***R**egional **C**ooperation for*
***L**imited **A**rea Modeling in **C**entral **E**urope*

LACE
nwp central europe

LACE – DYNAMICS & COUPLING

Petra Smolíková and D&C team: Jozef Vivoda (SHMI), Martina Tudor (DHMZ), Ján Mašek (CHMI), Gergely Bölöni, Balázs Szintai, László Kullmann (OMSZ)

Summary of 2012 work

1. NH VFE

- Stabilization of the method by well posed top and bottom boundary conditions for distinct terms (Jozef Vivoda talk)
- Convergence of the SI solver
- 2D model : various vertical levels distribution
- Real case simulations
- Verification with objective scores

2. Physics-dynamics interface

- SETTLS type physics interface
- Tuning SLHD in AROME

3. Coupling

- Choosing a leading model for AROME
- Rapid changes in surface pressure field

VFE in NH

Cooperation between ALADIN/LACE (Jozef Vivoda) and HIRLAM (Juan Simarro):

- was found to be interesting from both sides
- will continue ???

Main findings:

1. "Hand made" analysis of stability of VFE method is not tractable (even in Mathematica)
2. The mass coordinate (d4 with w in NL, PC scheme, acoustic temperature) seems to be more stable than the height based coordinate (esp. with steep orography).
3. Various sets of prognostic variables considered

VFE in NH

Vertical operators

HYD

integral

$\mathbb{S}^*, \mathbb{G}^*, \mathbb{N}^*$

NH

integral + first and second derivative

$\mathbb{S}^*, \mathbb{G}^*, \mathbb{N}^* + \mathbb{L}^*$

Moreover: In VFE

(C1) constraint not satisfied $-\mathbb{G}^*\mathbb{S}^* + \mathbb{S}^* + \mathbb{G}^* - \mathbb{N}^* \neq 0$

(C2) constraint not satisfied $g^2\mathbb{L}^*\left(\mathbb{S}^*\mathbb{G}^* - \frac{C_p}{C_v}\mathbb{S}^* - \frac{C_p}{C_v}\mathbb{G}^*\right) \neq c^2N^2\mathbb{I}$

the left hand side is nor tridiagonal as for VFD, nor c2N2*identity as for continuous case

VFE in NH

(C1) constraint not satisfied $-\mathbb{G}^*\mathbb{S}^* + \mathbb{S}^* + \mathbb{G}^* - \mathbb{N}^* \neq 0$

Semi-implicit solver - linear inversion formulated for a couple of variables (*d*,*D*) $\begin{pmatrix} \mathbb{H} & \mathbb{F}\mathbb{C} \\ -\mathbb{B} & \mathbb{A}+\mathbb{C} \end{pmatrix}\begin{pmatrix} d \\ D \end{pmatrix} = \begin{pmatrix} \mathbb{A} & \mathbb{F} \\ 0 & \mathbb{I} \end{pmatrix}\begin{pmatrix} d^\bullet \\ D^\bullet \end{pmatrix}$

VFD: $\mathbb{C} = 0$ algebraic elimination of all variables but *d*

$$\begin{pmatrix} \mathbb{H} & 0 \\ -\mathbb{B} & \mathbb{A} \end{pmatrix}\begin{pmatrix} d \\ D \end{pmatrix} = \begin{pmatrix} \mathbb{A} & \mathbb{F} \\ 0 & \mathbb{I} \end{pmatrix}\begin{pmatrix} d^\bullet \\ D^\bullet \end{pmatrix}$$

$$d = \mathbb{H}^{-1}\left(\mathbb{A}d^\bullet + \mathbb{F}D^\bullet\right), D = \mathbb{A}^{-1}\left(\mathbb{B}d + D^\bullet\right), T = \ldots$$

VFE: $\mathbb{C} \neq 0$ elimination not possible – **2 proposed solutions**

First solution: 2L solver to solve

- a system of 2L equations solved in spectral space (4x larger, inversion performed once in the setup) – not feasible for horizontally varying map factor (LESIDG), extra memory demanding

VFE in NH

Semi-implicit solver

VFE: $\mathbb{C} \neq 0$ elimination not possible – 2 proposed solutions

Second solution: stationary iterative method

Predictor: as if $\mathbb{C} = 0$

Corrector: *i*th step

$$\begin{pmatrix} \mathbb{H} & 0 \\ -\mathbb{B} & \mathbb{A} \end{pmatrix} \begin{pmatrix} d \\ D \end{pmatrix}^{(i)} = \begin{pmatrix} 0 & -\mathbb{F}\mathbb{C} \\ 0 & -\mathbb{C} \end{pmatrix} \begin{pmatrix} d \\ D \end{pmatrix}^{(i-1)} + \begin{pmatrix} \mathbb{A} & \mathbb{F} \\ 0 & \mathbb{I} \end{pmatrix} \begin{pmatrix} d^\bullet \\ D^\bullet \end{pmatrix}$$

$$d^{(i)} = \mathbb{H}^{-1} \left(\mathbb{A} d^\bullet + \mathbb{F} \left[D^\bullet - \mathbb{C} D^{(i-1)} \right] \right)$$

$$D^{(i)} = \mathbb{A}^{-1} \left(\mathbb{B} d^{(i)} - \mathbb{C} D(i-1) + D^\bullet \right)$$

System of L linear equations of the type

$$D^{(i)} = \mathbb{M} D^{(i-1)} + \mathbb{N}$$

VFE in NH

Convergence of the iterative SI solver

Testing of convergence

- linear equation of the form $D^{(i)} = \mathbb{M}D^{(i-1)} + \mathbb{N}$
- convergence being tested **in the setup** according to

$$\lim_{i\to\infty} D^{(i)} = D^{*} \text{ for any } D^{(0)} \Leftrightarrow \boxed{\rho(\mathbb{M}) < 1}$$

where $\rho(\mathbb{M}) = \max\{|\lambda|; \lambda \text{ is an eigenvalue of } \mathbb{M}\}$

is a spectral radius of M

Speed of convergence

- we define the *i*th residual as $r_i = \mathbb{M}D^{(i)} - D^{(i)} + \mathbb{N}$
- we need $\lim_{i\to\infty} r_i = 0$
- termination criterion on threshold τ : $\frac{||r_k||}{||r_0||} < \tau$ STOP

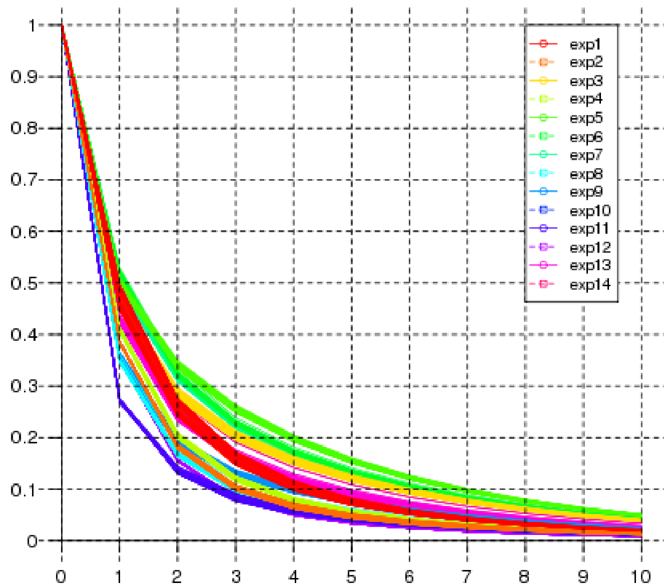
$||\cdot||$ is an l^2 norm over the whole domain

VFE in NH

Statement 1: The iterative SI solver converges and the speed of convergence is good in all tested cases.

Speed of convergence

$$\frac{||r_k||}{||r_0||}$$



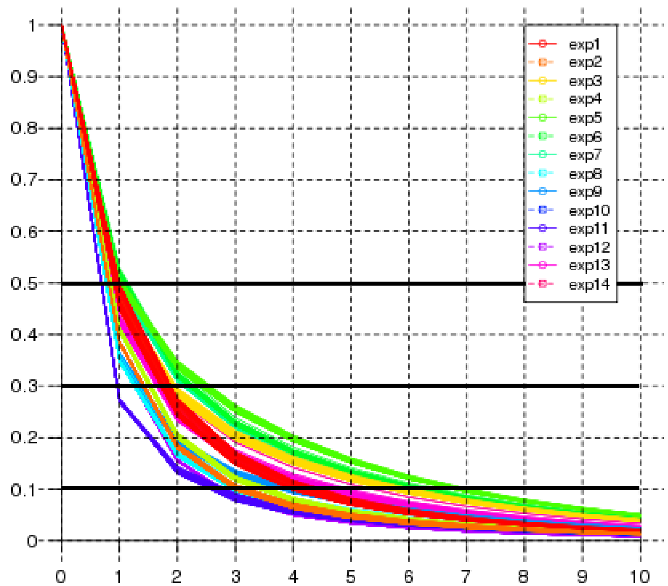
iteration

VFE in NH

Statement 1: The iterative SI solver converges and the speed of convergence is good in all tested cases.

