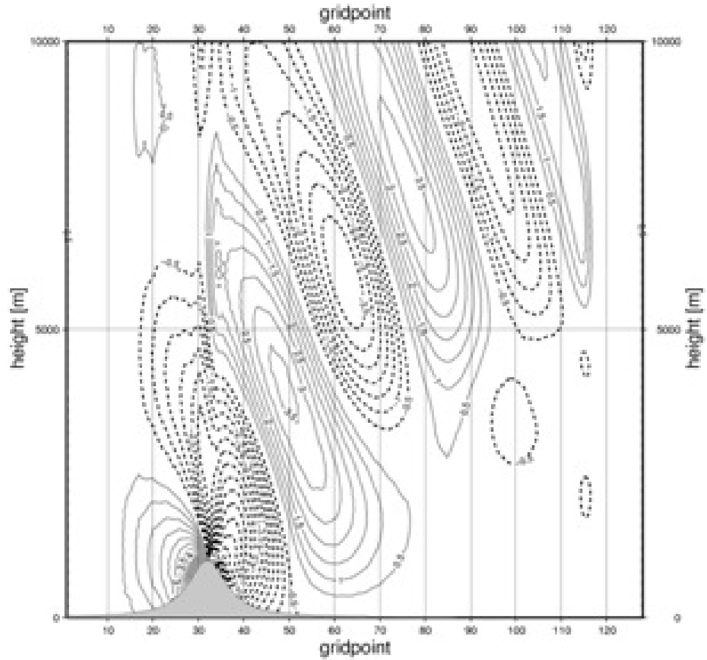
VFE scheme for NH dynamics

Constraints

- C1 constraint allows to have one structure equation for the solver. Otherwise solver becomes of 2Lx2L kind to be solved iteratively (extra 30% of CPU).





VFE scheme for NH dynamics

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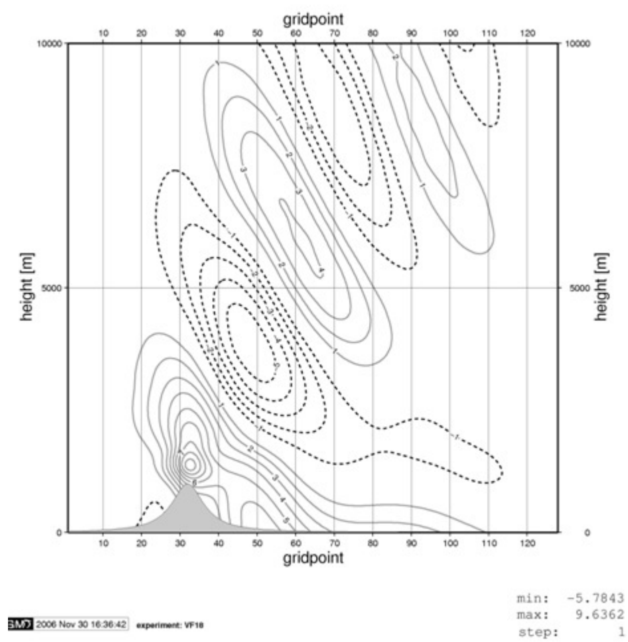
- C2 constraint defines stability requirements. (Even in case of C1 is not satisfied, C2 is required assuming that C1 is almost satisfied.)
- Stability properties are equivalent to those of FD model

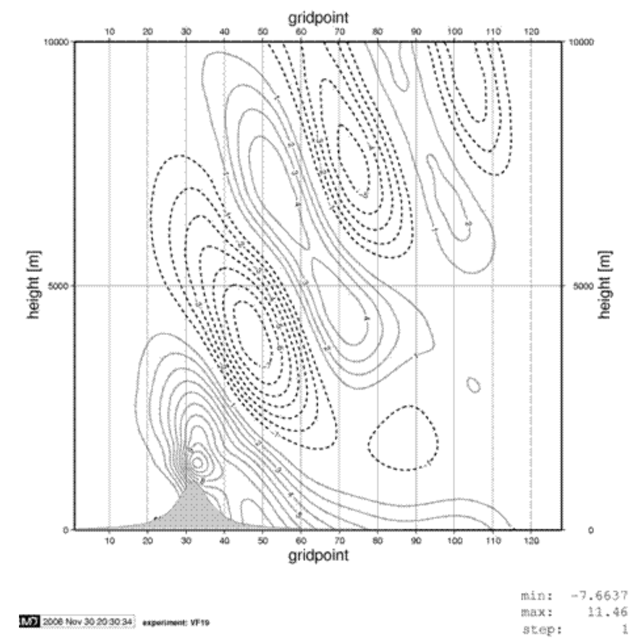
VFE scheme for NH dynamics

Non-liner model discretization

Z-term: $Z = \frac{p}{mRT} \nabla g w \frac{\partial \vec{V}}{\partial \eta}$ X-term: $X = \frac{p}{mRT} \nabla \Phi \frac{\partial \vec{V}}{\partial \eta}$



VFE (X-term FD)



VFE(Z-term FD)

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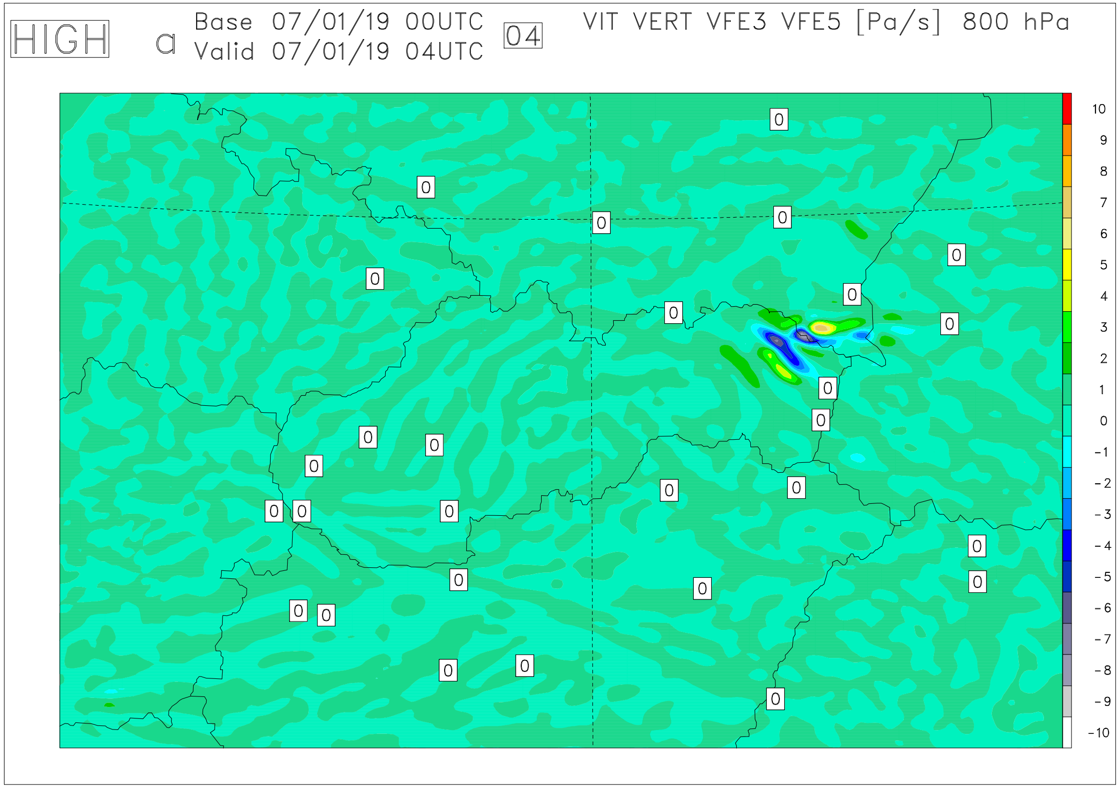
VFE scheme for NH dynamics

Non linear terms on 3D tests:



VFE (integral and laplacian only) - VFE (. . . + X-term)

VFE scheme for NH dynamics

Conclusions

- Analysis of stability in linear framework suggests that HY VFE extension to NH VFE is possible.

