Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

Dynamics in LACE

Petra Smolíková

thanks to Alexandra Craciun, Jozef Vivoda and other colleagues

DHMZ ARSO METEO Slovenia OMSZ ZAMG ROMANIA ANM

Outline

1. **Dynamic definition of the time scheme**
2. **Finite elements used in vertical in NH**
3. **The trajectory search in the SL advection scheme**

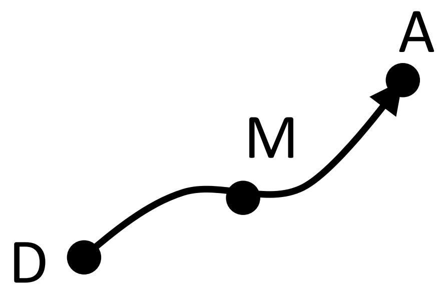
Dynamic definition of the time scheme

work of Jozef Vivoda

Advection equation $$\frac{df(t,x)}{dt} = N(t,x)$$

Time centered explicit
semi-Lagrangian approach

$$\frac{f_A^+ - f_D^0}{\Delta t} = N_M^m$$



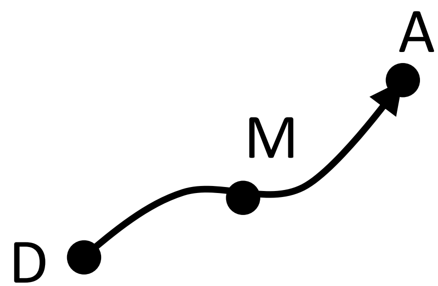
t+ Δt	+
t+ $\frac{\Delta t}{2}$	m
t	0
t -Δt	–

Dynamic definition of the time scheme

Advection equation $$\frac{df(t,x)}{dt} = N(t,x)$$

Time centered explicit
semi-Lagrangian approach

$$\frac{f_A^+ - f_D^0}{\Delta t} = N_M^m$$



t+ Δt	+
t+ $\frac{\Delta t}{2}$	m
t	0
t - Δt	–

available information

Dynamic definition of the time scheme

First order treatment **NESC**: $$N_M^m = \frac{1}{2}(N_A^0 + N_D^0) + \mathcal{O}(\Delta t)$$

The time centered scheme **using available information**

$$N_M^m = a_1 N_A^0 + a_2 N_A^- + a_3 N_D^0 + a_4 N_D^-$$

For any α:

$$N_M^m = (-\alpha + \frac{3}{4})N_A^0 + (\alpha - \frac{1}{4})N_A^- + (\alpha + \frac{3}{4})N_D^0 + (-\alpha - \frac{1}{4})N_D^- + \mathcal{O}(\Delta t^2)$$

For $\alpha = \frac{1}{4}$ we get **SETTLS** (Hortal, 2002):

$$N_M^m = \frac{1}{2}(N_A^0 + N_D^0) + \frac{1}{2}(N_D^0 - N_D^-) + \mathcal{O}(\Delta t^2)$$

Dynamic definition of the time scheme

NESC $$N_M^m = \frac{1}{2}(N_A^0 + N_D^0)$$

SETTLS $$N_M^m = \frac{1}{2}(N_A^0 + N_D^0) + \boxed{\frac{1}{2}(N_D^0 - N_D^-)}$$

COMBINED SCHEME $$N_M^m = \frac{1}{2}(N_A^0 + N_D^0) + \frac{\boxed{\beta}}{2}(N_D^0 - N_D^-)$$

We may change β arbitrarily from 0 to 1.

We consider solution in the shape $N(t,x) = (\lambda + i\omega)f(t,x)$

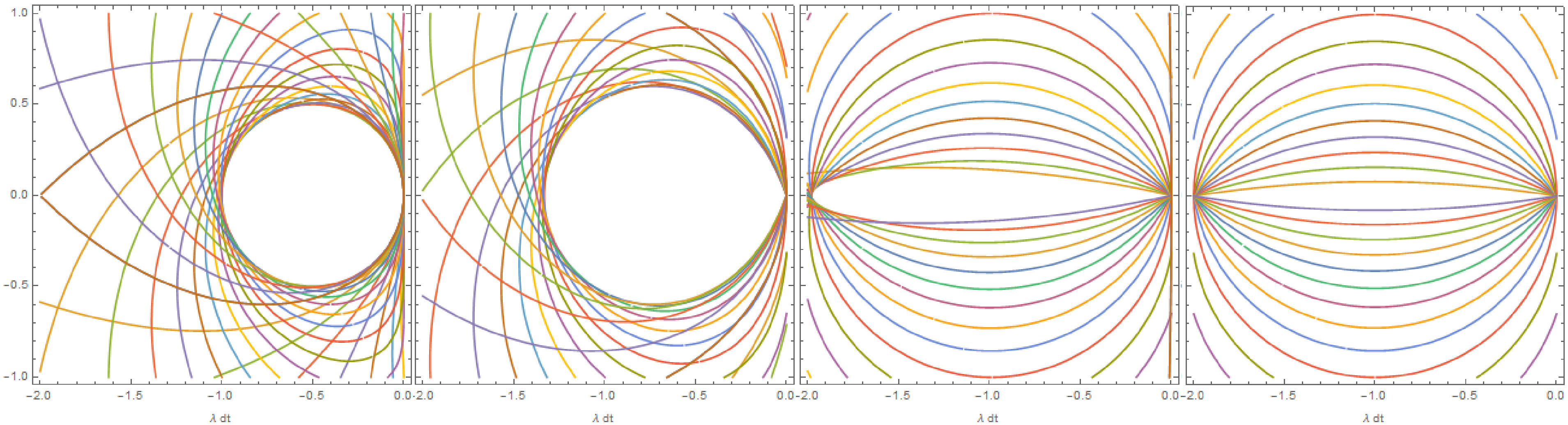
and analyse single Fourier component advected with a constant wind U

$$f(n\Delta t, j\Delta x) = A^n e^{ijUk\Delta t}$$

Stability reached when $|A| \leq 1$.