Speed of convergence

$$\frac{||r_k||}{||r_0||}$$



iteration

For our 3D experiments, we needed

$\tau = 0.5$ ... 1 iteration

$\tau = 0.3$ ... 3 iterations

$\tau = 0.1$ ... 7 iterations

- may be assigned dynamically

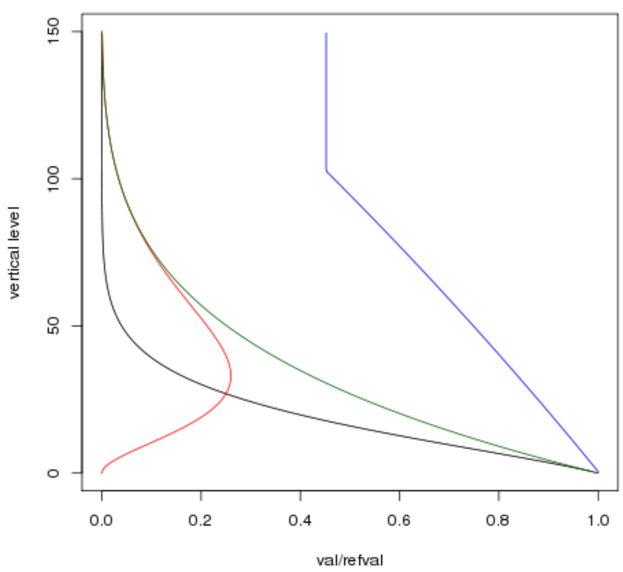
VFE in NH

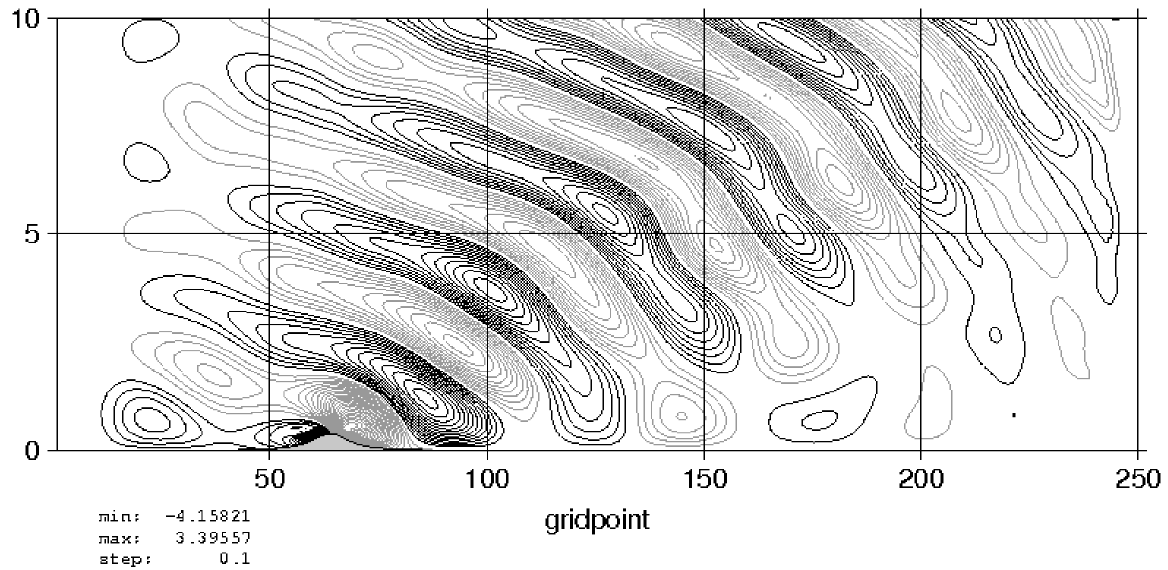
Statement 2: Vertical levels distribution is not crucial for stability.

2D tests: NLNH flow over Agnesi shaped mountain

A regular vertical levels distribution with dz=200m

A—, B—, p—, T—





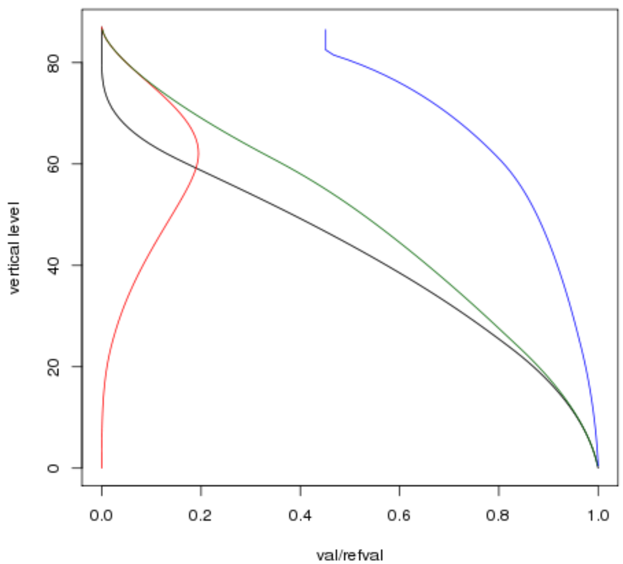
VFE in NH

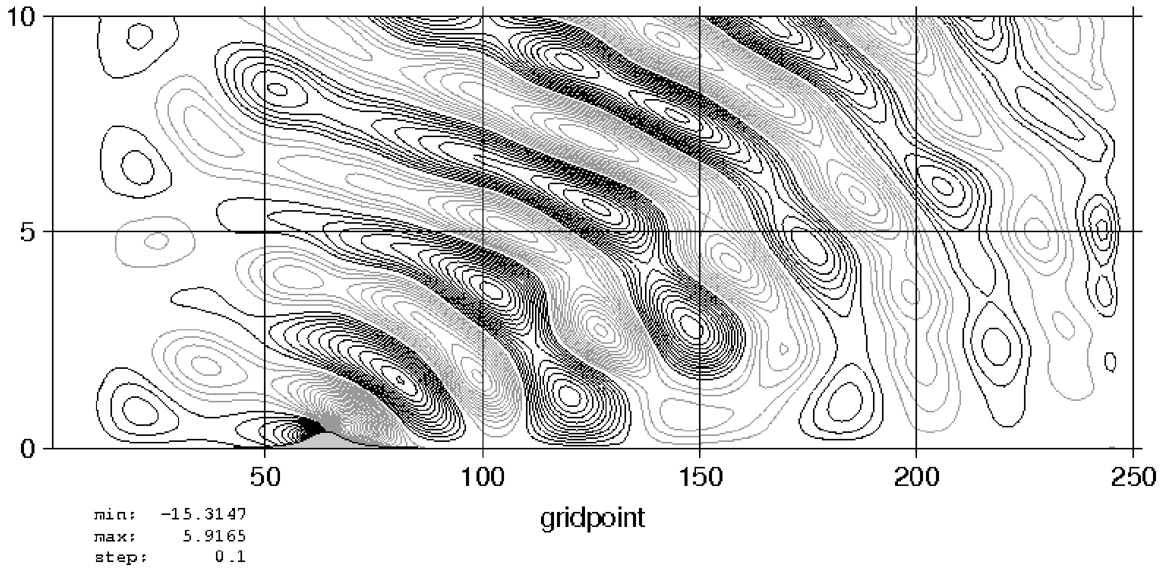
Statement 2: Vertical levels distribution is not crucial for stability.

2D tests: NLNH flow over Agnesi shaped mountain

Czech operational 87 vertical levels

A—, B—, p—, T—





VFE in NH

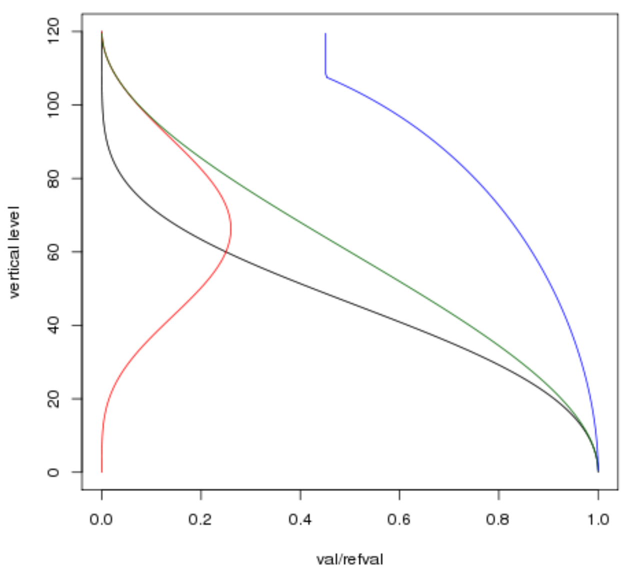
2D tests: NLNH flow over Agnesi shaped mountain

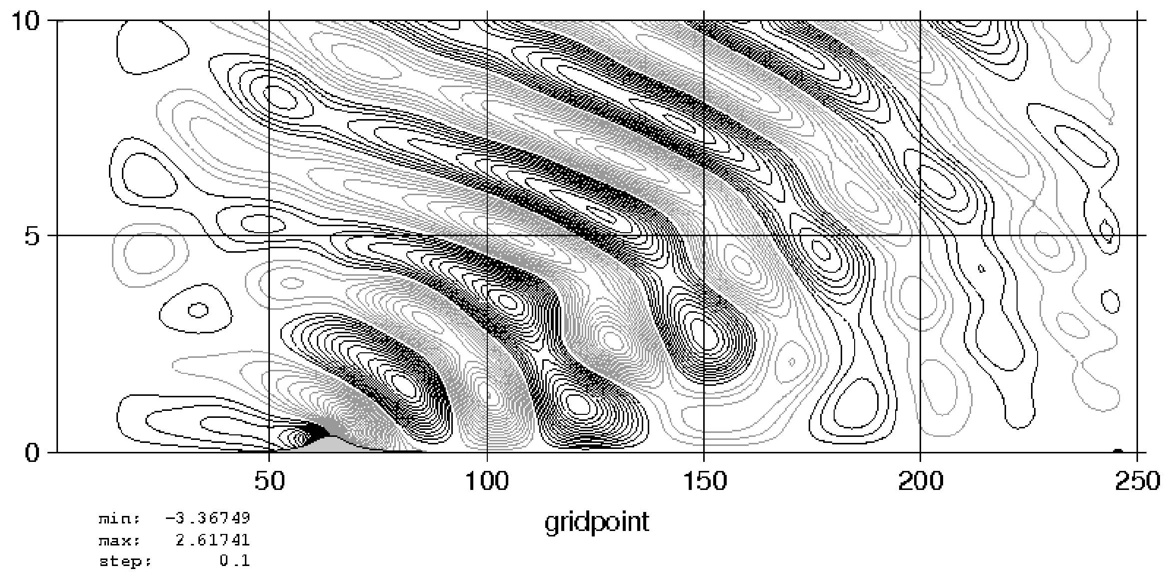
An **“arbitrary” levels distribution**: α=0

$$\sigma_l = \frac{l}{L}, \beta = 3(1-\alpha), \eta_l = \alpha\sigma_l + \beta\sigma_l^2 + (1-\alpha-\beta)\sigma_l^3$$