VFE scheme for NH dynamics

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VFE scheme for NH dynamics

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- Analysis of stability in linear framework suggests that HY VFE extension to NH VFE is possible.
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- Spectral solver is made iterative, the convergence is very fast.
- The scheme is stable (3D tests with Δx= 2.5 km, Δt=120 s).
- The BCs for non-liner terms are source of noise.

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New interpolators for SL

Work of: J. Mašek (Sk) and F. Váňa (Cz)

Family of two parametric cubic interpolators

$$\begin{aligned}\mathbf{F(x,y)} &= \mathbf{w_0(x)y_0 + w_1(x)y_1} \\ &\quad \mathbf{+ w_1(1-x)y_2 + w_0(1-x)y_3}\end{aligned}$$

where

$$\begin{aligned}\mathbf{w_0(x)} &= \mathbf{a_1x + a_2x^2 - (a_1 + a_2)x^3} \\ \mathbf{w_1(x)} &= \mathbf{1 + (a_2 - 1)x - (3a_1 + 4a_2)x^2 + 3(a_1 + a_2)x^3}\end{aligned}$$

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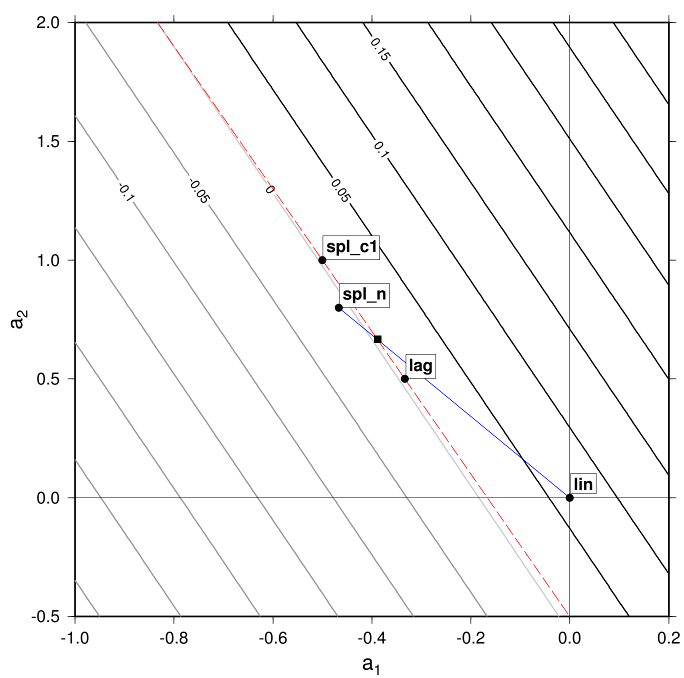
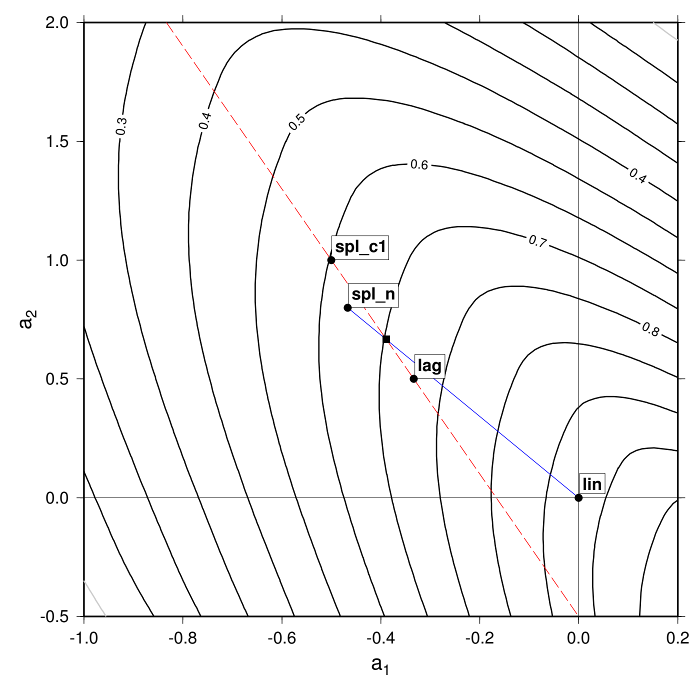
New interpolators for SL

Dimensionless damping rate

Damping factor for N = 100, m = 10



Damping factor for N = 100, m = 40



New interpolators for SL

New (SLHD) time-step organization

original data-flow

new data-flow

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New (SLHD) time-step organization

	original data-flow	*new data-flow*
`Step 1`	computation of weights for	computation of all weights:
	A_1,A_L	A = A_1 + κ (A_2 - A_1)

New interpolators for SL

New (SLHD) time-step organization

	original data-flow	*new data-flow*
Step 1	computation of weights for A_1,A_L	computation of all weights: $A = A_1 + \kappa\,(A_2 - A_1)$
Step 2	high order (A_1) interpolation	all (A) interpolation

New interpolators for SL

New (SLHD) time-step organization

	original data-flow	*new data-flow*
Step 1	computation of weights for A_1, A_L	computation of all weights: $A = A_1 + \kappa (A_2 - A_1)$
Step 2	high order (A_1) interpolation	all (A) interpolation
Step 3	diffusive interpolation by using A_L weights	-

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New interpolators for SL

New (SLHD) time-step organization

	original data-flow	*new data-flow*
Step 1	computation of weights for A_1,A_L	computation of all weights: $A = A_1 + \kappa\,(A_2 - A_1)$
Step 2	high order (A_1) interpolation	all (A) interpolation
Step 3	diffusive interpolation by using A_L weights	-
Step 4	combination of high order and diffusive interpolation according κ	-

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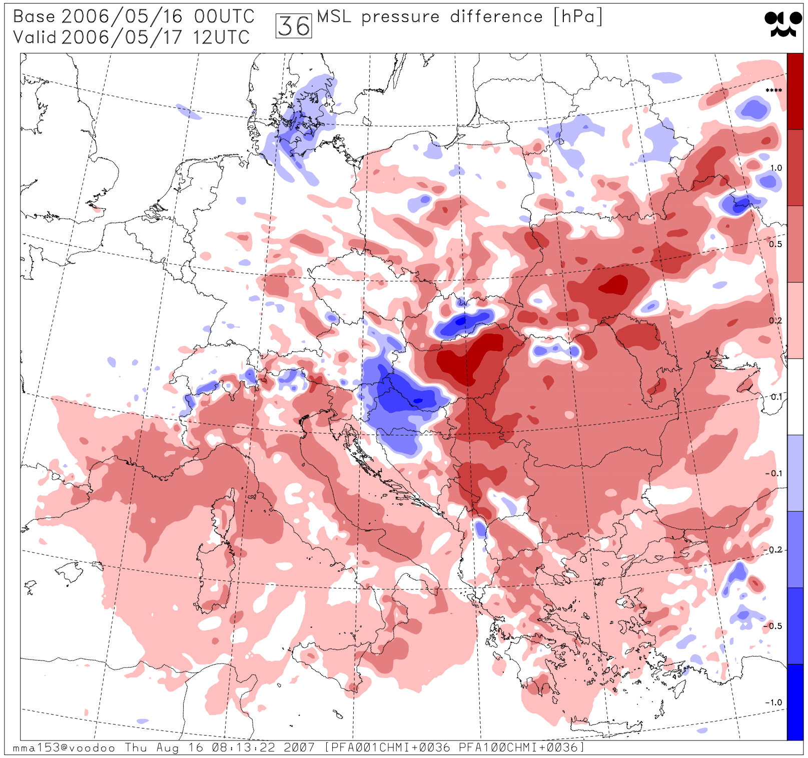
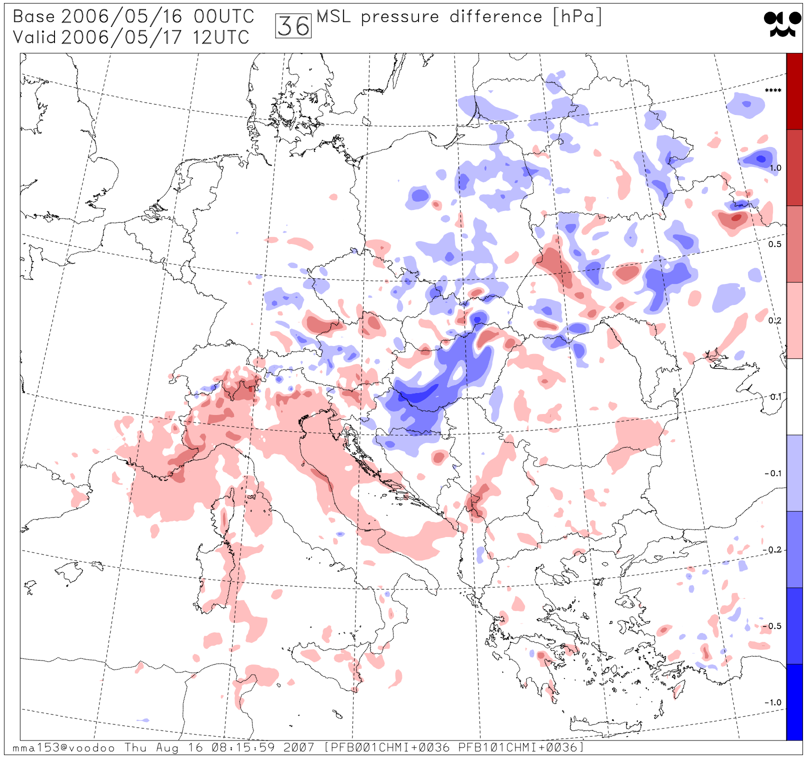
New interpolators for SL