Stability analysis

β = 1 β = 1/2 β = 1/100 β = 0



↑ωΔt →λΔt (Courtesy of J.Vivoda)

SETTLS: λ, ω constraints

NESC: ω=0

Dynamic definition of the time scheme

Introduce implicitness:

$$\frac{df(t,x)}{dt} = N(t,x) + L(t,x)$$

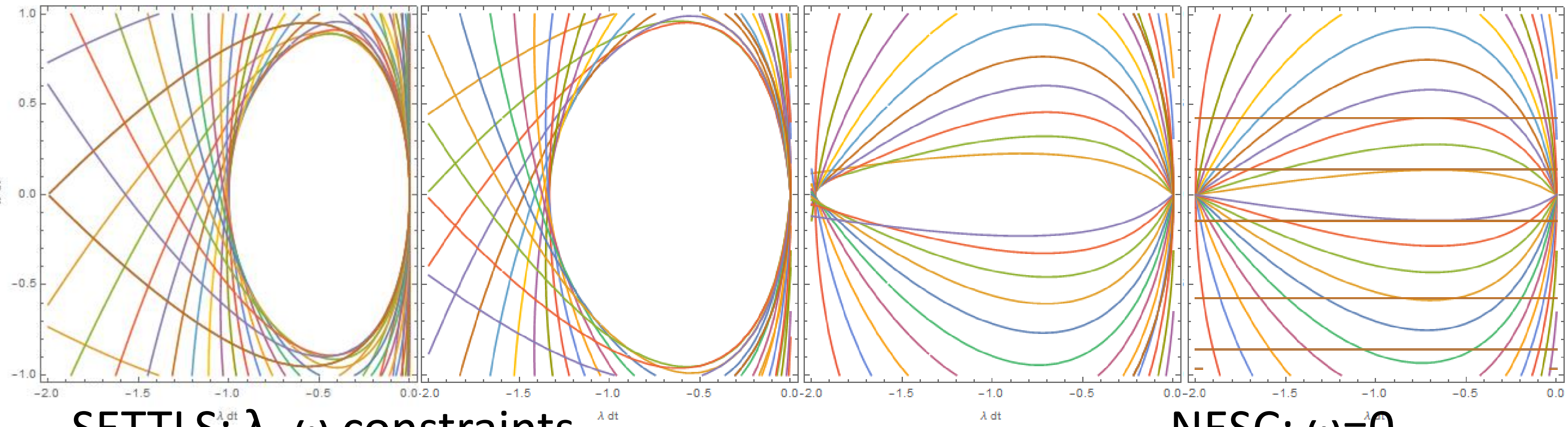
$$\frac{f_A^+ - f_D^0}{\Delta t} = N_M^m + \frac{1}{2}(L_A^+ + L_D^0)$$

Stability analysis for solution

$$L(t,x) = \delta i\omega f(t,x)$$

$$N(t,x) = (\lambda + (1-\delta)i\omega)f(t,x)$$

δ=3/4 β = 1 β = 1/2 β = 1/100 β = 0



SETTLS: λ, ω constraints NESC: ω=0

DHMZ SHMU ARSO Sloven (Courtesy of J.Vivoda)

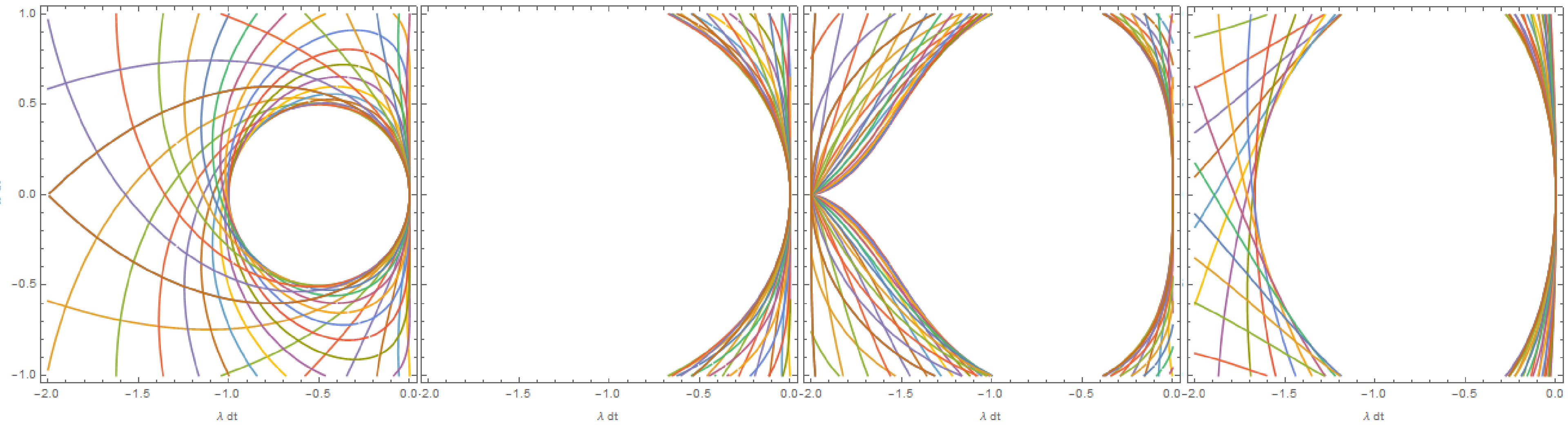
Dynamic definition of the time scheme

Introduce explicit guess:

$$\frac{f_A^+ - f_D^0}{\Delta t} = (\frac{1}{4}+\alpha)N_A^0 + (\frac{1}{4}-\alpha)\widetilde{N_A^+} + (\frac{3}{4}+\alpha)N_D^0 + (-\frac{1}{4}-\alpha)N_D^- + \frac{1}{2}(L_A^+ + L_D^0)$$

Stability analysis shows better stability in both, ω and λ direction.