A—, B—, p—, T—

$$B_l = (3-2\eta_l)\eta_l^3, A_l = \eta_l - B_l$$





VFE in NH

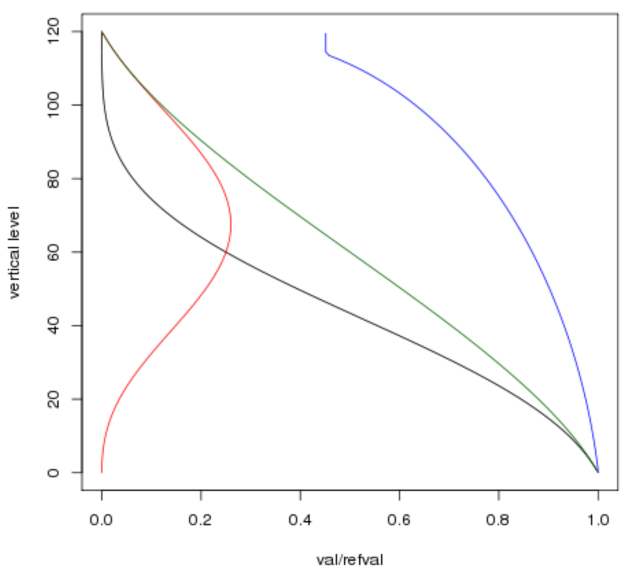
2D tests: NLNH flow over Agnesi shaped mountain

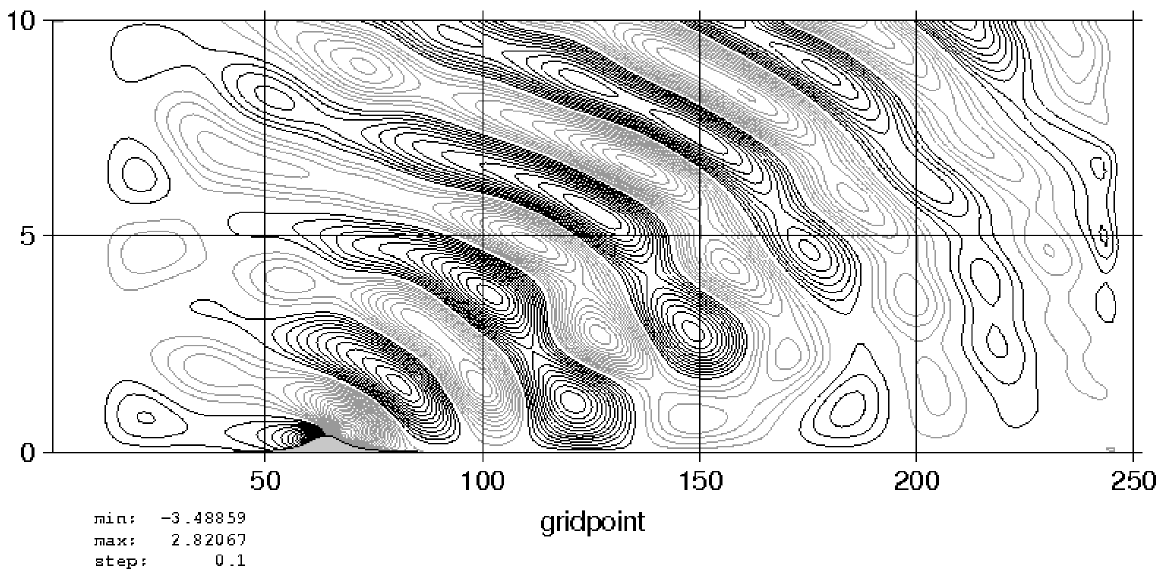
An **"arbitrary" levels distribution**: α=0.5

$$\sigma_l = \frac{l}{L}, \beta = 3(1-\alpha), \eta_l = \alpha\sigma_l + \beta\sigma_l^2 + (1-\alpha-\beta)\sigma_l^3$$

A—, B—, p—, T—

$$B_l = (3-2\eta_l)\eta_l^3, A_l = \eta_l - B_l$$





VFE in NH

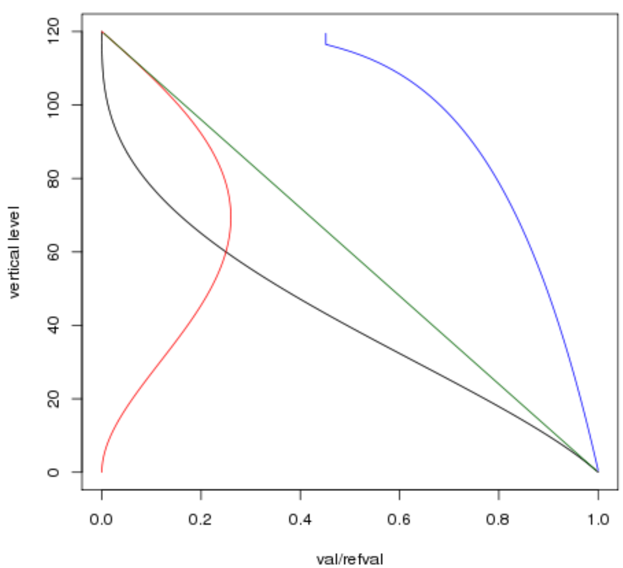
2D tests: NLNH flow over Agnesi shaped mountain

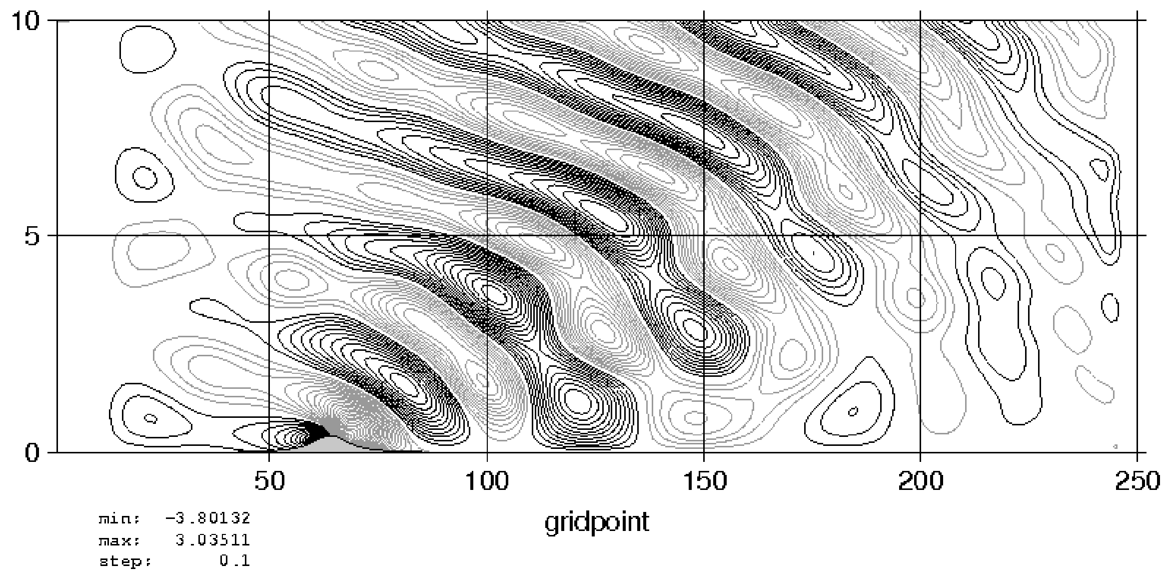
An **"arbitrary" levels distribution**: α=1

$$\sigma_l = \frac{l}{L}, \beta = 3(1-\alpha), \eta_l = \alpha\sigma_l + \beta\sigma_l^2 + (1-\alpha-\beta)\sigma_l^3$$

A—, B—, p—, T—

$$B_l = (3-2\eta_l)\eta_l^3, A_l = \eta_l - B_l$$





VFE in NH

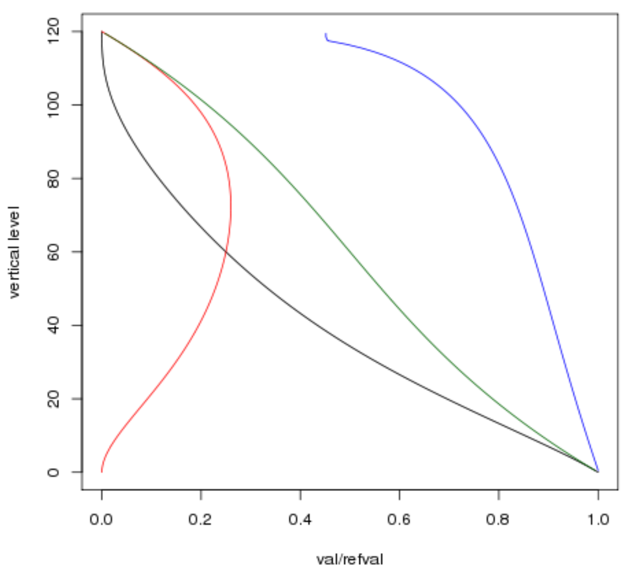
2D tests: NLNH flow over Agnesi shaped mountain

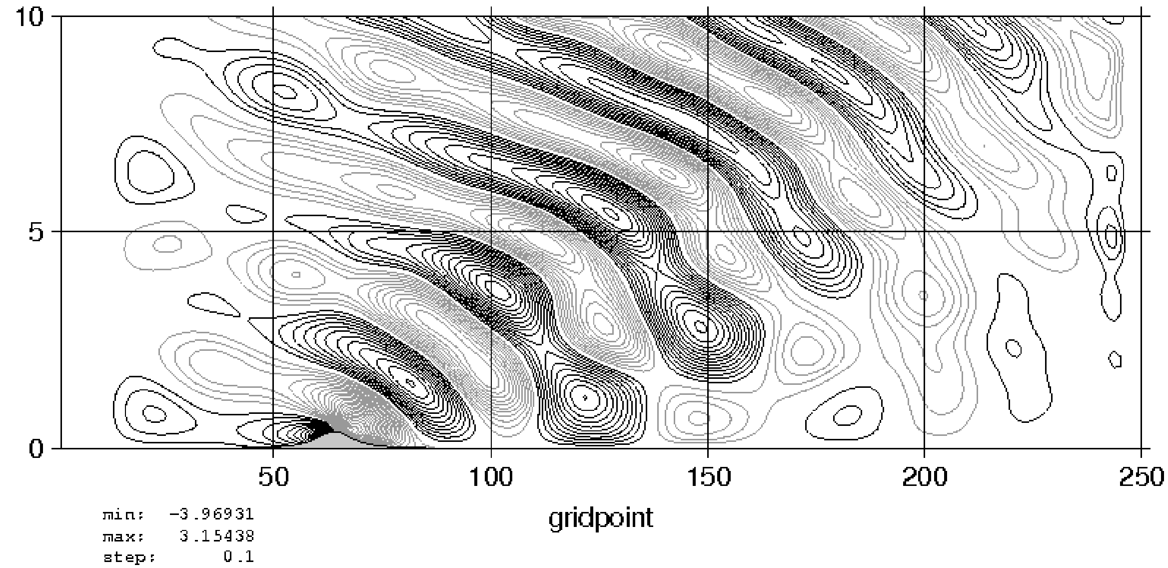
An **"arbitrary" levels distribution**: α=1.5

$$\sigma_l = \frac{l}{L}, \beta = 3(1-\alpha), \eta_l = \alpha\sigma_l + \beta\sigma_l^2 + (1-\alpha-\beta)\sigma_l^3$$