MSL pressure differences SLHD vs. spec. diffusion



original



new

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New interpolators for SL

Conclusions

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New interpolators for SL

Conclusions

- More freedom to SL interpolation.
- SLHD becomes just “a special case” of standard interpolation $\Rightarrow$ TL/AD of SL can be easily adapted to TL/AD of SLHD.
- Algorithmically more efficient (SLHD = extra 2% of CPU).

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TL/AD of LAM SL

Work of: F. Váňa (Cz)

- Ready since January 2007 (available since April 2007)

TL/AD of LAM SL

Work of: F. Váňa (Cz)

- Ready since January 2007 (available since April 2007)
- More efficient and more accurate

Eulerian advection (1 hour, Δt = 120 s)

*ADJOINT TEST: THE DIFFERENCE IS **10.395** TIMES THE ZERO OF THE MACHINE*

SL advection (1 hour, Δt= 120 s)

*ADJOINT TEST: THE DIFFERENCE IS **16.562** TIMES THE ZERO OF THE MACHINE*

SL advection (1 hour, Δt= 360 s)

*ADJOINT TEST: THE DIFFERENCE IS **5.452** TIMES THE ZERO OF THE MACHINE*

TL/AD of LAM SL

Specific development related to vectorization in AD

Global update of all interpolations:

```
!cdir nodep
DO JINC=ISTART,ISTOP
  PSLBUF1(INC(JINC,JROF)) = &
    & PSLBUF1(INC(JINC,JROF)) + ZINC(JINC,JROF)
ENDDO
```

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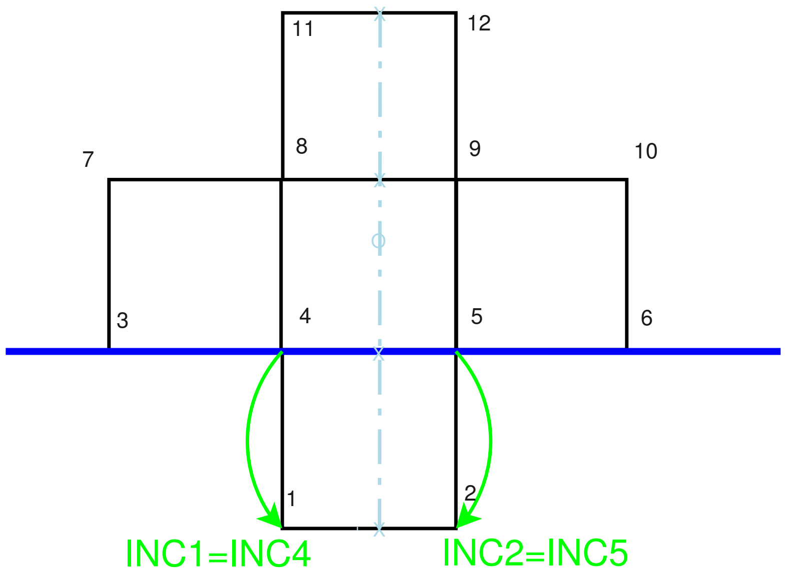

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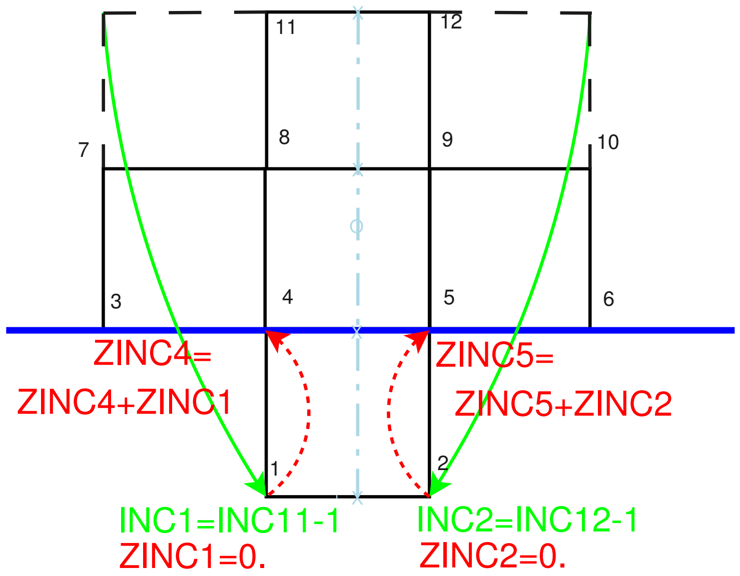