δ=0, α = 1/4 | δ=0, α = 0 | δ=0, α = -1/4 | δ=3/4, α = 1/10



(Courtesy of J.Vivoda)

Dynamic definition of the time scheme

Iterative centered implicit scheme

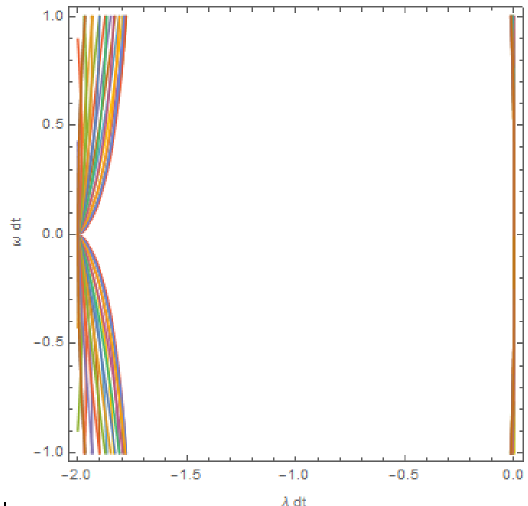
Predictor step using combined scheme:

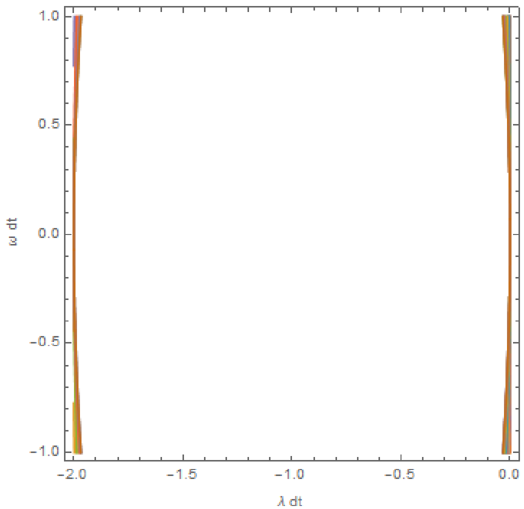
$$\frac{f_A^{+(0)} - f_D^0}{\Delta t} = \frac{1}{2}(N_A^0 + N_D^0) + \frac{\beta}{2}(N_D^0 - N_D^-) + \frac{1}{2}(L_A^{+(0)} + L_D^0)$$

Corrector step using NESC :

$$\frac{f_A^{+(n)} - f_D^0}{\Delta t} = \frac{1}{2}(N_A^{+(n-1)} + N_D^0) + \frac{1}{2}(L_A^{+(n)} + L_D^0)$$

β = 1
SETTLS





β = 0
NESC

(Courtesy of J.Vivoda)

Dynamic definition of the time scheme

The advection treatment used

1) in SL trajectory search
2) for non-linear residuum in the SI scheme

From experience:

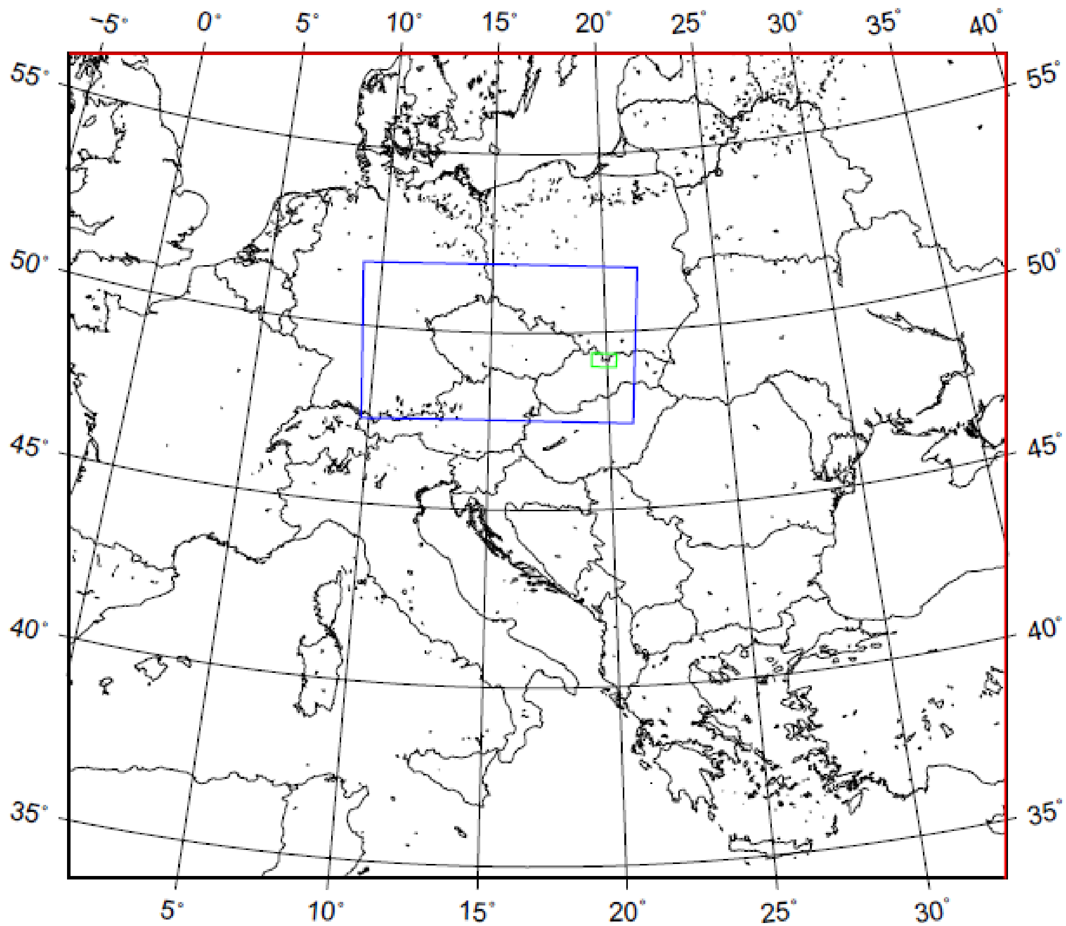
1) SETTLS beneficial for trajectory search
2) Instability may occur when SETTLS applied on non-linear residuum, while NESC is stable (and only first order accurate)

