Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

LACE : News in dynamics 2017

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thanks to Alexandra Craciun, Jozef Vivoda and other colleagues

DHMZ ZAMG ROMANIA ANM

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 for one prognostic variable, 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. **Dynamic definition of the time scheme**

   (Jozef Vivoda, SHMU)

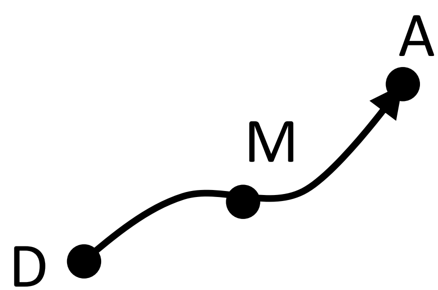
2. **The trajectory search in the SL advection scheme**

   (Alexandra Craciun, Meteo Romania)

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	–

Dynamic definition of the time scheme

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

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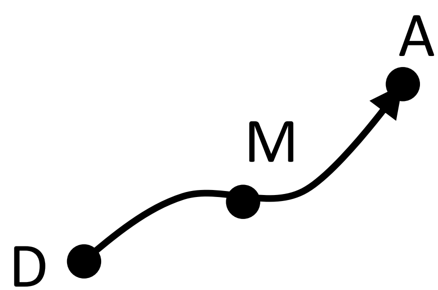


t+ Δt	+
t+ $\frac{\Delta t}{2}$	m
t	0
t -Δt	–

available information (t, t -Δt)

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

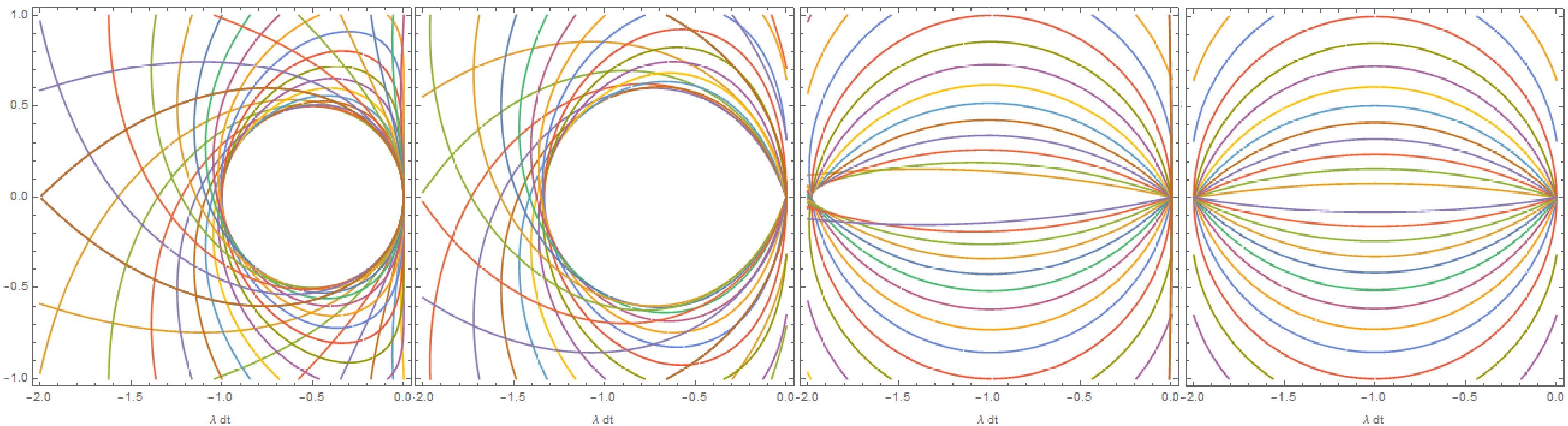
and analyse single Fourier component advected with a constant wind U

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

Stability reached when A ≤ 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

Semi-implicit scheme:

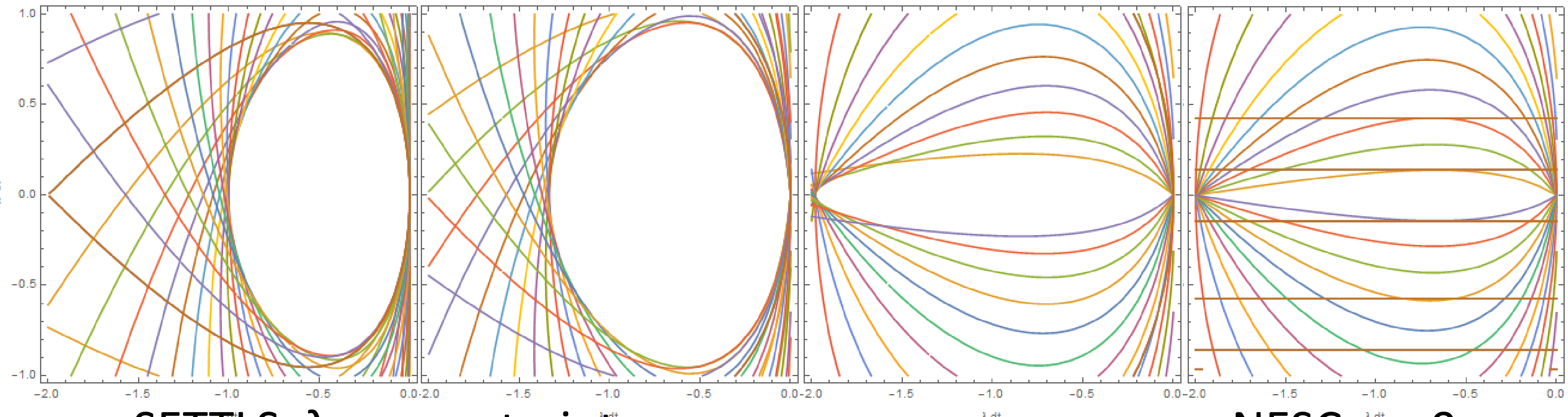
$$\frac{df(t,x)}{dt} = N(t,x) + L(t,x)$$

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

Stability analysis for solution

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

β = 1 | β = 1/2 | β = 1/100 | β = 0



SETTLS: λ, ω constraints

NESC: ω=0

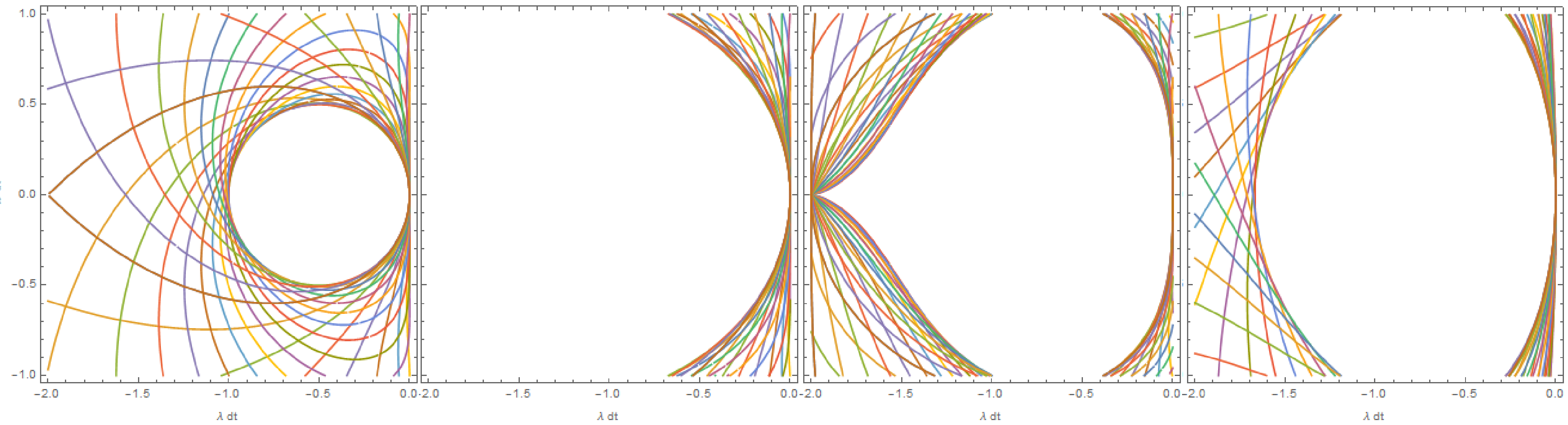
(Courtesy of J.Vivoda)