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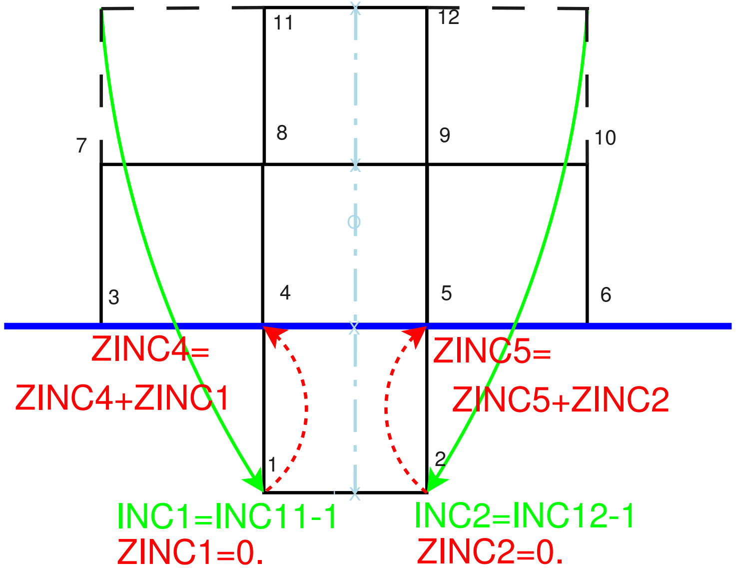
```

V.Op.Ratio = 98.814048 %

VLEN = 225.948825

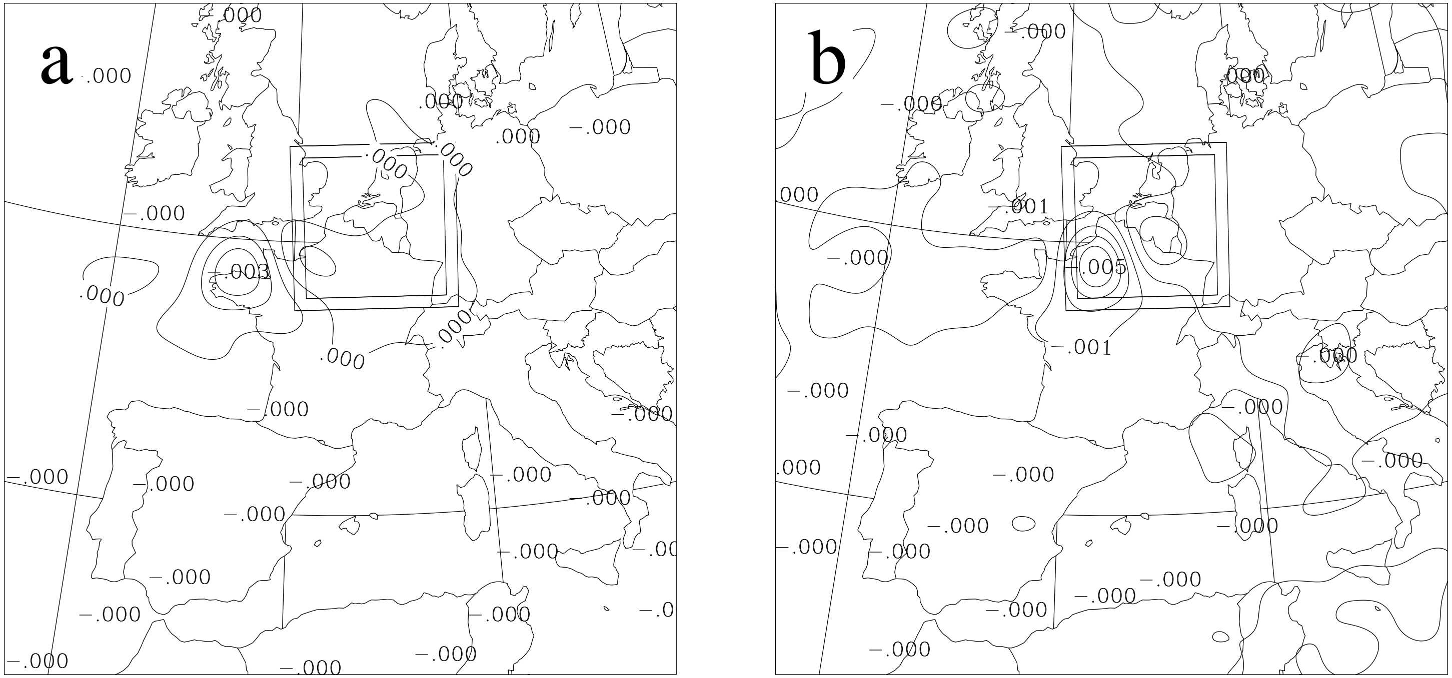


MCUF

Work of: P. Termonia (Be) and A. Deckmyn (Be)

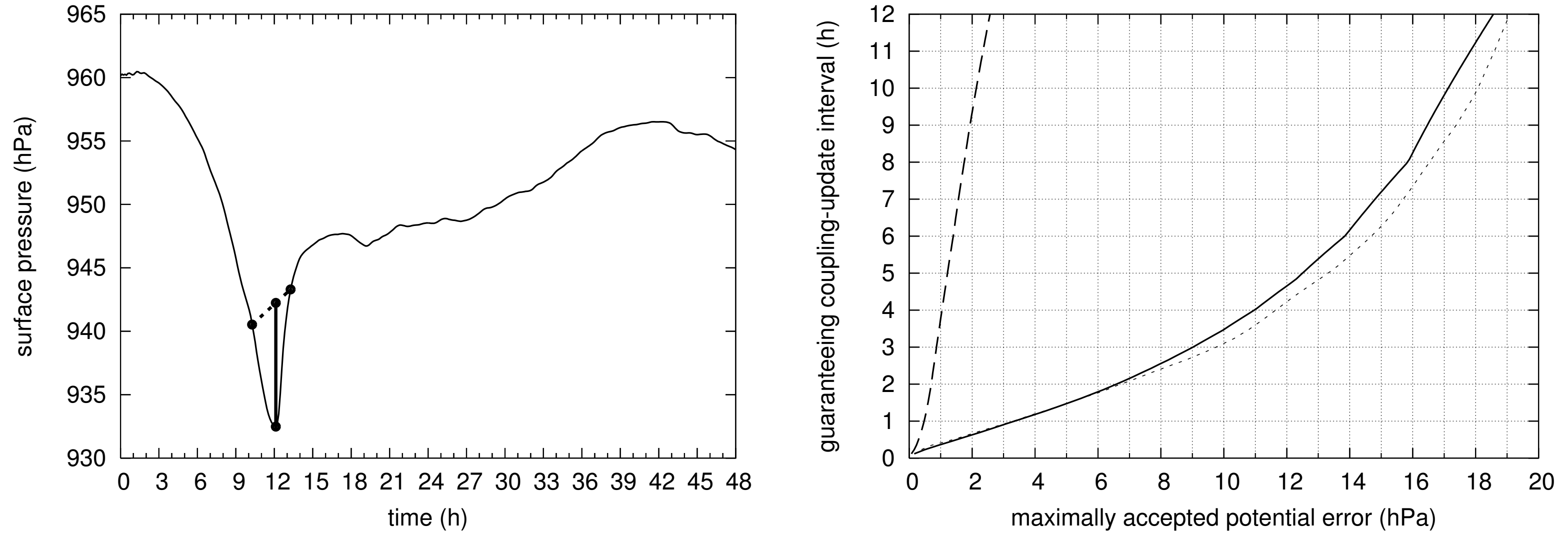
Monitoring the Coupling-Update Frequency

Termonia (2004), *Mon. Wea. Rev.*



This field is now present in the coupling files for ALADIN: `CUF1PRESSURE`!

MCUF

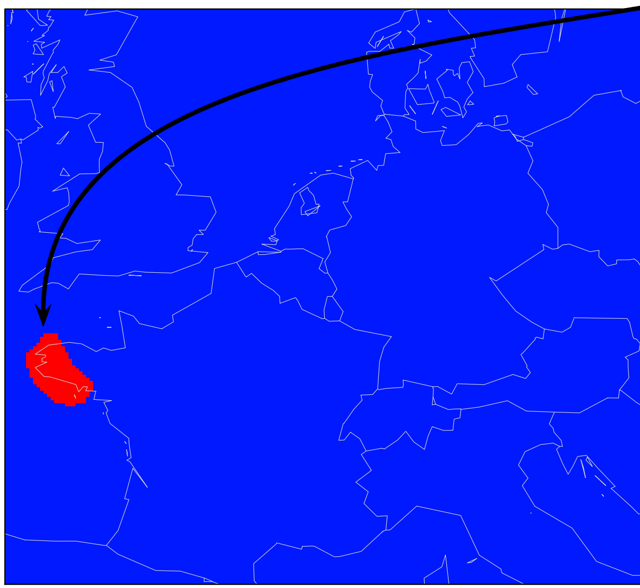


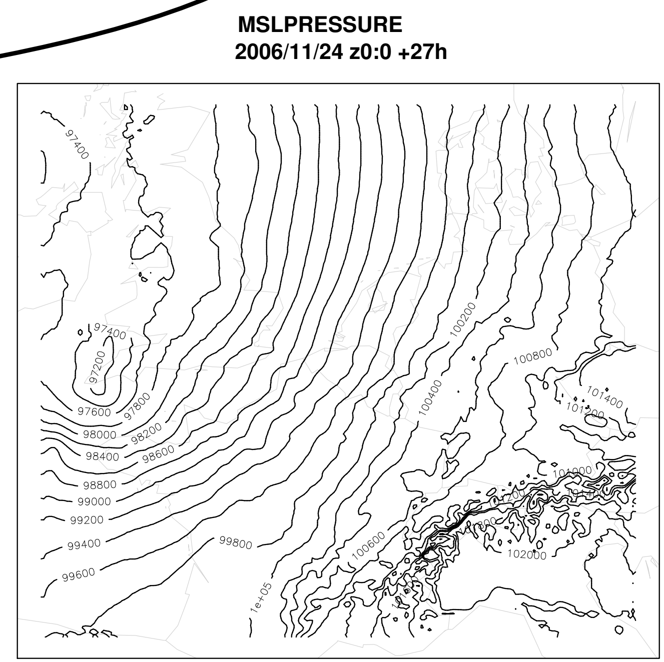
We need coupling intervals of about 20 min to guarantee that we do not make interpolation errors bigger than 1 hPa.

⇒ NOT feasible

MCUF

If the CUF1PRESSURE field exceeds the threshold of 0.003 (red) then make an additional run starting from this moment, e.g. at +27 h forecast range of this run. The storm is then in the domain.

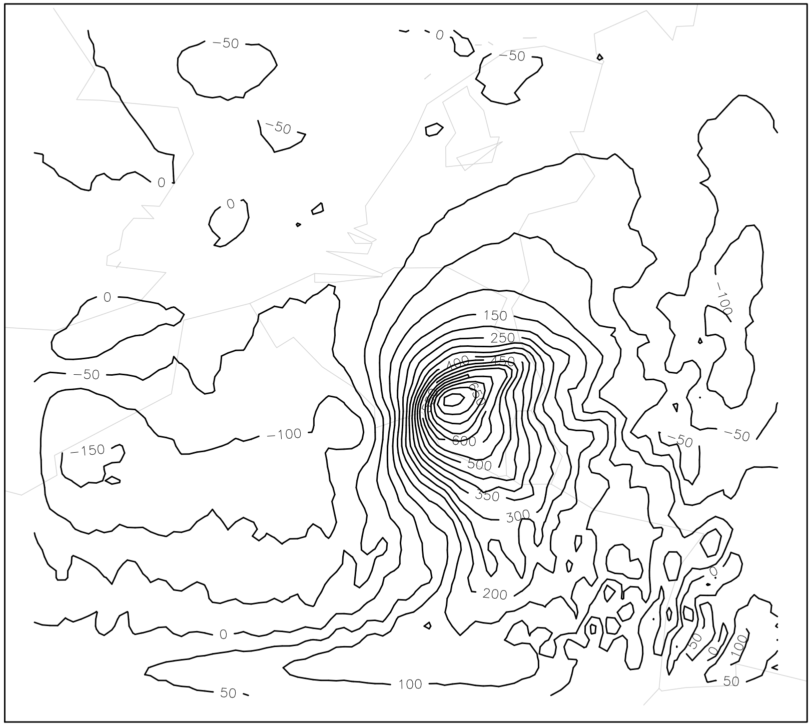




DFI filters storms !!!

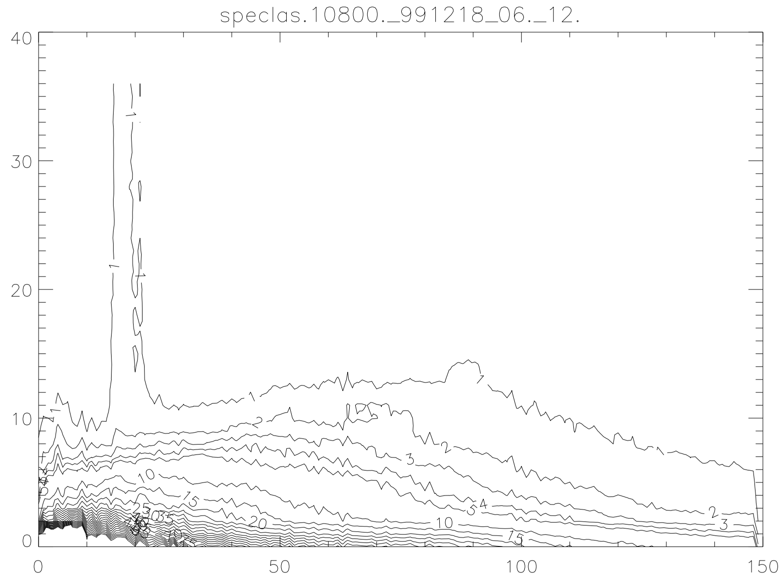
However, for the later start with the storm in the domain, DFI filters the signal of the storm:

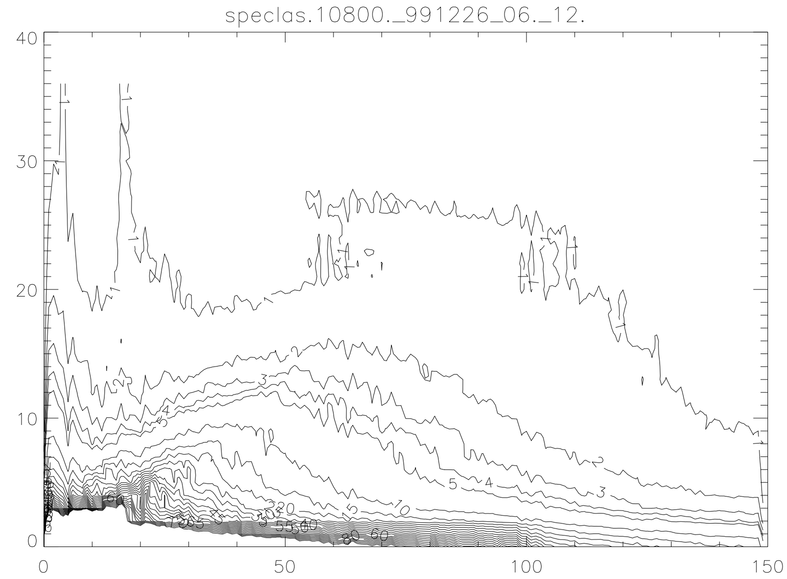
MSLP 26/12/1999 +9h
DFI(3h) – no DFI



DFI with `TAUS=10800.`: max difference of about 8.5 hPa!

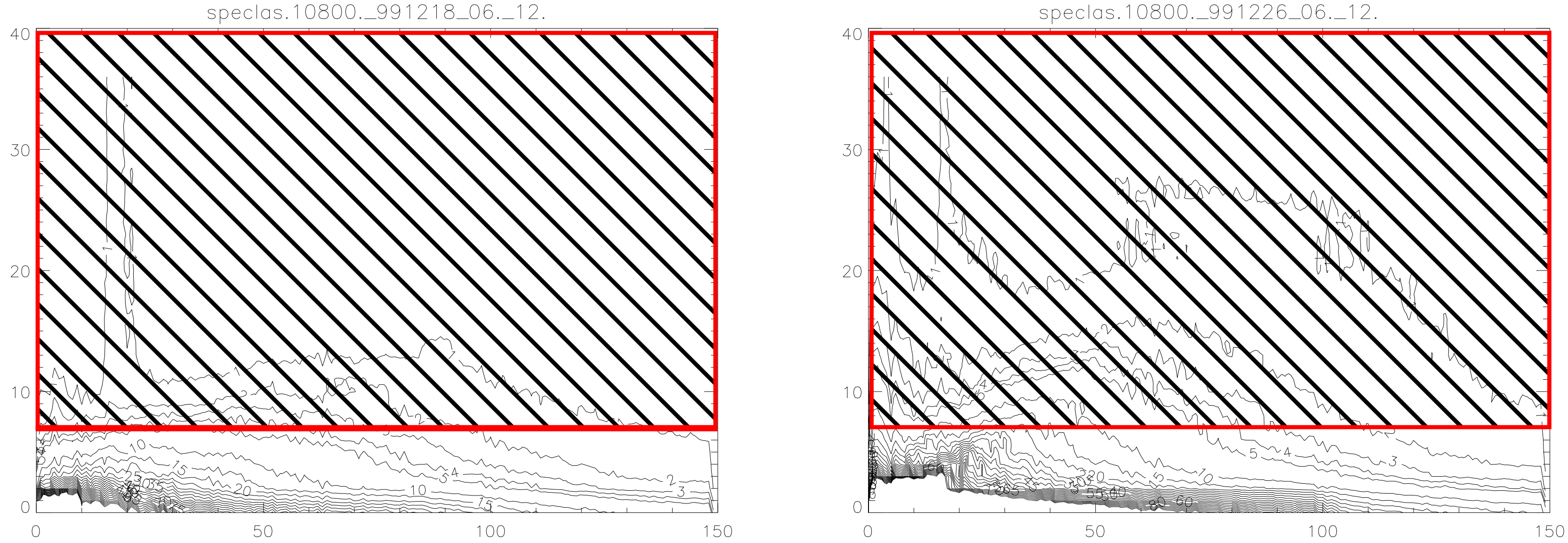
DFI filters storms !!!





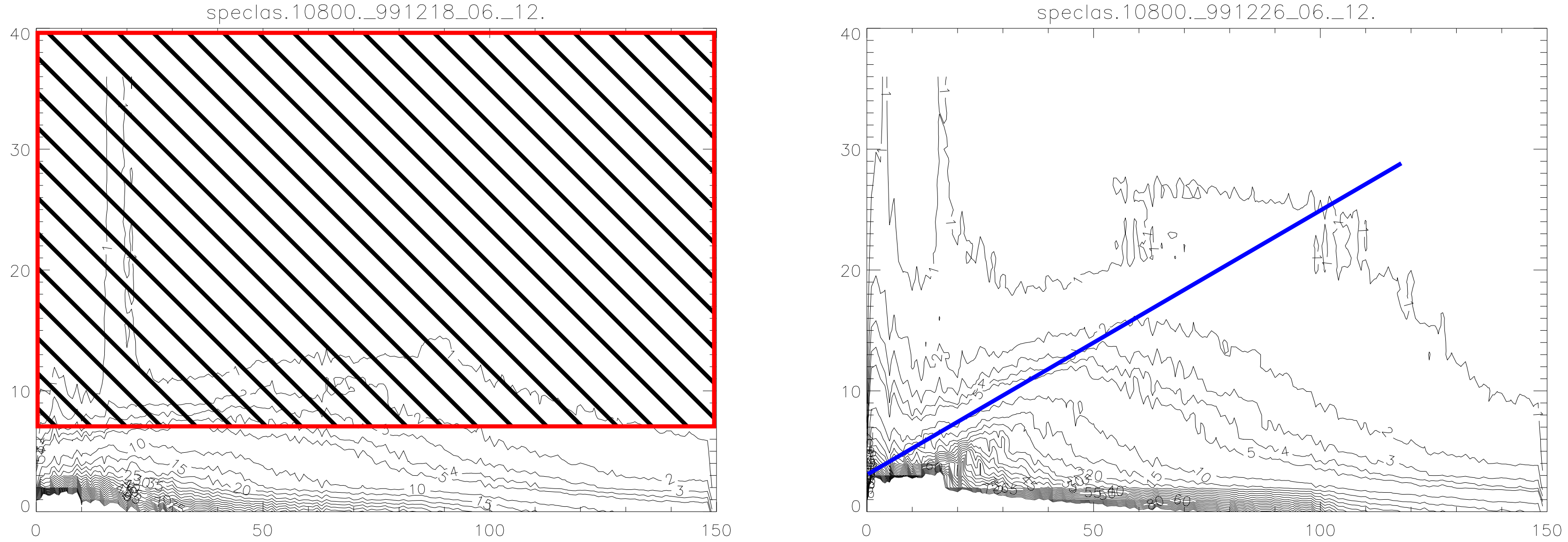
spectral decomposition in the space and time domain of a forecast without storm (left) and the Lothar storm (right).

DFI filters storms !!!



filtering

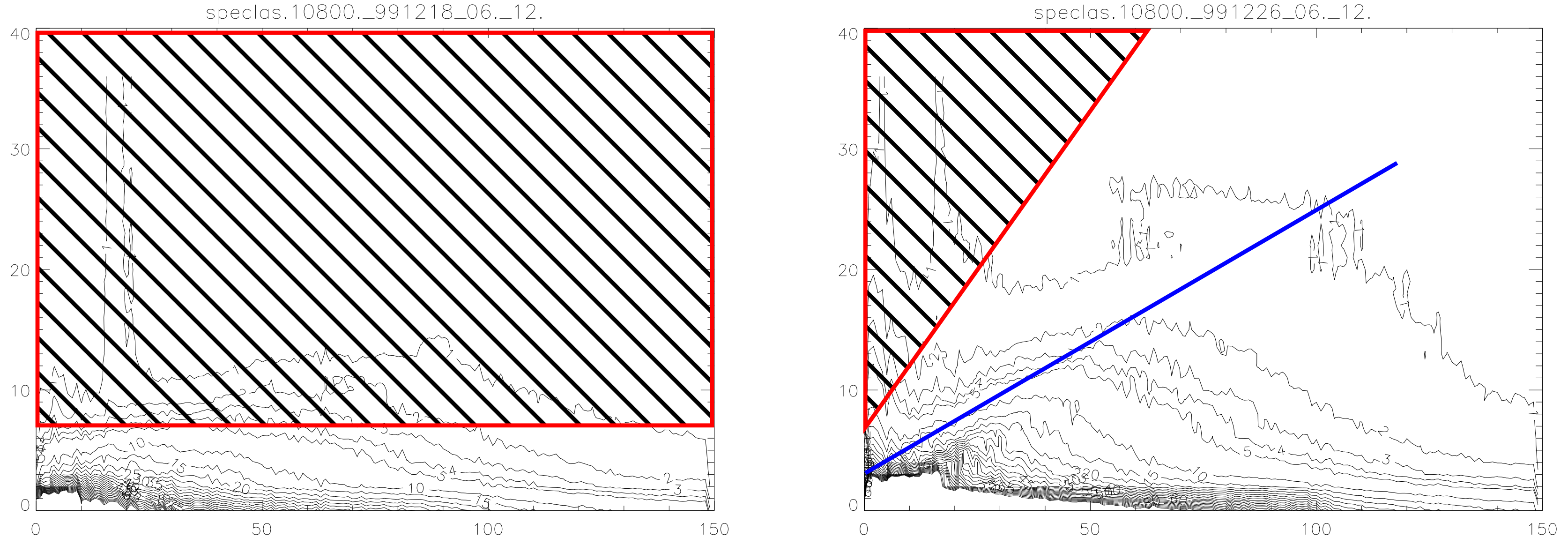
DFI filters storms !!!



blue line corresponds to propagation speed of the Lothar storm

$\omega/k \approx 100km/h$

DFI filters storms !!!



idea: scale-selective filtering

MCUF and DFI: conclusions

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- In case the required CUF is too small it seems better to restart integration with the storm inside the domain
- But DFI filters storms!
- With recent ALADIN cycles the Lothar run is stable without DFI, it is possible to restart without DFI.