A—, B—, p—, T—

$$B_l = (3-2\eta_l)\eta_l^3, A_l = \eta_l - B_l$$





VFE in NH

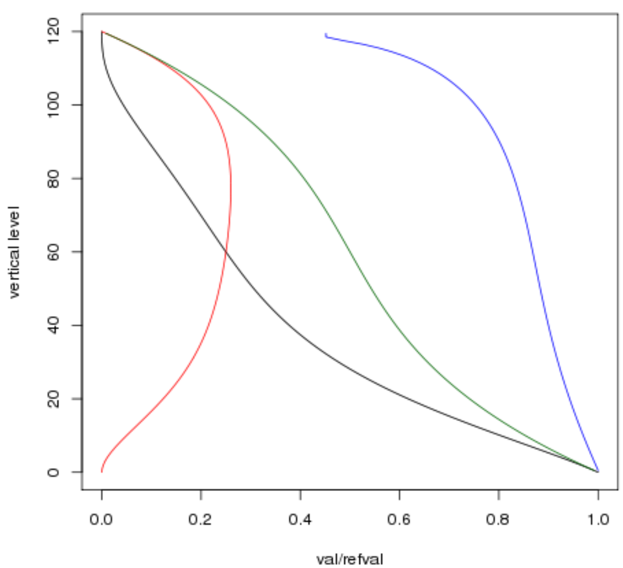
2D tests: NLNH flow over Agnesi shaped mountain

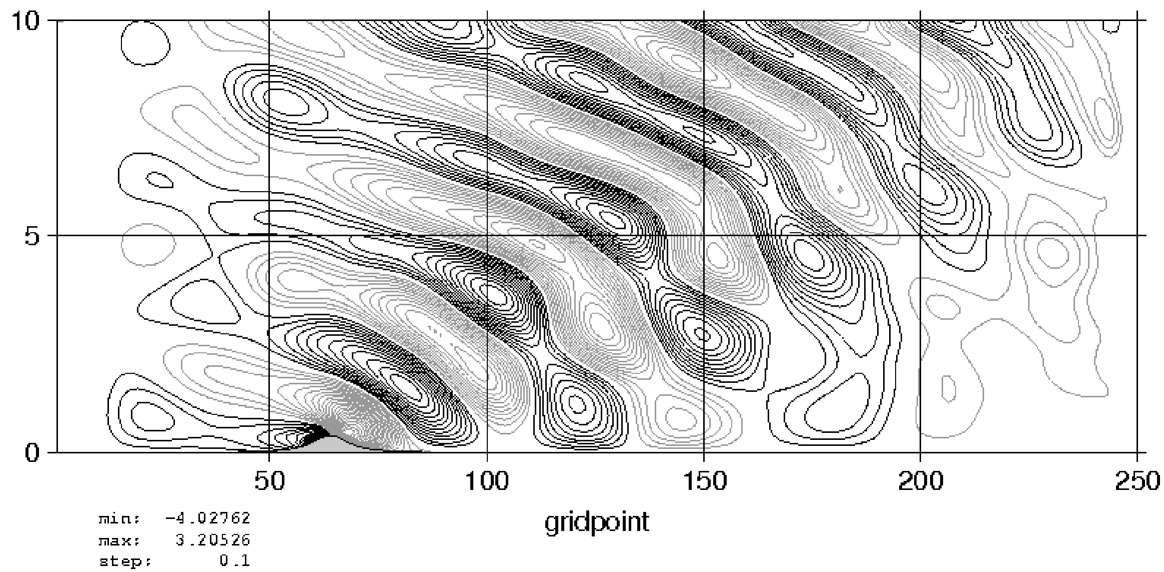
An **“arbitrary” levels distribution**: α=2

$$\sigma_l = \frac{l}{L}, \beta = 3(1-\alpha), \eta_l = \alpha\sigma_l + \beta\sigma_l^2 + (1-\alpha-\beta)\sigma_l^3$$

A—, B—, p—, T—

$$B_l = (3-2\eta_l)\eta_l^3, A_l = \eta_l - B_l$$

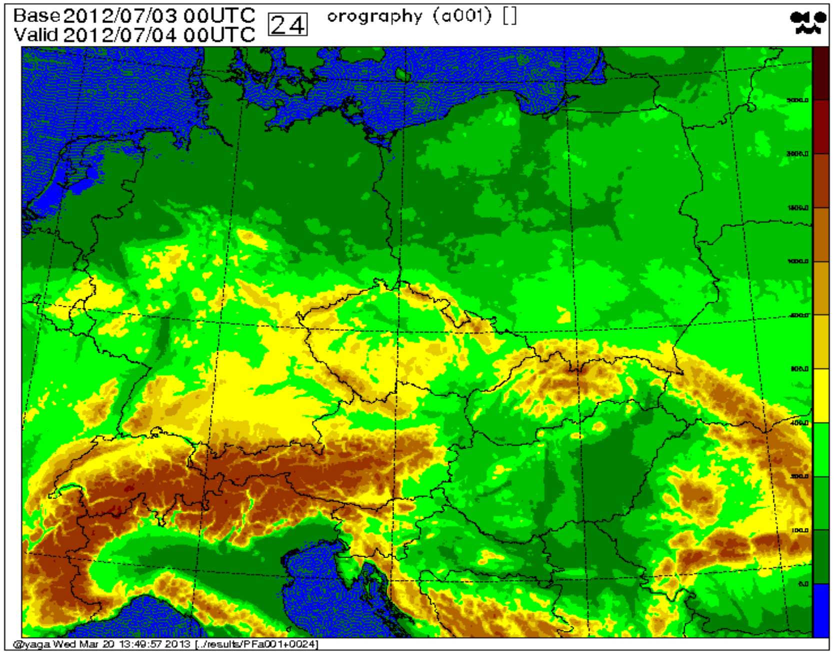




VFE in NH

3D real case simulations:

- 2.2km horizontal resolution, 87 vertical levels
- Central Europe domain over Czech Republic with Alps
- ALARO physics with LSTRAPRO=T (diagnostic deep convection, microphysics applied to resolved clouds and precipitations)
- Time step 90s
- PC NESC scheme, 1 iteration
- LGWADV=T
- Integration for 24 hours
- 3hours coupling interval



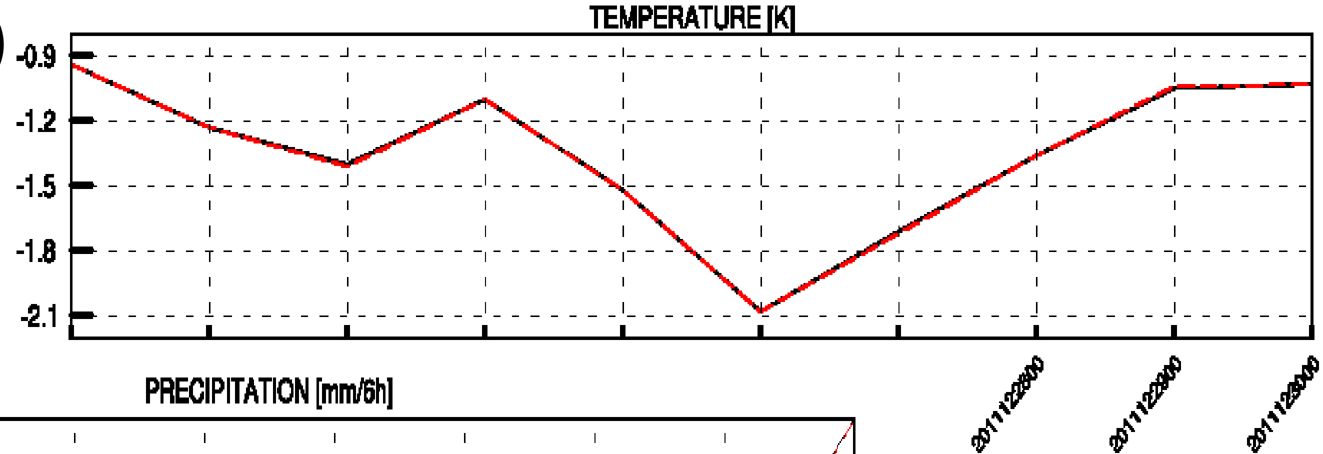
2 periods:
winter 21.12.-30.12.2011
summer 01.07.-10.07.2012

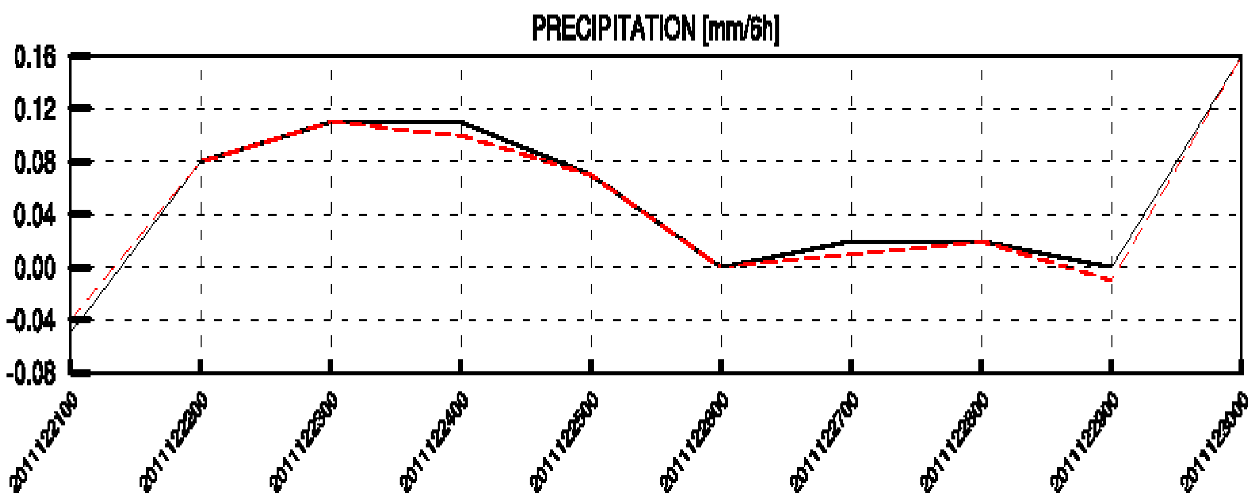
VFE in NH

3D real case simulations:

- Stable without apparent problems
- Iterative SI solver converges, objective scores of the results with 1 iteration and with 8 iterations coincide ➡ 1 iteration is enough (?)