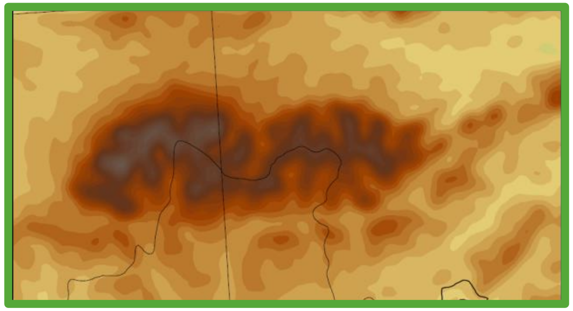
The idea: To use SETTLS whenever possible, and switch to NESC if needed. If it si not "very often", we keep sufficient accuracy and restore stability.

Dynamic definition of the time scheme

Experiments

on small domain





(Courtesy of J.Vivoda)

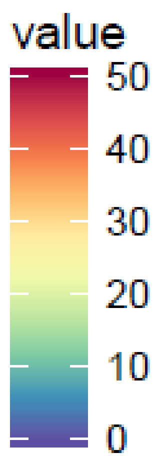
Experiments on small domain

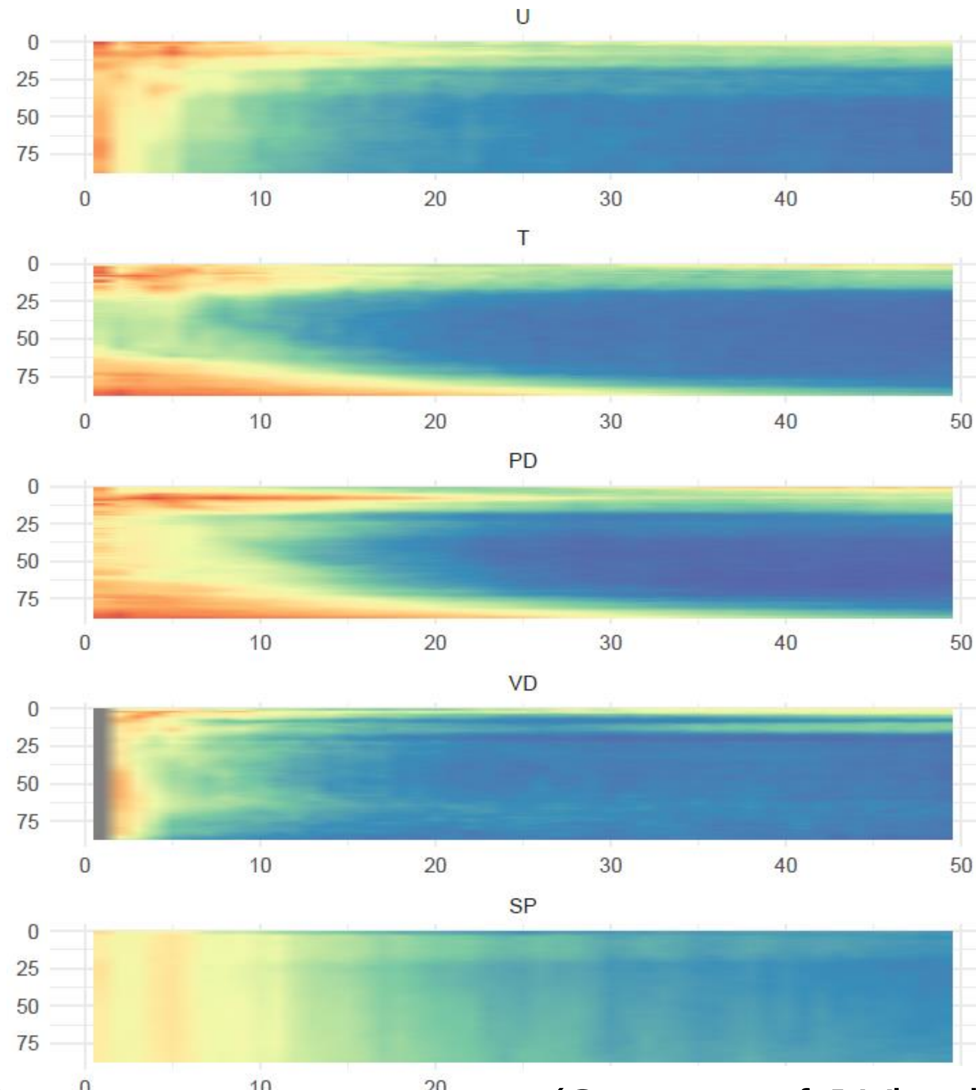
PC with one iteration:

$$\mu = 1 - \frac{|N^0 - N^-|}{|N^0| + |N^-|}$$

for pressure departure.
When $\mu \approx 1$ use SETTLS, otherwise use NESC in each grid point in predictor.