- Additional research needed on scale-selective DFI. Not much progress due to lack of time but planned for the future.

New approach to LBC's

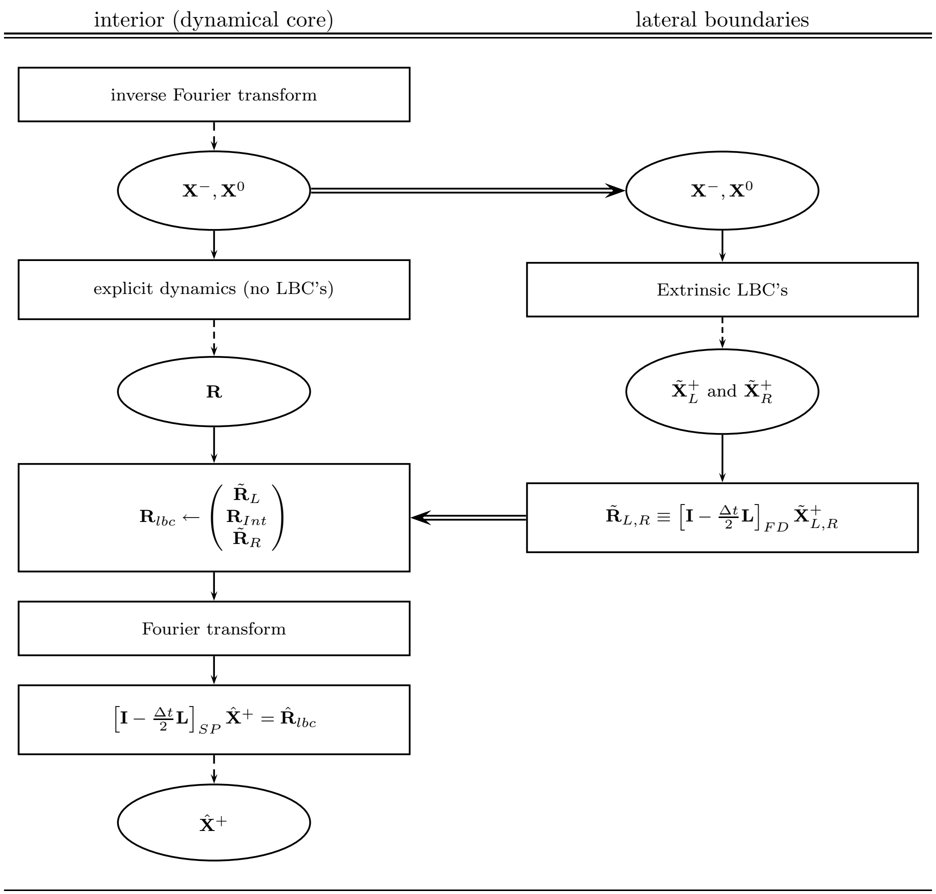
Work of: P. Termonia (Be) and F. Voitus (Fr)

- Some alternative ideas for the Davies scheme exist where one imposes the characteristic values at the inflow LBC's and extrapolates (by upstream time differencing) the outgoing characteristics
- The work of Aidan McDonald (2000; 2003; 2005; 2006) has led to a formulation for the semi-implicit semi-Lagrangian scheme in the HIRLAM model which leads to a quality that is comparable to the Davies scheme.

New approach to LBC's

- This is done by adapting the dynamical equations at the boundaries, i.e. in *distinct* points only.
- In order to have a stable scheme as a net result, this adaptation should be done in the implicit part of the semi-implicit scheme, in practice being the Helmholtz equation.
- In spectral models this equation is solved in spectral space where the value of a field can not be changed in distinct points!