1 iteration
8 iterations

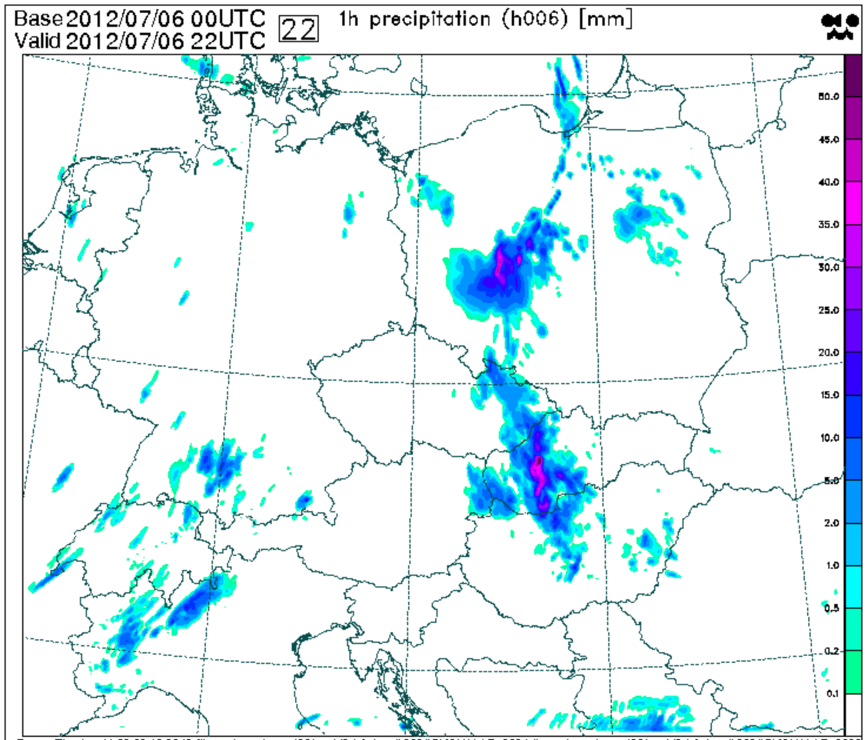




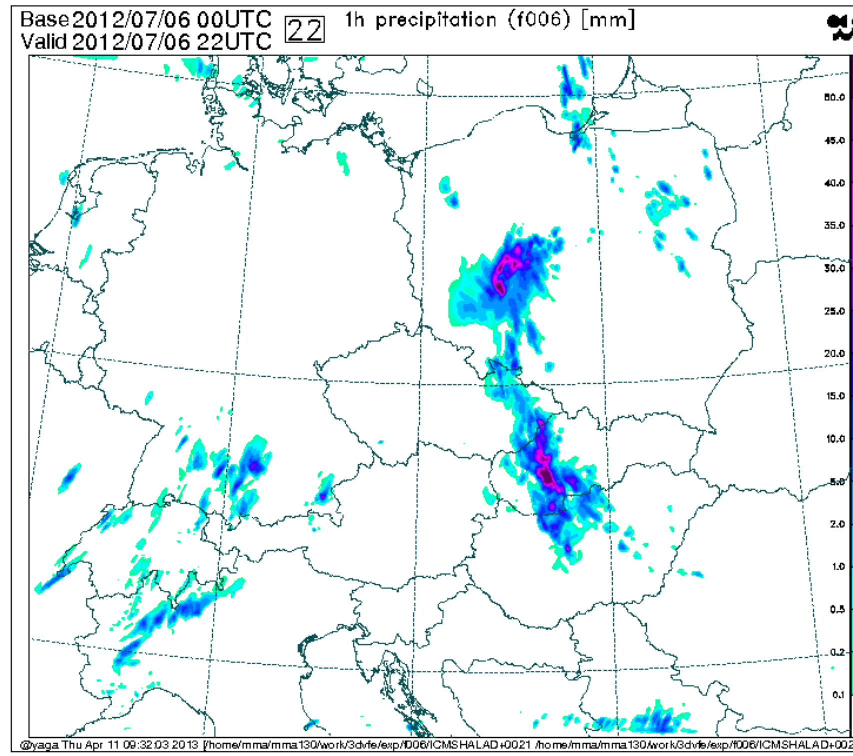
VFE in NH

3D real case simulations:

- Objective scores are **neutral** to the change of vertical discr.
- Interaction with convection may be observed



VFD

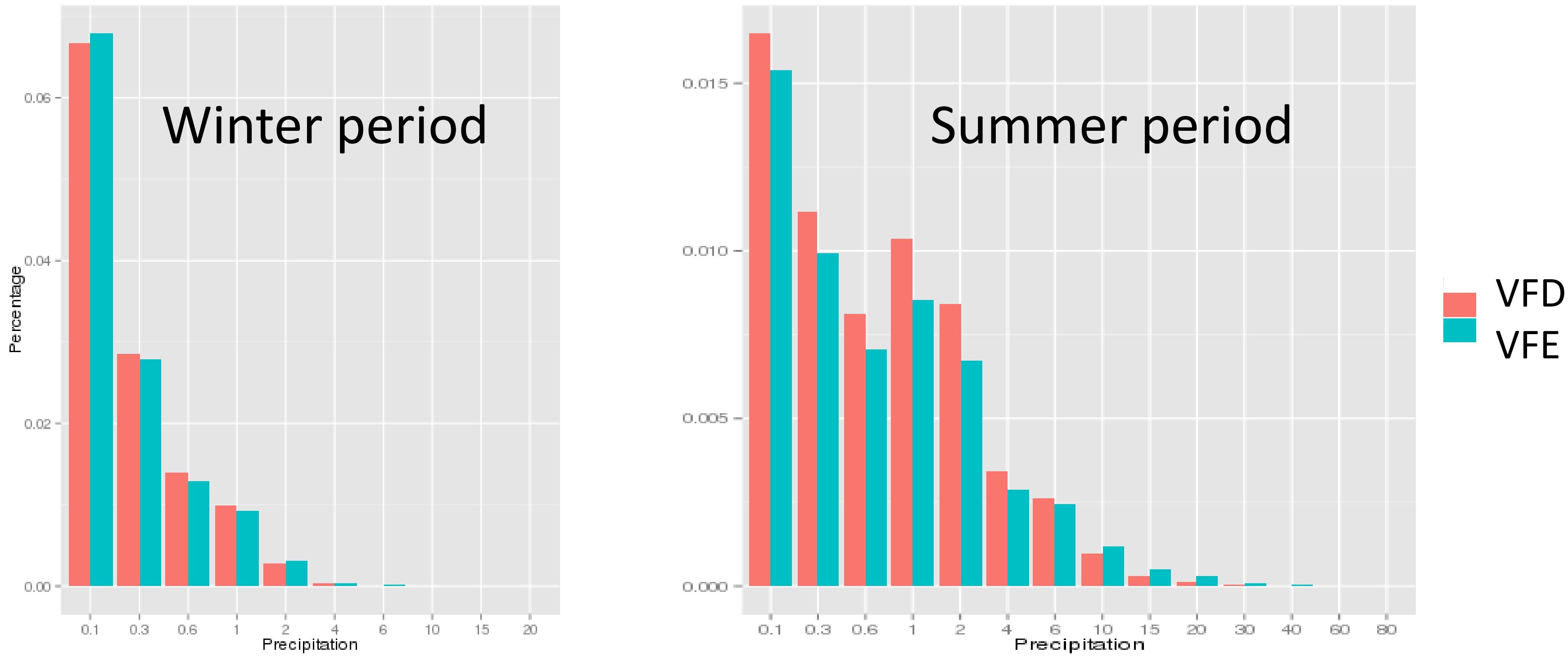


VFE, 1 iteration of SI solver

VFE in NH

3D real case simulations:

- Interaction with convection may be observed



Weak precipitations occur less often with VFE, there is a shift to more intense precipitations

VFE in NH

Statement 3: VFE scheme which has been implemented in NH dynamics is stable enough to be tested in various contexts.

Future plans:

- to check the behavior of VFE in higher atmosphere
- to clean and consolidate the existing research code modification
- to optimize on time and memory requirements
- to study the accuracy of proposed solution (verification with objective scores for longer periods, …)
- to study the consistency with other model options (LESIDG)
- to implement the modification into the official ALADIN cycle
- to prepare documentation and report on VFE NH

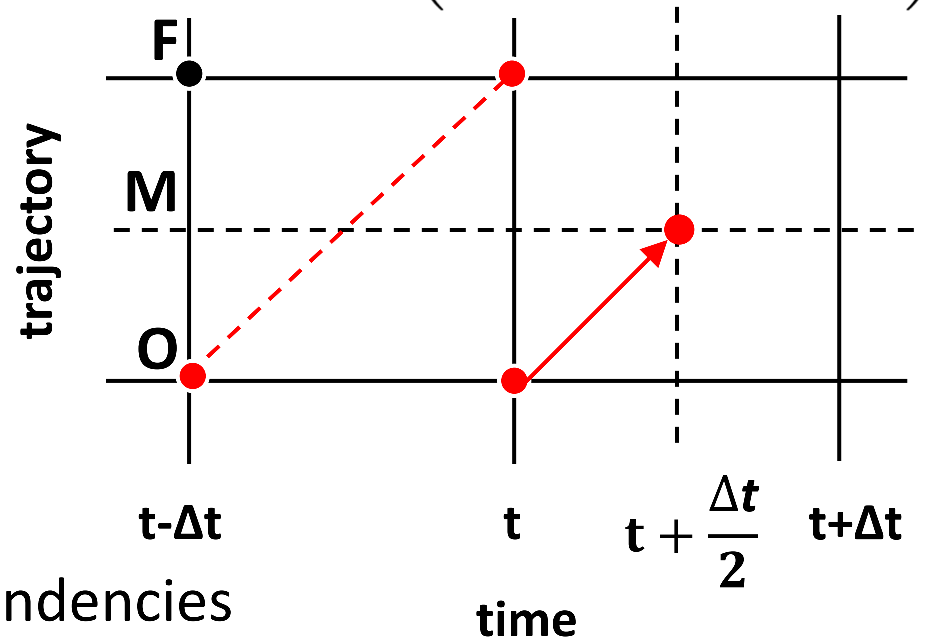
Physics dynamics interface

Currently in ALADIN/AA:

first-order in time accurate, explicit $X_F^+ = \cdots + \Delta t \cdot P_O^0$

Proposed: **second order accurate** (M.Hortal, 2001) **SETTLS type**

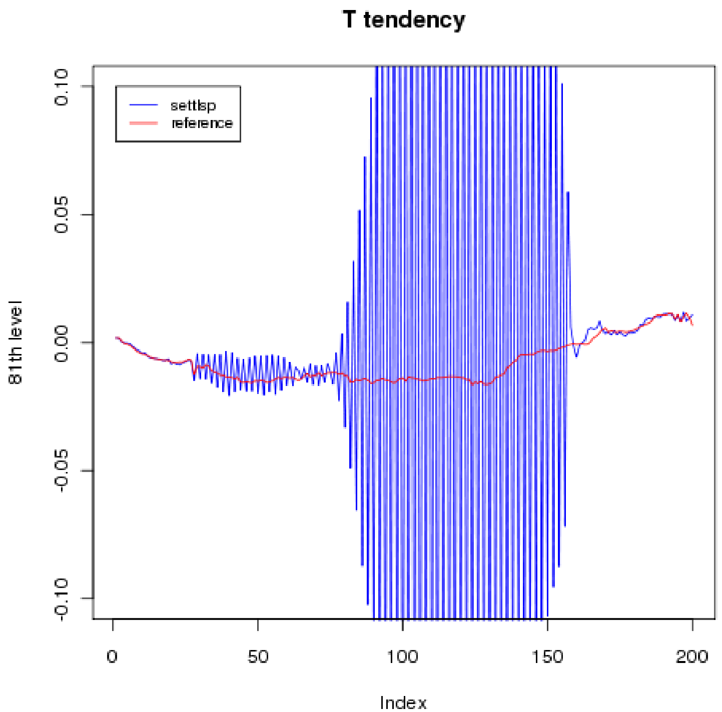
$$X_F^+ = \cdots + \Delta t \cdot \left(P_O^0 - \frac{1}{2} P_O^- + \frac{1}{2} P_F^0 \right)$$



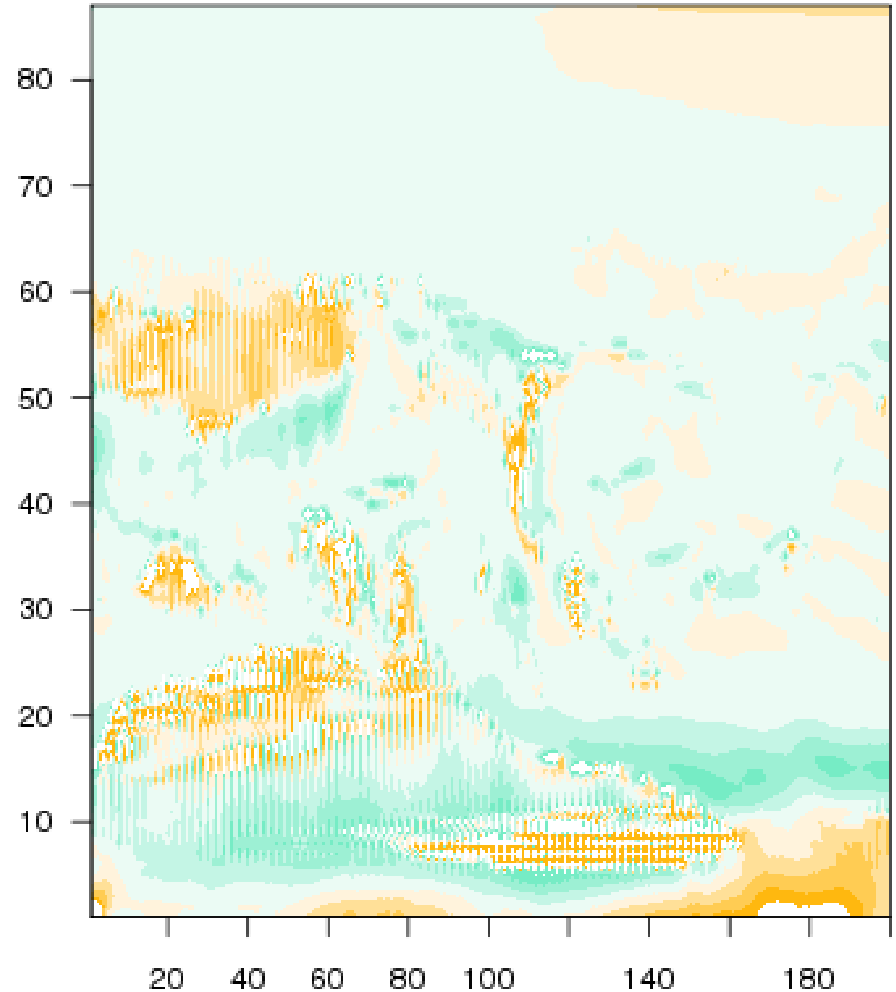
- used for non-linear terms
- we applied it on physical tendencies

Physics dynamics interface

Locally developed unrealistic values in the field of T



Time evolution of *phys(T)* in a single point: $2\Delta t$ oscillations



Physics dynamics interface

SETTLS type coupling of physical tendencies:

- applied on all advected variables ⇒ time oscillations, poor stability, locally unrealistic values
- applied on GMV (*u*, *v*, *T*) variables only
  - stability OK
  - the enhanced accuracy not detected (validation for one month)
- applied on GMV+*q* ⇒ enough to create oscillations

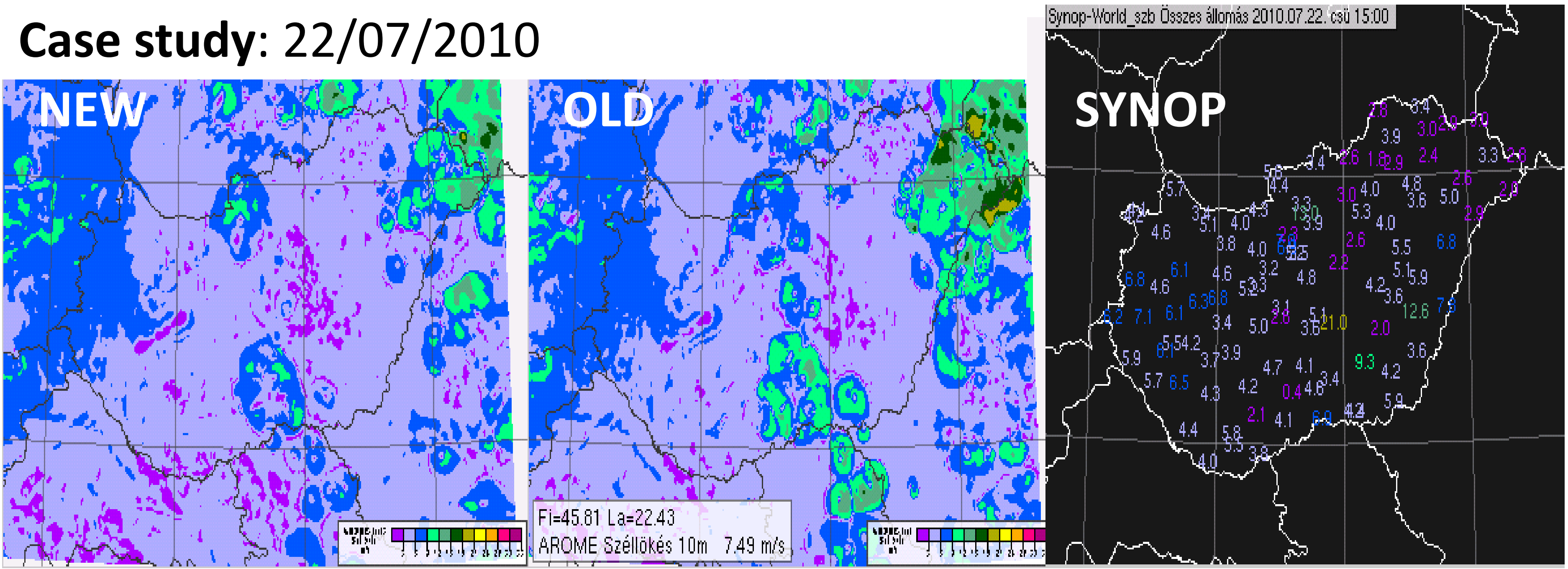
Conclusion: We stay with the current explicit technique which is robust and stable and resign on the enhanced accuracy.

Tuning SLHD for AROME (B.Szintai)

The SLHD modification (operational since July 2011 in Hu):

- SLHD not applied to falling hydrometeors
- spectral diff. switched off below 100hPa

Case study: 22/07/2010



➡ significantly reduces the max. precipitation and the wind gust forecasts

Tuning SLHD for AROME (B.Szintai)