Dynamic definition of the time scheme

Using explicit guess: $N_M^m = a_1 N_A^0 + a_2 \widetilde{N_A^+} + a_3 N_D^0 + a_4 N_D^-$

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

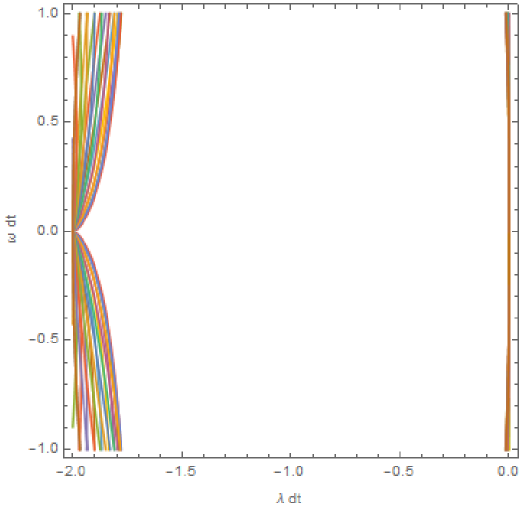
Predictor step using combined scheme:

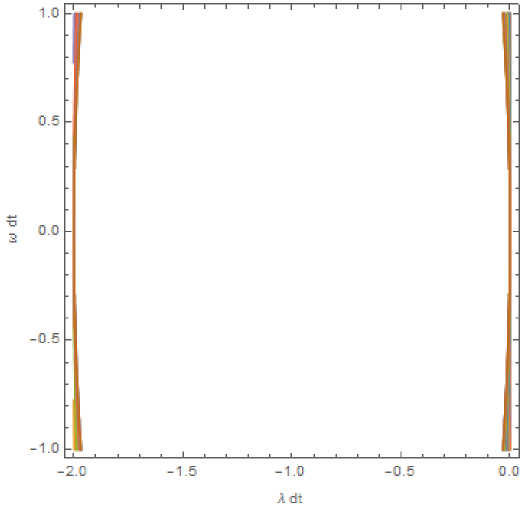
$$\frac{f_A^{+(0)} - f_D^0}{\Delta t} = \frac{1}{2}(N_A^0 + N_D^0) + \frac{\beta}{2}(N_D^0 - N_D^-) + \frac{1}{2}(L_A^{+(0)} + L_D^0)$$

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 NESC/SETTLS used

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

From experience:

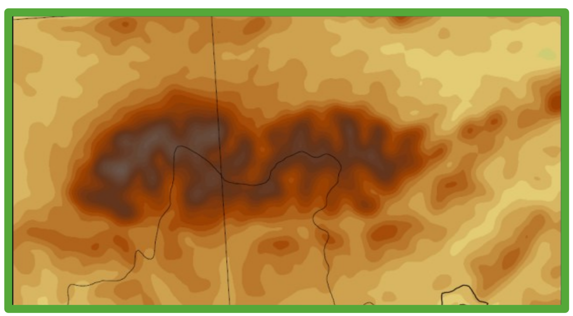
1) SETTLS beneficial for trajectory search
2) Instability may occur when SETTLS applied on non-linear residuum, while NESC is stable (and only first order accurate)