- *Extrinsic* LBC's approach is proposed where the LBC's are computed with a numerical finite-difference scheme that is different than the SI SL scheme of the dynamical core. This can be applied in a gridpoint model but much more interestingly, it may allow to solve the problem of LBC's in spectral models ...

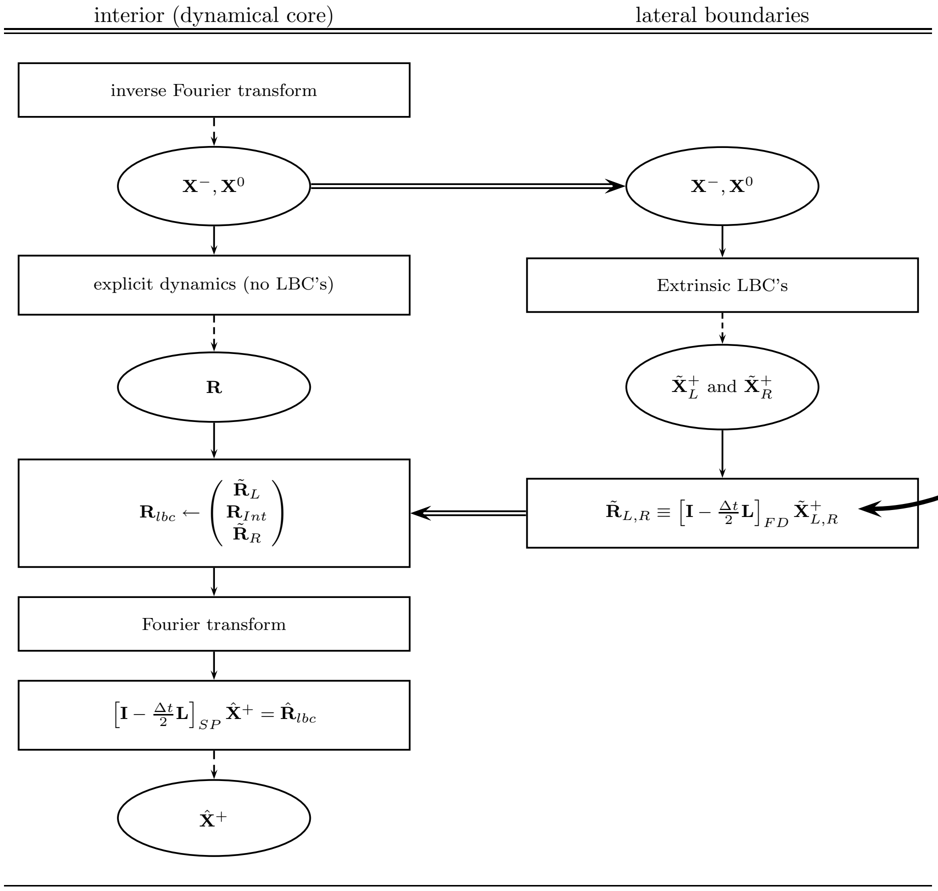
Extrinsic LBC's



It has been shown that the result of these extrinsic schemes can be imposed at the lateral boundaries by

1. applying the implicit operator $[1 - \frac{1}{2}\Delta t\mathbf{L}]_{FD}$ to the result of the extrinsic LBC's in gridpoint space, and
2. overwriting the result of the explicit part $\mathbf{R}$ of dynamics at the boundaries, before going to spectral space.

Extrinsic LBC's



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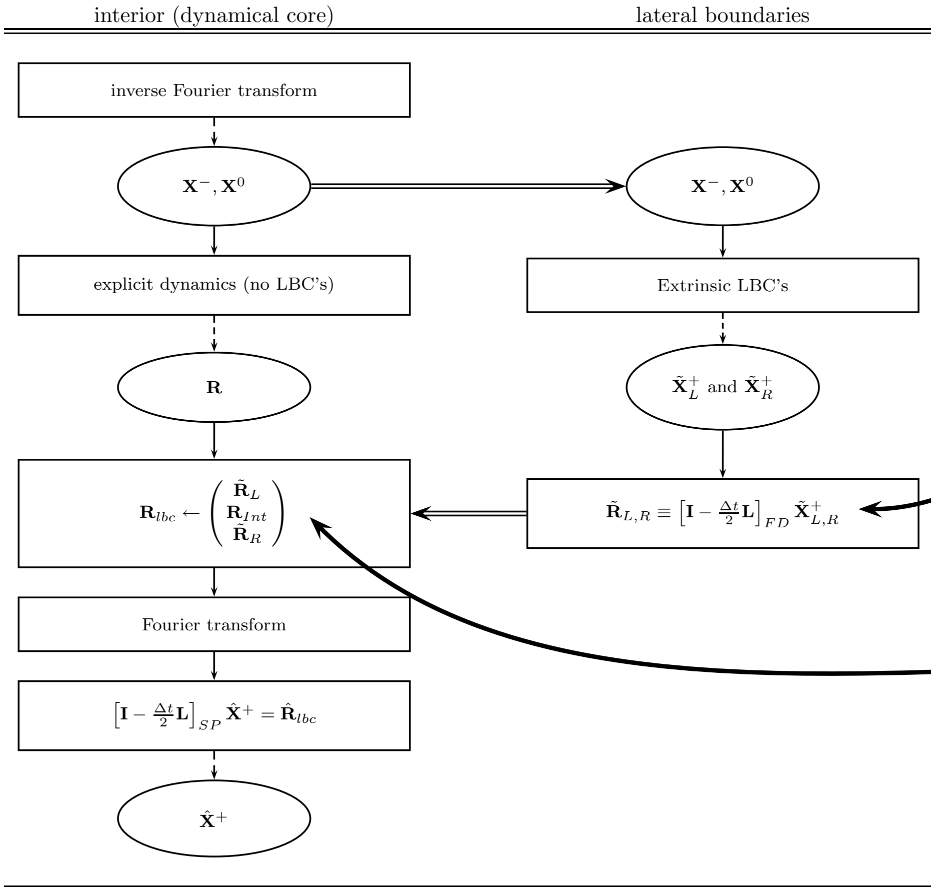

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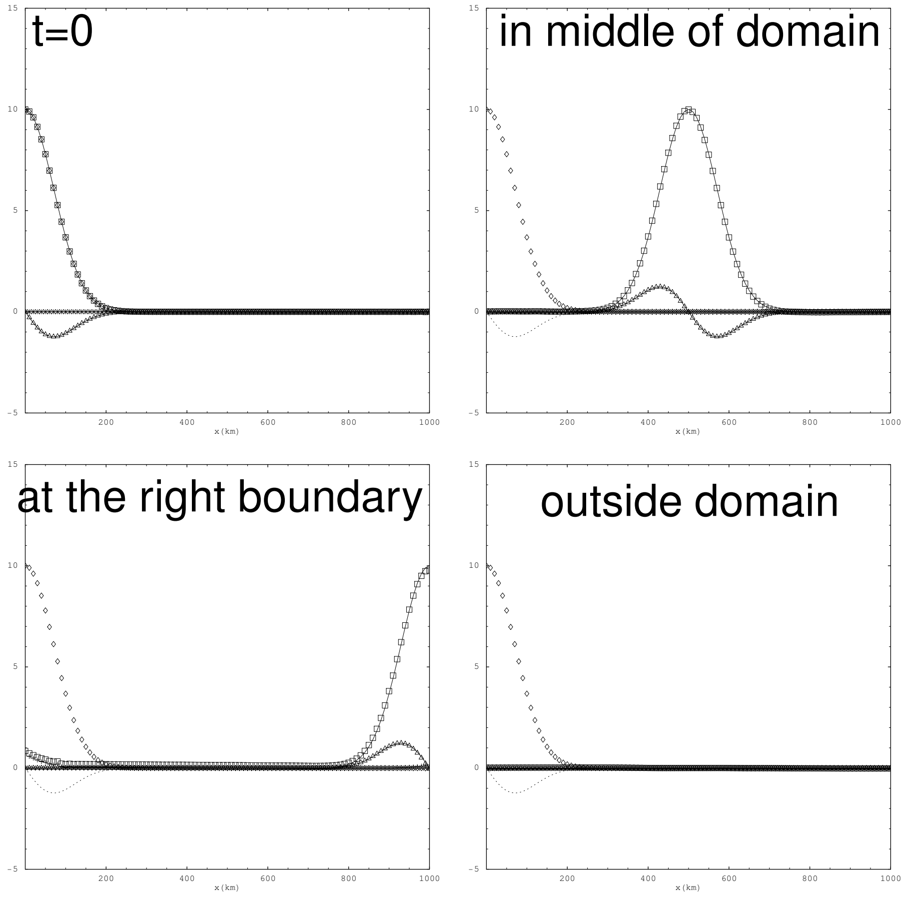
Tests in 1D shallow water

Bell-shaped feature passing the domain