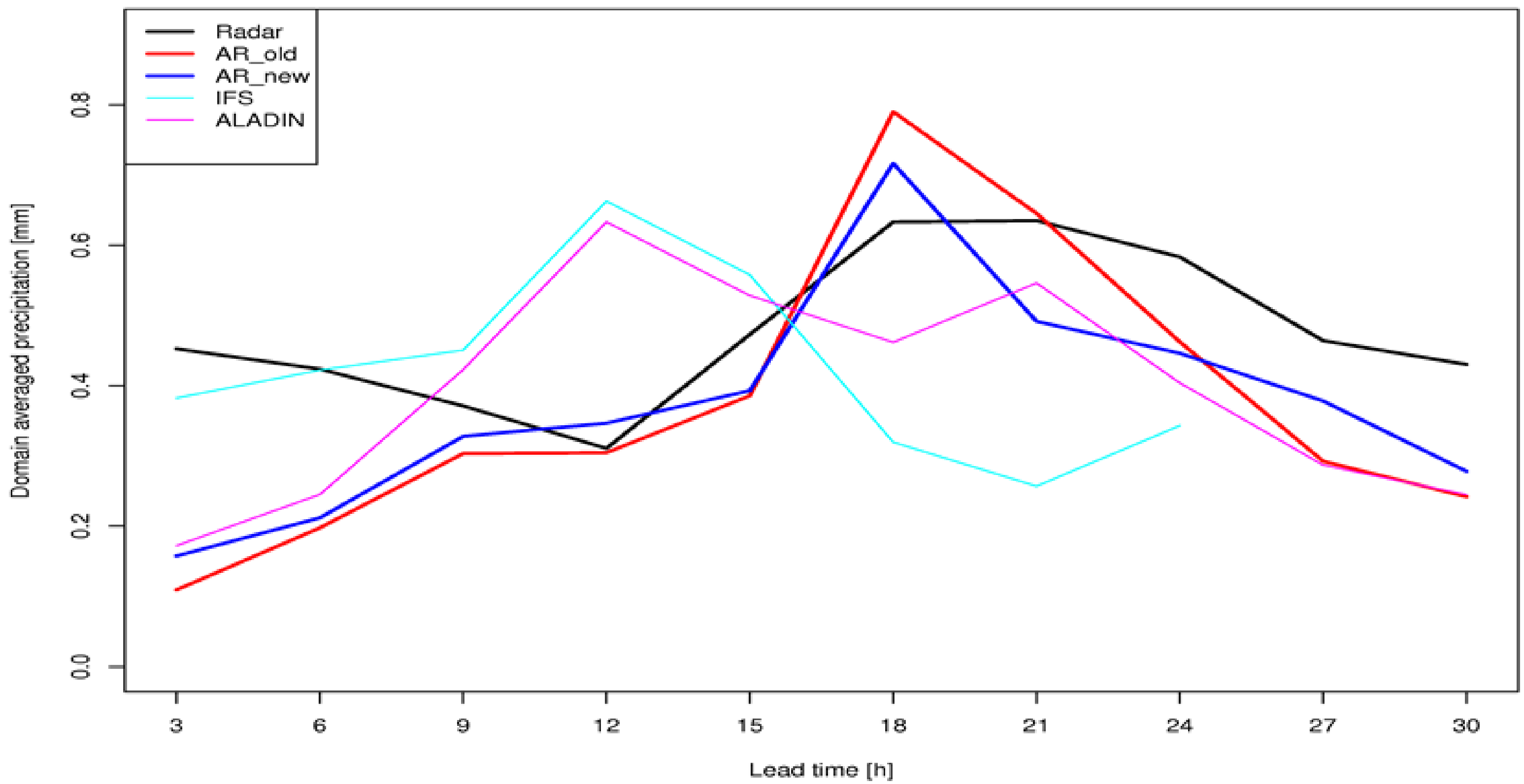
Verification with objective scores:

	Max. temperature		Precipitation		Wind speed		Wind gusts		Cloud cover	
Experiment	ME	RMSE	ME	RMSE	ME	RMSE	ME	RMSE	ME	RMSE
AROME_new	-0.2	1.46	0.2	3.91	0.6	0.95	0.5	2.7	-0.2	0.88
AROME_old	-0.3	1.44	0.3	3.92	0.7	0.99	1.1	3.29	-0.1	0.82

	Min. temperature		Precipitation		Wind speed		Wind gusts		Cloud cover	
Experiment	ME	RMSE	ME	RMSE	ME	RMSE	ME	RMSE	ME	RMSE
AROME_new	1.1	1.7	-0.6	3.69	0.9	1.2	0.4	2.38	0.2	1.18
AROME_old	1	1.55	-0.5	3.69	0.9	1.21	1	2.54	0.4	1.15

The SLHD modification slightly deteriorates temperature, has neutral impact on precipitation and wind speed, and significantly improves the wind gust forecasts.

Tuning SLHD for AROME (B.Szintai)



The timing of convection: observed and predicted diurnal cycle of domain-averaged precipitation, one month period.

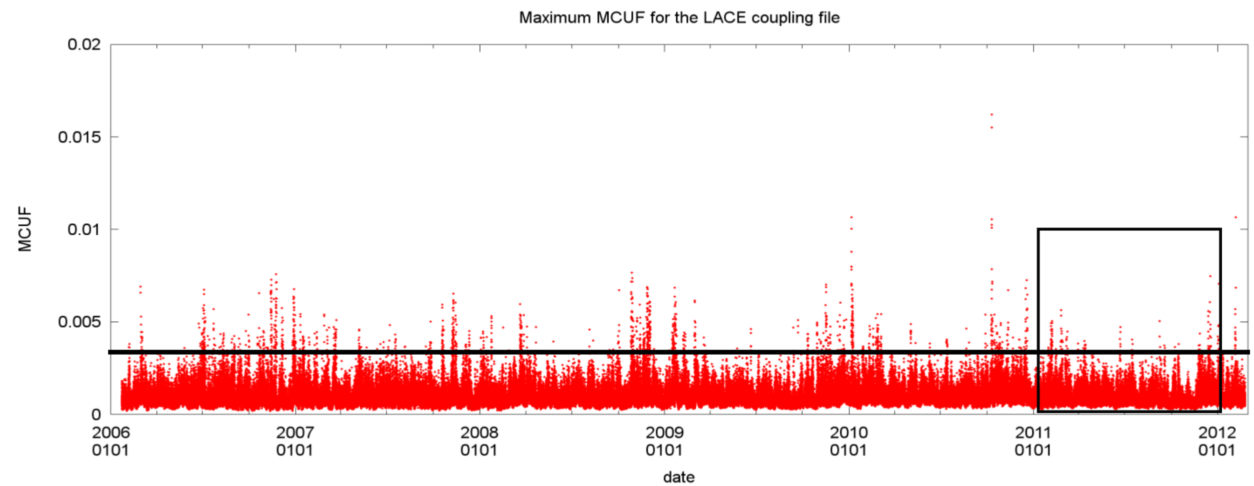
Coupling – fast changes in ps (M.Tudor)

- LBC data of the large scale model are (linearly) **interpolated** in time ➡ interpolation procedure distorts the model fields, larger coupling zone yields dual cyclone structure ➡ LAM **forecast failures** in case of fast propagating storms
- a recursive high-pass filter applied to the surface pressure field ➡ **MCUF field provided by ARPEGE**
- large values of MCUF indicate a rapidly moving disturbance in the surface pressure through the model grid point

---

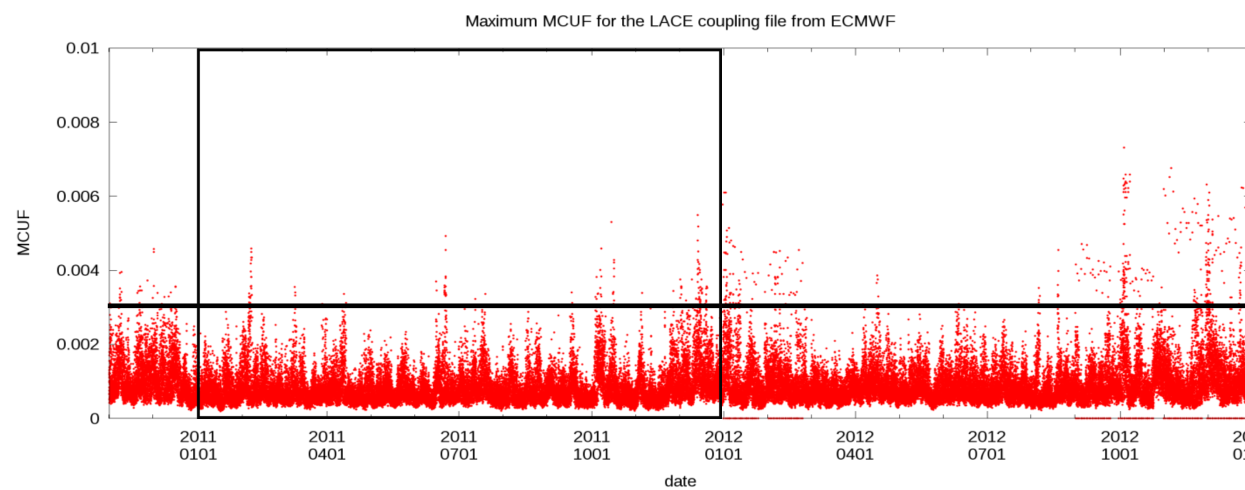
- **MCUF field is not available** in the coupling files provided by **ECMWF** ➡ an error function of surface pressure and mean sea level pressure was **computed** for these LBC files
- requires running the ALADIN forecast in low resolution up to 78 hours

Coupling – fast changes in ps (M.Tudor)



ARPEGE

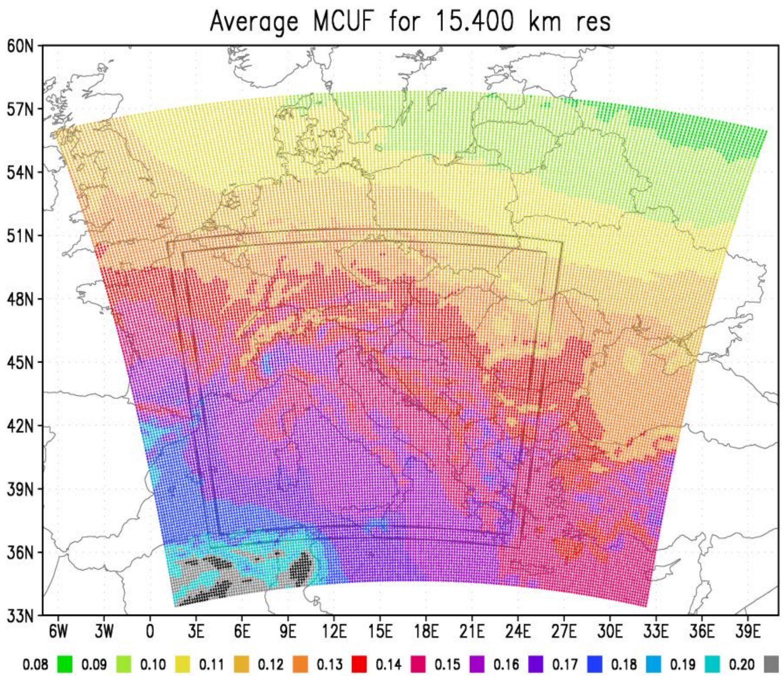
Time series of maximum value of MCUF on the LACE domain.