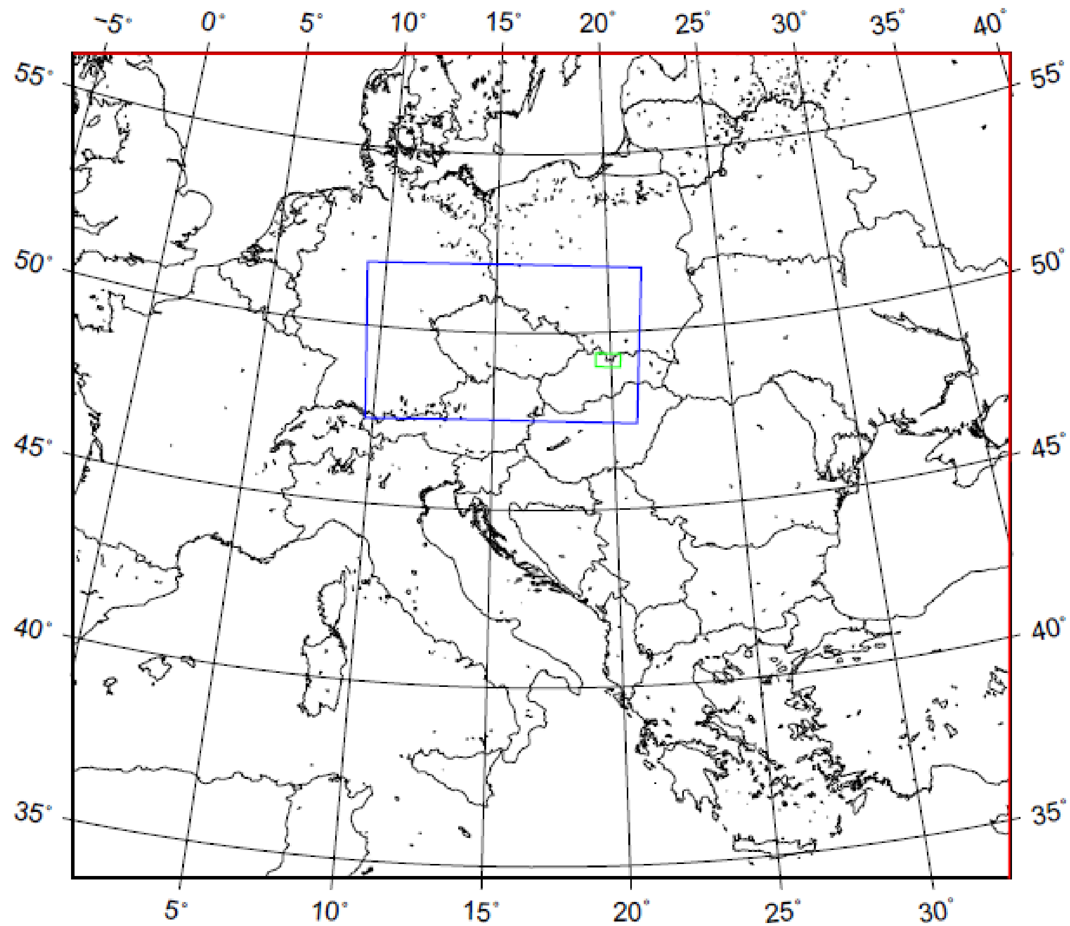
The idea: To use SETTLS whenever possible, and switch to NESC if needed. If it si not “very often”, we keep sufficient accuracy and restore stability.