Number of points with NESC calculation:



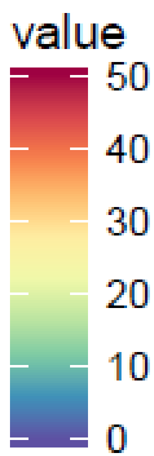


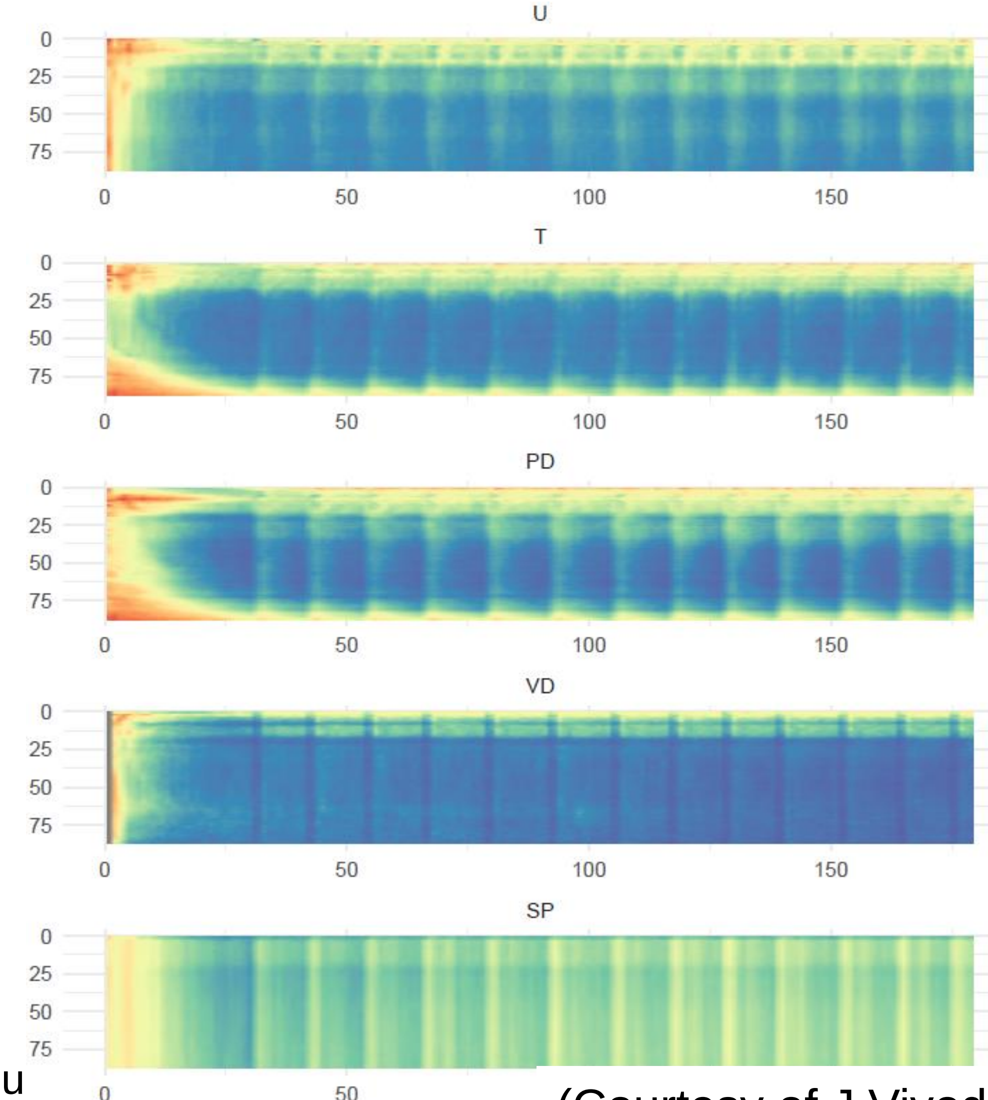
(Courtesy of J.Vivoda)

Experiments on small domain

Collect globally information on the usage of NESC; if NESC applied in less then 10% of grid points, skip corrector.

Number of points with NESC calculation:



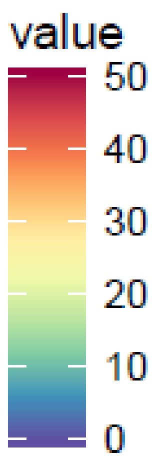


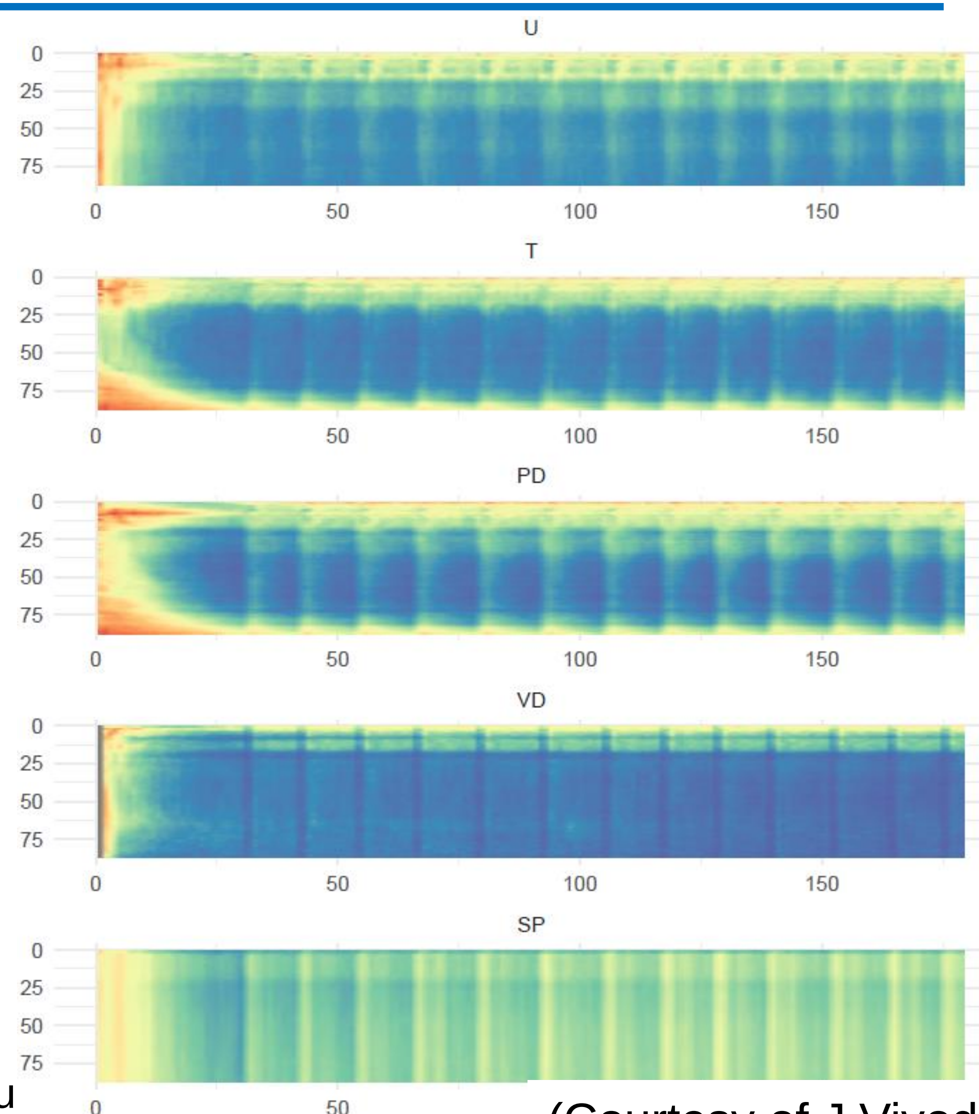
(Courtesy of J.Vivoda)