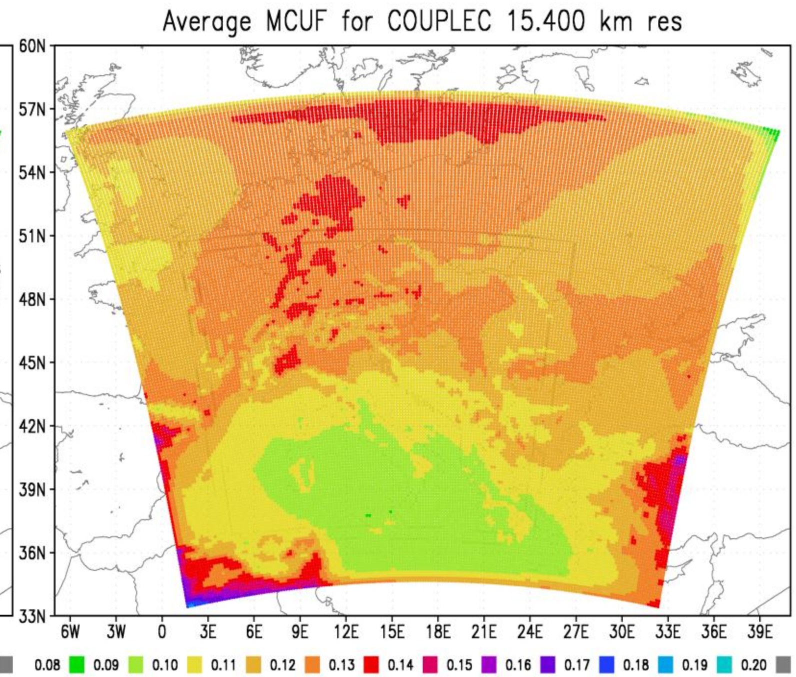
ALADIN from IFS

Coupling – fast changes in ps (M.Tudor)

ARPEGE



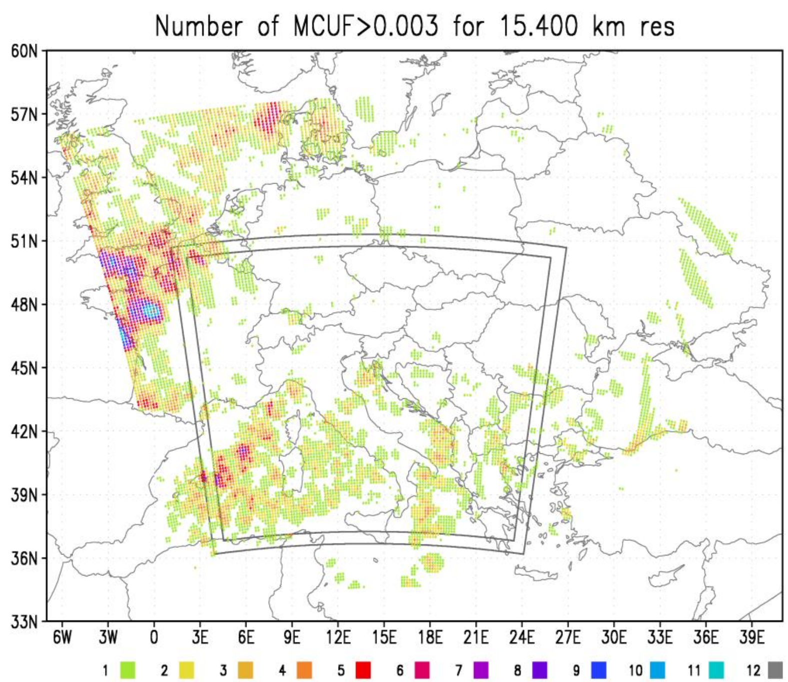
ALADIN from IFS



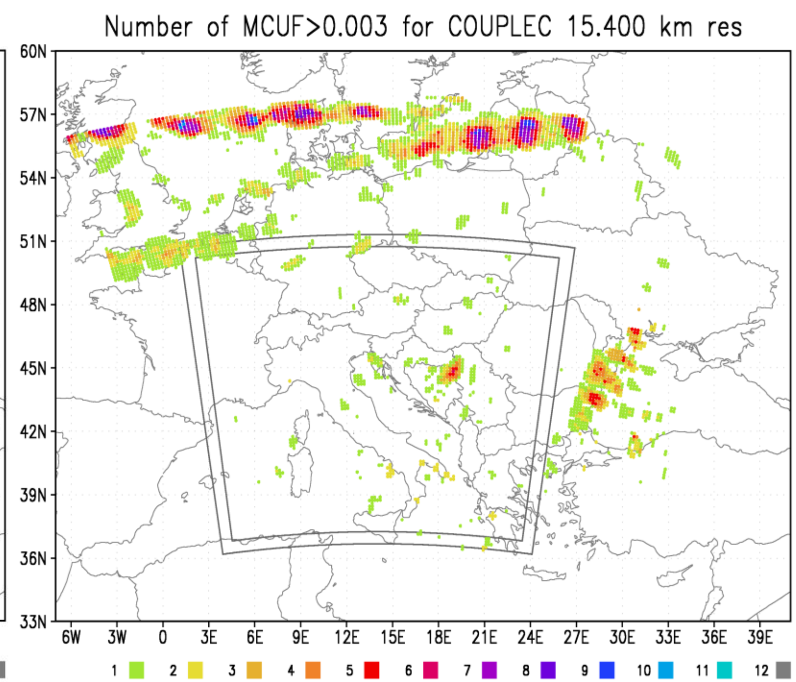
Spatial distribution of the average MCUF values *1000.

Coupling – fast changes in ps (M.Tudor)

ARPEGE



ALADIN from IFS



Spatial distribution of the number of occurrences when MCUF values exceed the value 0.003.

Coupling – fast changes in ps (M.Tudor)

Conclusions:

- **Western Mediterranean** is an area where storms frequently propagate with high velocities and can not be resolved in LBCs of a 8 km resolution LAM when provided with 3 hour interval.

Computed values of MCUF:

- can be **too low close to the edge** of the LBC domain
- running ALADIN on the coupling file domain **can not model the cyclones** forming in the lee of north African mountains since much of these mountains are outside of the domain
- **low MCUF activity** in the northern Africa and western Mediterranean

Coupling – choosing leading model for AROME (G.Bölöni)

One month period (June-July 2012) exp. on Hungarian operational domain, 1 hour coupling frequency - results:

Coupling to IFS

- better verification results for upper air variables, except wind bias
- slightly improved precipitation
- better precipitation amplitude with SAL

Coupling to ALARO

- smaller wind bias
- better precipitation structure and location with SAL

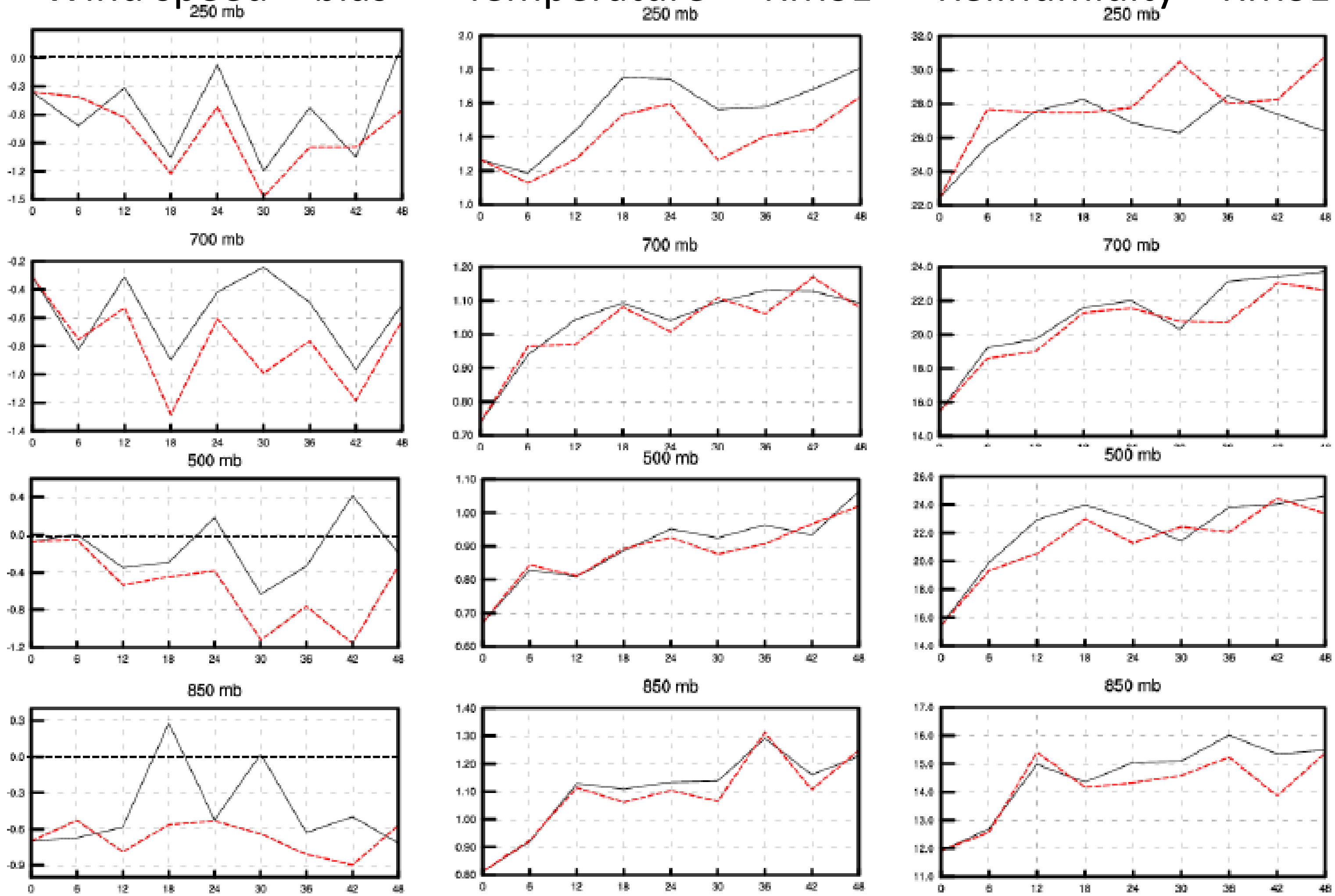
→ Coupling of AROME **to IFS** introduced **operationally in Dec 2012** in Hungary

Coupling – choosing leading model for AROME (G.Bölöni)

Wind speed – bias | Temperature – RMSE | Rel.humidity – RMSE

--- IFS

--- ALARO



Thank you for your attention!