Dynamic definition of the time scheme

Experiments

on a small domain





(Courtesy of J.Vivoda)

Experiments on small domain

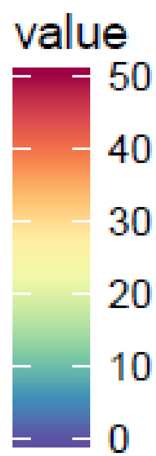
PC with one iteration:

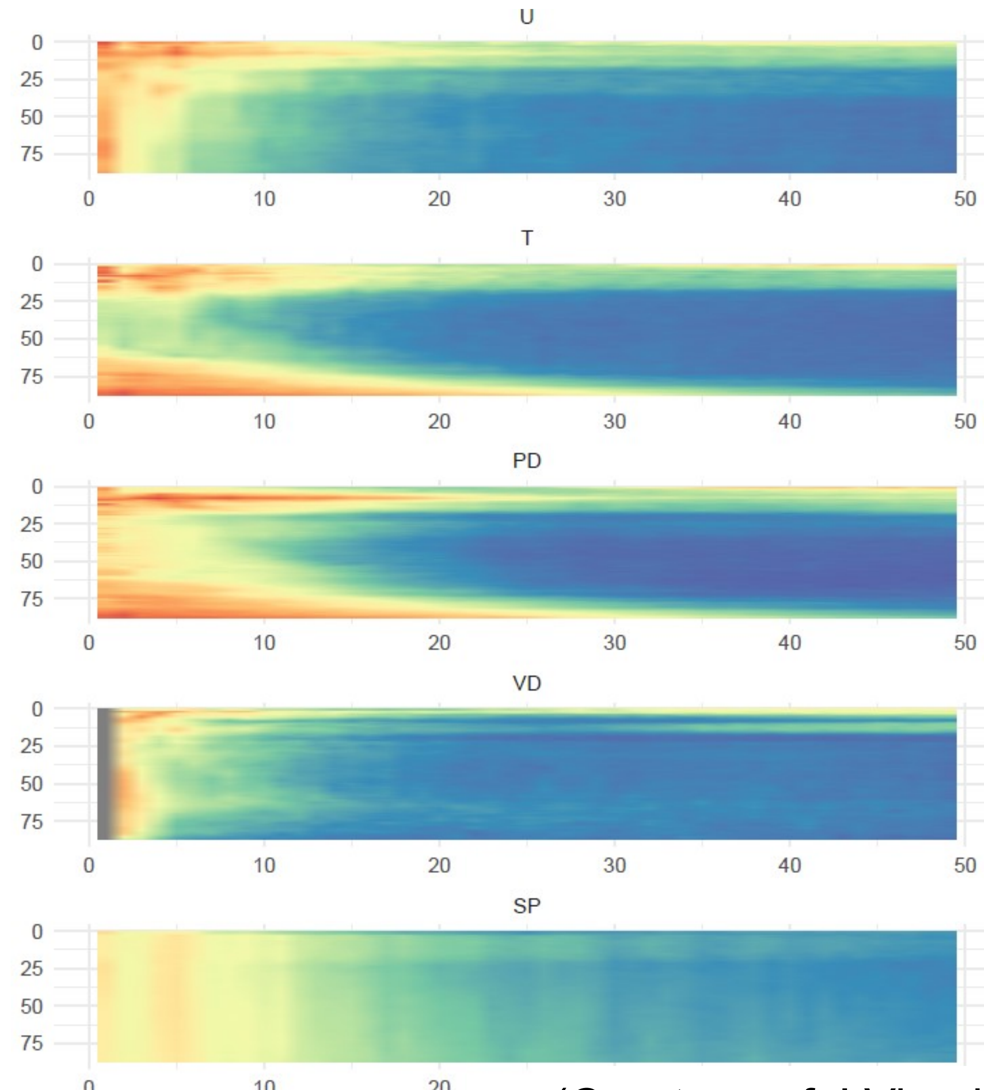
$$\mu = 1 - \frac{|N^0 - N^-|}{|N^0| + |N^-|}$$

for pressure departure*.