Experiments on small domain

Hence corrector is applied only once per several time steps.

The accuracy and stability is restored.





(Courtesy of J.Vivoda)

Dynamic definition of the time scheme

Conclusions:

- SETTLS scheme is enabled in predictor step of the PC scheme (For LPC_CHEAP as well).
- Dynamic choice of the predictor used (SETTLS/NESC) and of the number of correctors applied may be an efficient answer to stability/accuracy trade-off.
- When using dynamic definition of the time scheme we are not able to predict exactly in advance the time to results, some threshhold may be established.

Finite elements in the vertical in NH (Jozef Vivoda)

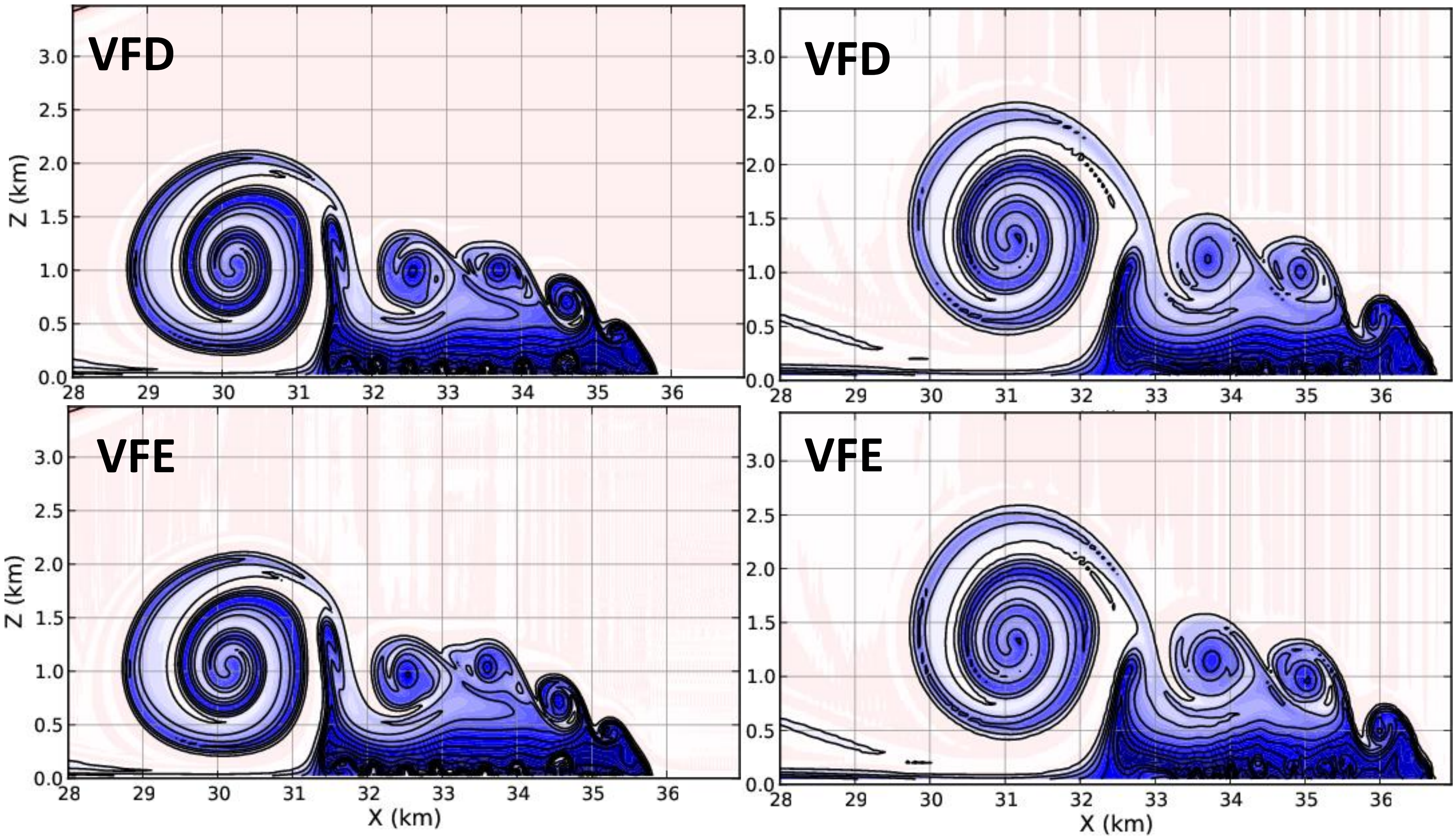
Phased to CY45T1: still many parameters, correct namelist setting needed, as