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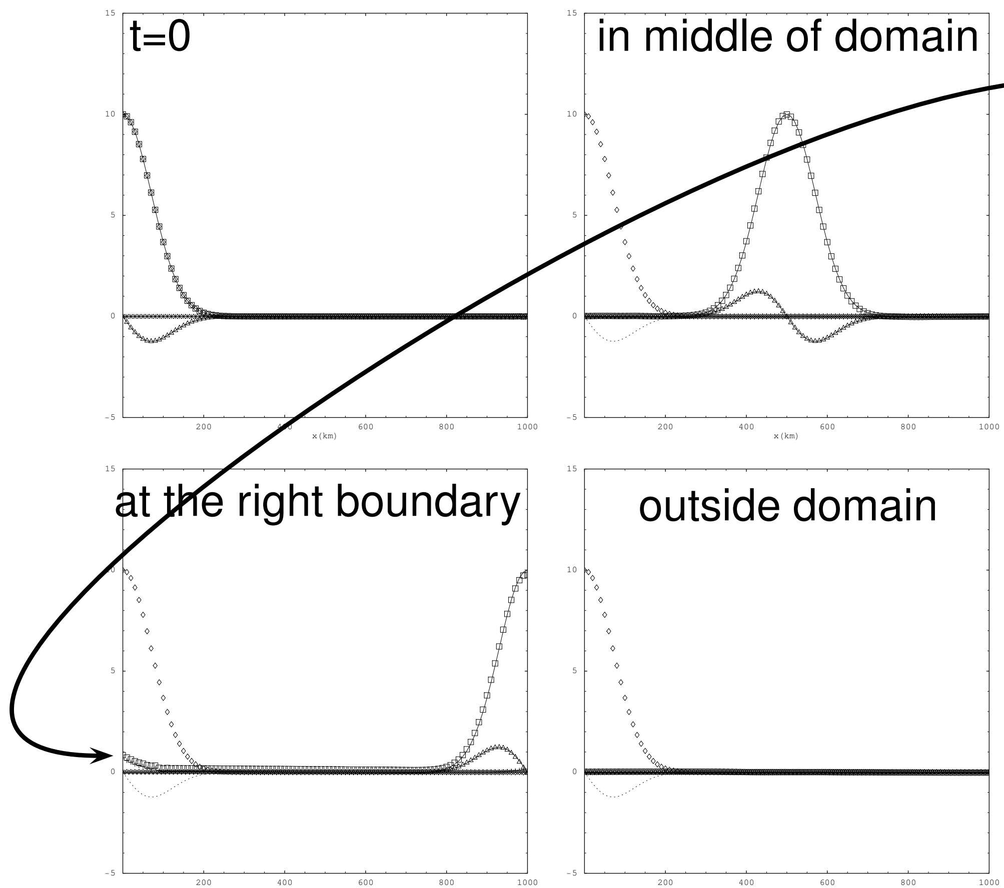
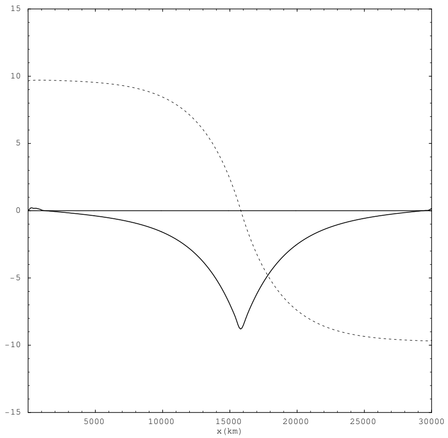


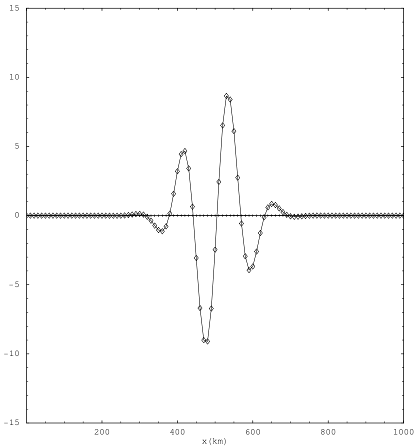
Inaccuracy due to inconsistency between the operator $[1 - \frac{1}{2}\Delta t \mathbf{L}]_{FD}$ in gridpoint space and the one in spectral space $[1 - \frac{1}{2}\Delta t \mathbf{L}]_{SP}$.

Boyd (2005) proposes a better periodic extension yielding more accurate derivatives than the one in ALADIN, and used here. We expect this to improve.

Tests in 1D shallow water

Some tests as they have also been done by McDonald in the shallow-water model, but here in the spectral model.





The adjustment experiment. The gravity waves are leaving the domain correctly without leaving reflections. The final state (see Gill 1982) is correctly reproduced.

A radiation experiment. The initial state is radiated away through the boundaries to infinity.

New approach to LBC's

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- Renewed optimism to find alternatives for the Davies scheme in spectral models.