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

Number of points with NESC calculation:





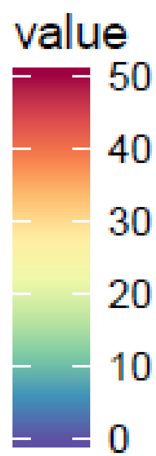
(*adopted from M.Diamantakis, LSETTLSVF option)

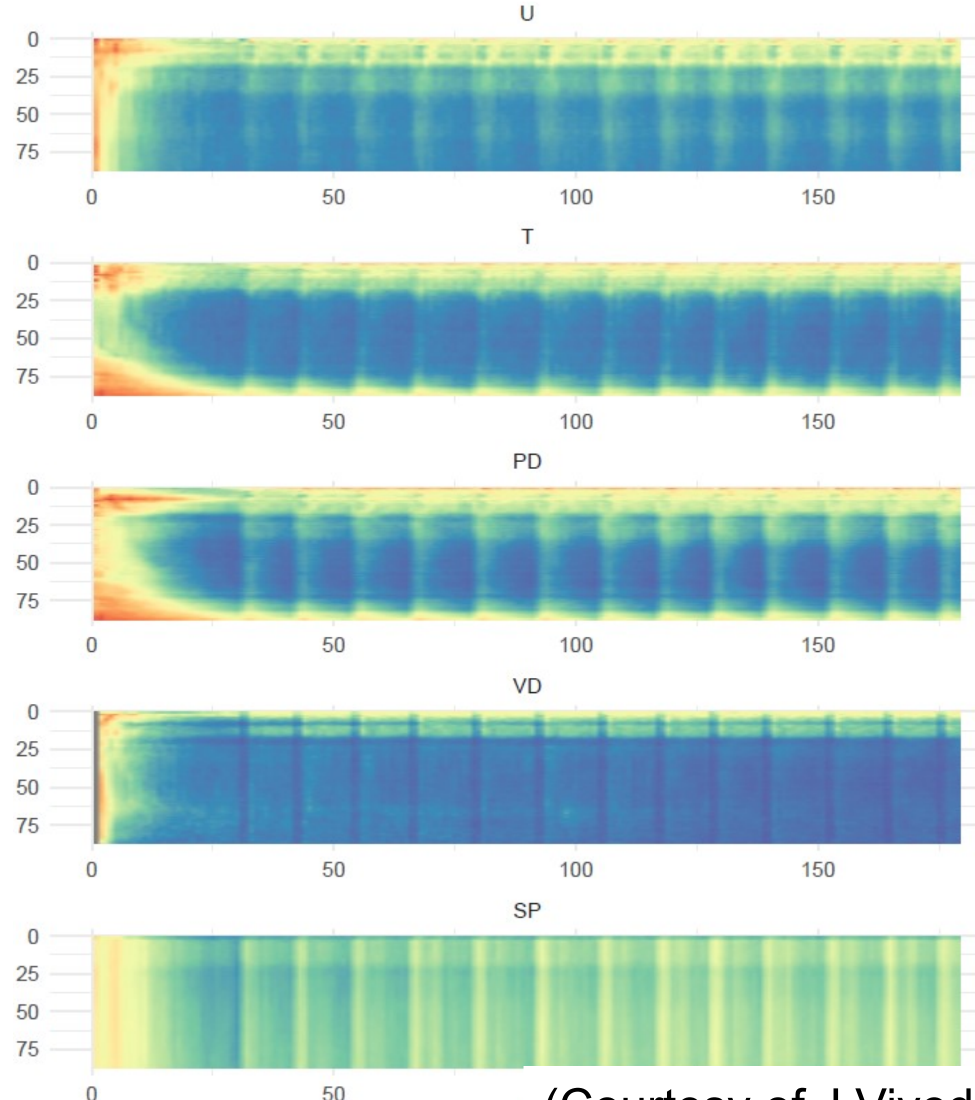
(Courtesy of J.Vivoda)

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:



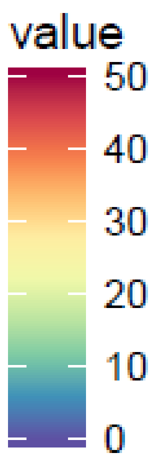


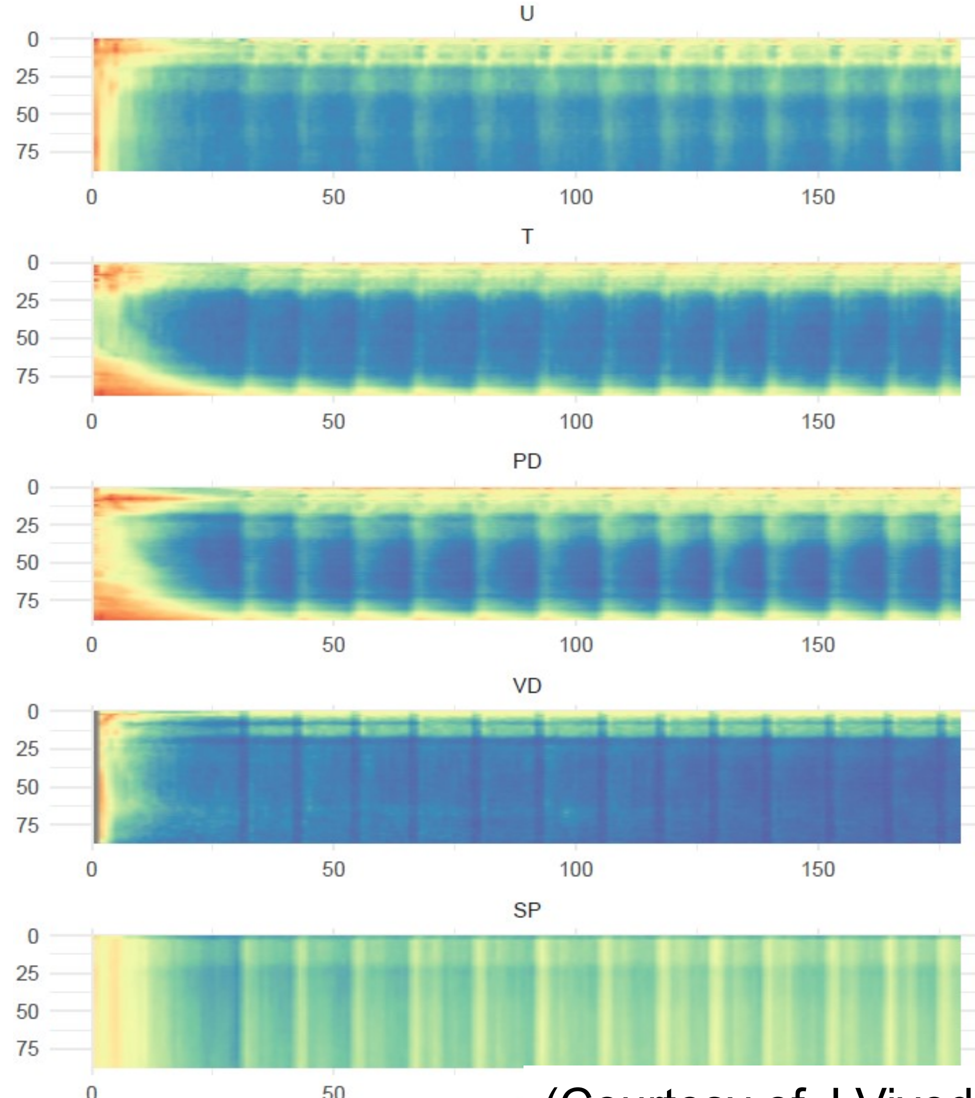
(Courtesy of J.Vivoda)

Experiments on small domain

Hence corrector is not applied in all 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/efficiency 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.

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 (M.Diamantakis).