LVERTFE=.T.
NVFE_TYPE=3
LVFE_FIX_ORDER=.T.
LVFE_DELNHPRE=.T.
LVFE_ECMWF=.F.
LVFE_LAPL=.T.
LVFE_X_TERM=.T.
NVFE_DERBC=2
NVFE_INTBC=2

Finite elements in the vertical in NH

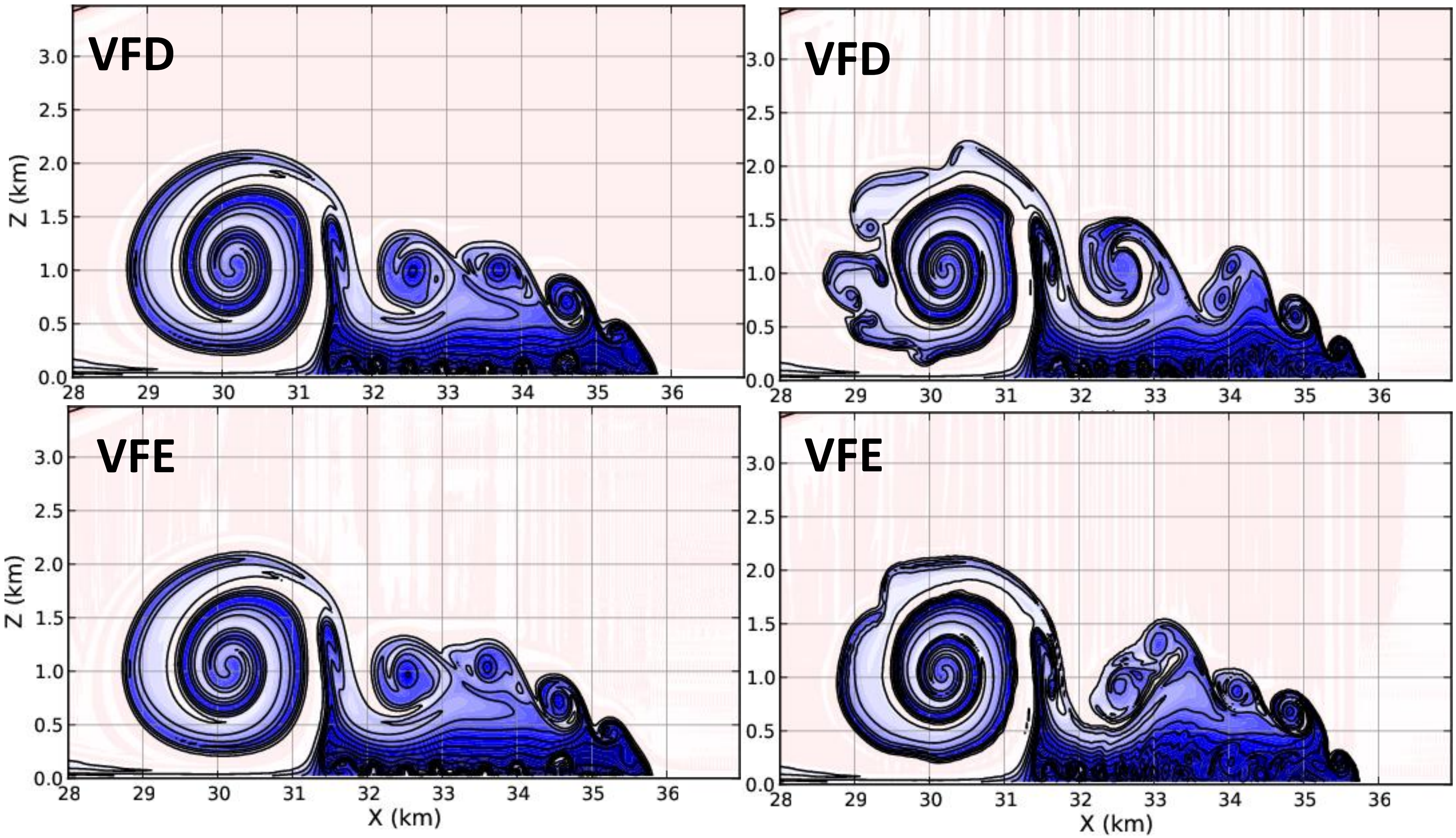
small Δz, short Δt

2x longer Δz



Finite elements in the vertical in NH

small Δz, short Δt | 10x longer Δt



Finite elements in the vertical in NH

Phased to CY45T1:

New calculation of full level A,B through simplyfied process.

We want:

$$\underline{\mathbf{I}_0^1}\cdot\frac{\boldsymbol{\delta A}}{\boldsymbol{\delta\eta}} = 0$$

$$\underline{\mathbf{I}_0^1}\cdot\frac{\boldsymbol{\delta B}}{\boldsymbol{\delta\eta}} = 1$$

We guess:

$$\widehat{\delta A_l} = A_{\tilde{l}} - A_{\widetilde{l-1}}$$

$$\widehat{\delta B_l} = B_{\tilde{l}} - B_{\widetilde{l-1}}$$

We calculate:

$$\frac{1}{p_0}\frac{\delta A_l}{\delta\eta_l}+1 = \frac{1}{\beta}\left(\frac{1}{p_0}\frac{\widehat{\delta A_l}}{\delta\eta_l}+1\right)$$

$$\delta B_l = \frac{\widehat{\delta B_l}}{\underline{\mathbf{I}_0^1}\cdot\widehat{\frac{\boldsymbol{\delta B}}{\boldsymbol{\delta\eta}}}}$$

$$\underline{\mathbf{I}_0^\eta}\cdot\frac{\boldsymbol{\delta A}}{\boldsymbol{\delta\eta}} = \boldsymbol{A}$$

$$\underline{\mathbf{I}_0^\eta}\cdot\frac{\boldsymbol{\delta B}}{\boldsymbol{\delta\eta}} = \boldsymbol{B}$$

Finite elements in the vertical in NH

Phased to CY45T1:

New idea of Fabrice Voitus **for the Helmholtz solver** – we may eliminate all the variables but D (horizontal divergence) and **get rid of the iterative process** used up to now.

$$\begin{pmatrix} \underline{\mathbf{E}} & -\underline{\mathbf{F}} \\ -\underline{\mathbf{B}} & \underline{\mathbf{A}}+\underline{\mathbf{C}} \end{pmatrix} \begin{pmatrix} d \\ D \end{pmatrix} = \begin{pmatrix} R_d \\ R_D \end{pmatrix}$$

$$\left(\underline{\mathbf{BE}}^{-1}\underline{\mathbf{F}}+\underline{\mathbf{A}}+\underline{\mathbf{C}}\right) D = R_D + \underline{\mathbf{BE}}^{-1} R_d$$

May be solved directly even if C≠0.

The trajectory search in the SL advection scheme

- PC scheme with reiteration of SL trajectories produces noisy solution in some cases.
- If model horizontal resolution increased => local divergence may increase => Lipschwitz criteria may be broken locally => divergent algorithm for searching SL origin point => increase in the number of iterations may lead to even less accurate solutions.
- Similar problems have been identified at ECMWF in IFS and fixed by local change of the computation of the half level wind.

The trajectory search in the SL advection scheme

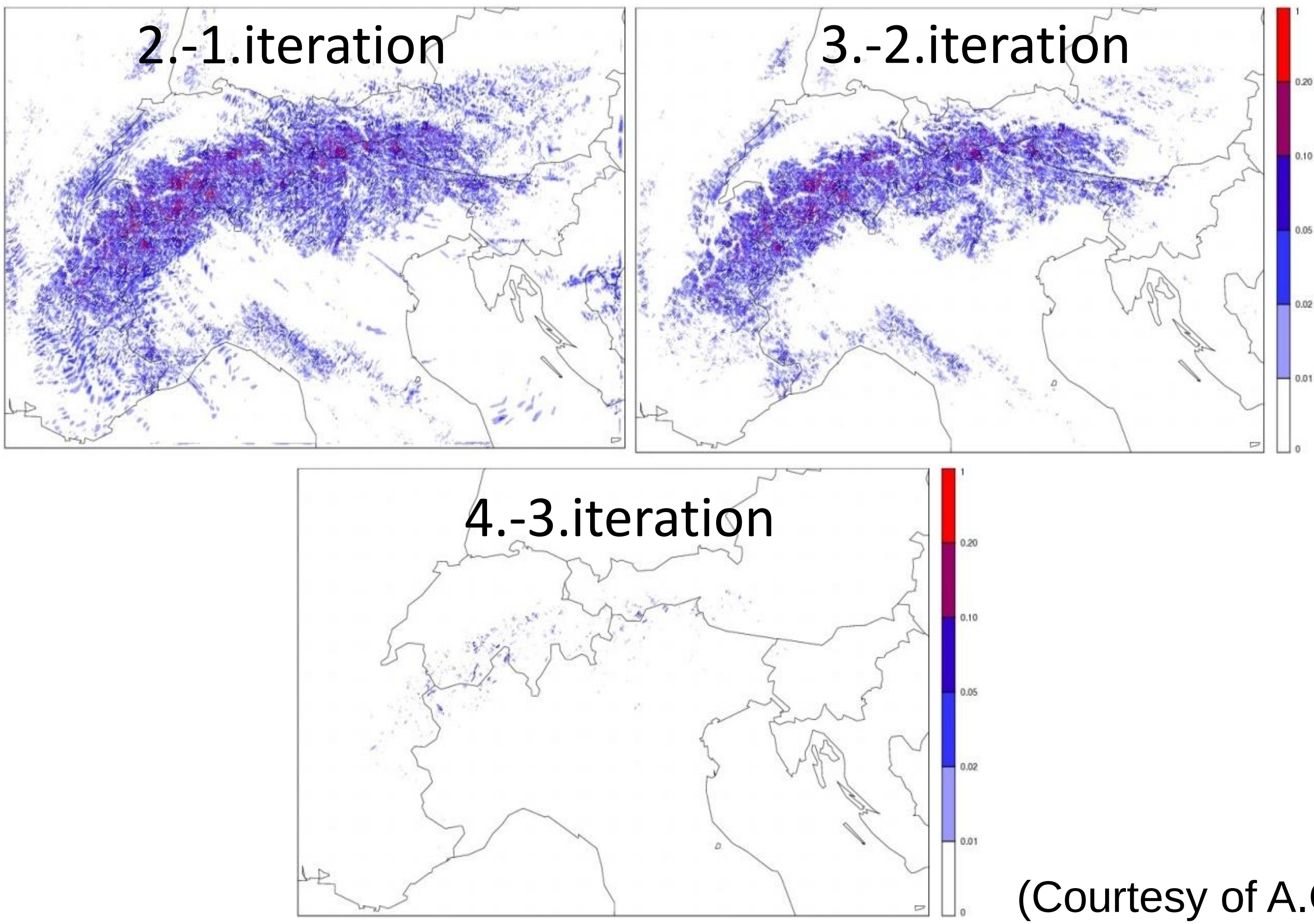
Current work:

- to calculate distances between two points representing estimations of the origin point from two successive iterations
- applied separately for horizontal and vertical components
- applied on several real cases

Conclusions:

- Second iteration already very close to the first one.
- Depending on the criteria we may find some divergent grid points, but the origin points are not moved by more then dms.
- More systematic testing on longer period is needed.

The trajectory search in the SL advection scheme



(Courtesy of A.Craciun)


© Curiosity Escapes
JE VOUDRAIS VOUS REMERCIER POUR VOTRE ATTENTION!