The trajectory search in the SL advection scheme

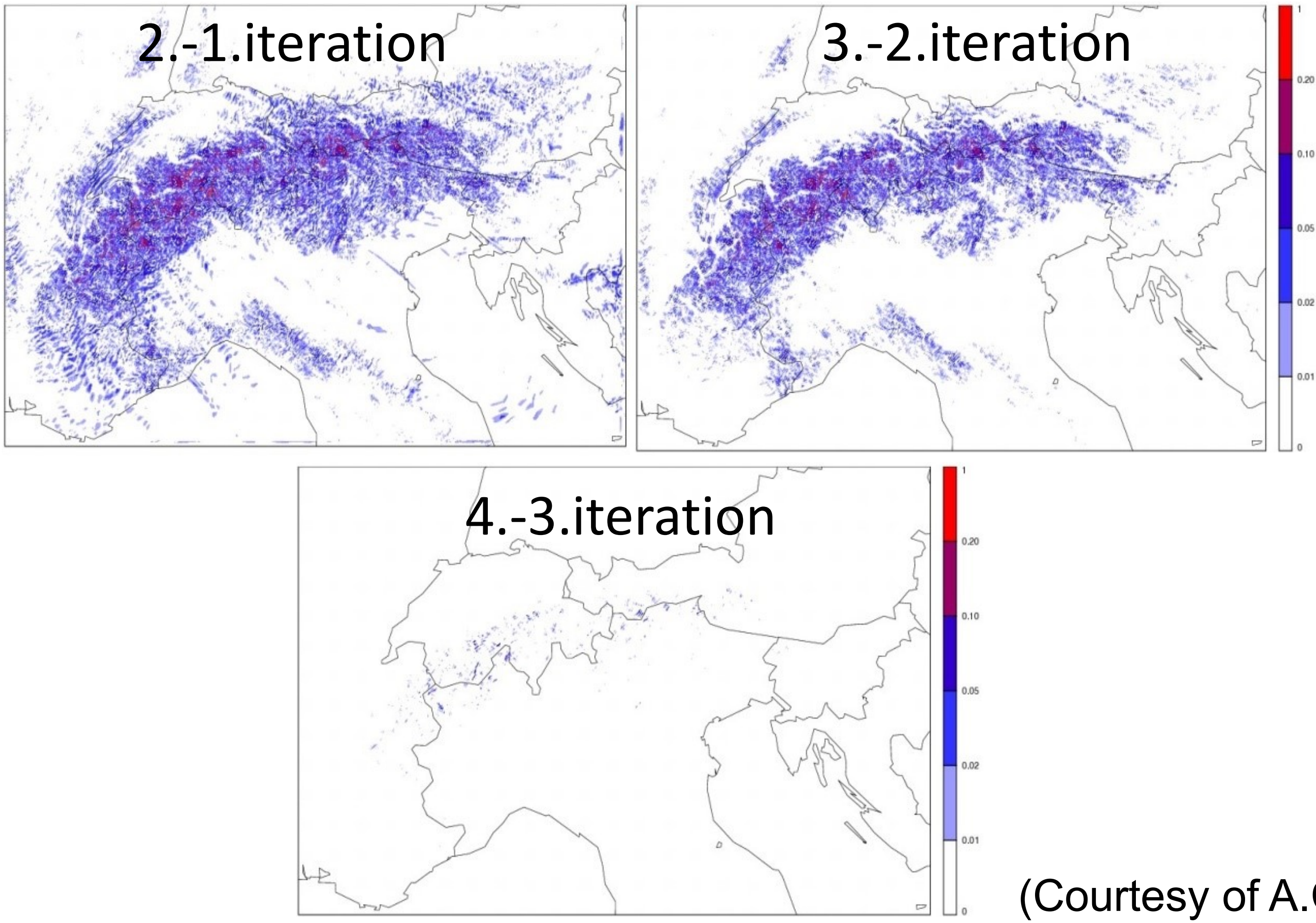
Current work:

- 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)

Thank you for your attention!