RECENT DEVELOPMENTS RELATED TO DYNAMICS IN LACE CONSORTIUM

Petra Smolíková, LACE Area Leader for Dynamics&Coupling

Thanks to Filip Váňa (CHMI), Jozef Vivoda (SHMI), Gergely Bölöni (OMSZ), Ján Mašek (CHMI), Balasz Szintai (OMSZ), Martina Tudor (DHMZ)

Topics being solved:

- Physics-dynamics interface based on SETTLS
- Vertical finite elements for NH dynamics (J.Vivoda,Sk)
- ALADIN NH in high resolutions (F.Váňa,Cz)
- Impact of horizontal diffusion (SLHD) in AROME (B.Szintai,Hu)

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- Coupling strategy with regard to rapid changes in surface pressure field (M.Tudor, Cr)

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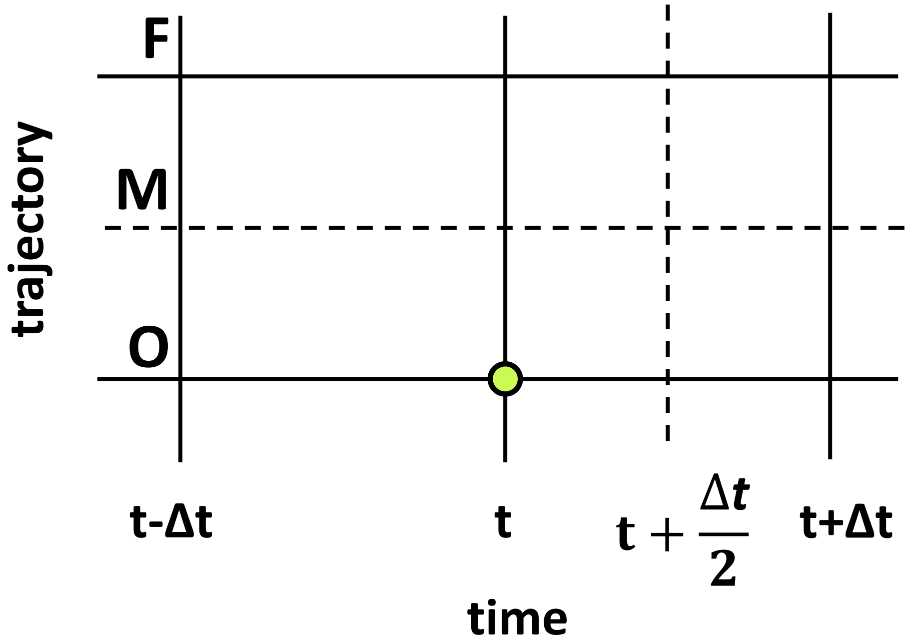
Currently in ALADIN/AA:

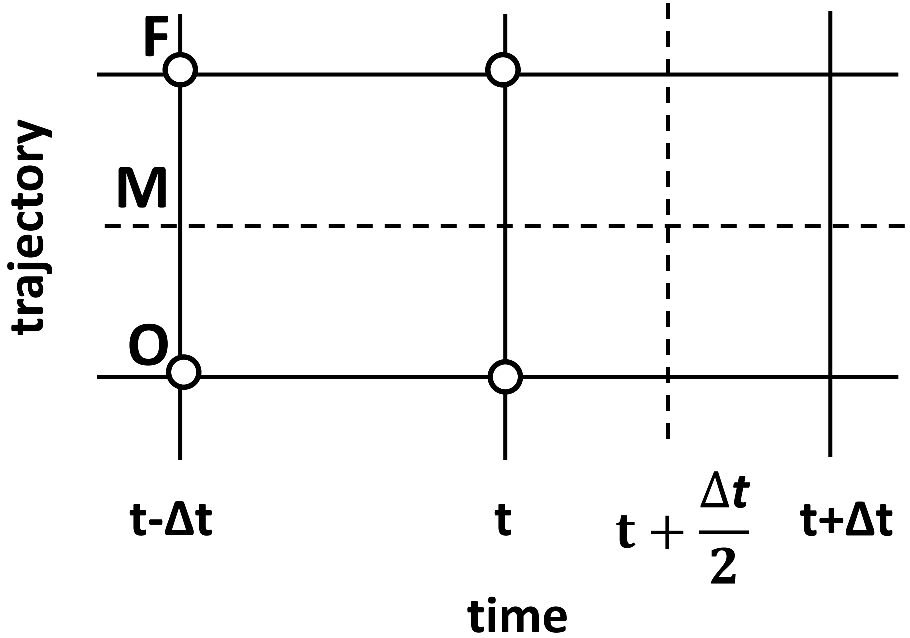
first-order in time accurate, explicit $X_F^+ = \cdots + \Delta t \cdot P_O^0$



Available information: P_O^- , P_O^0 , P_F^-, P_F^0

Second-order in time accuracy for

$$\left(\frac{3}{4}-\alpha\right)P_F^0+\left(\frac{3}{4}+\alpha\right)P_O^0-\left(\frac{1}{4}-\alpha\right)P_F^--\left(\frac{1}{4}+\alpha\right)P_O^-$$

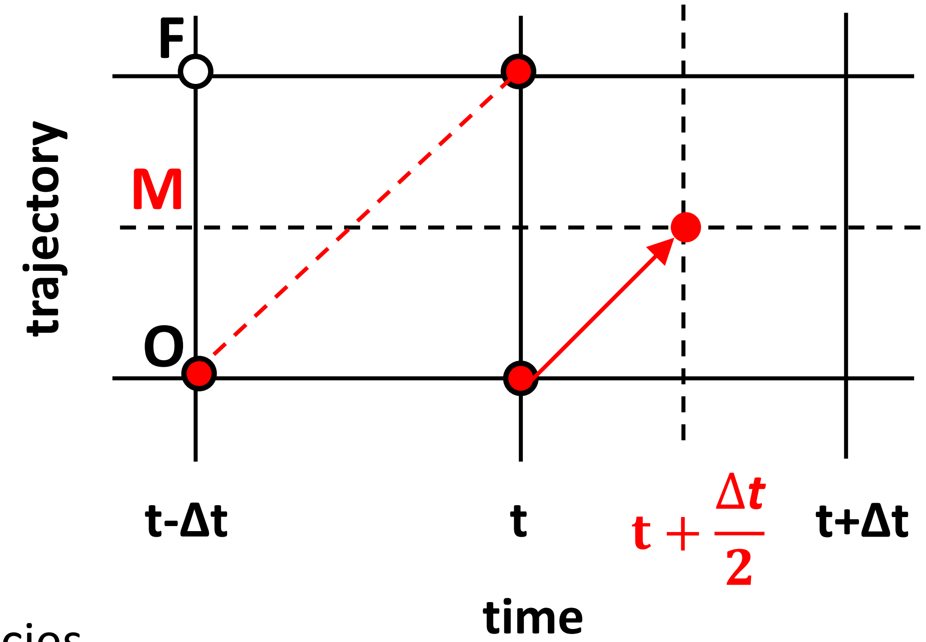


Most stable for : $\alpha = \frac{1}{4}$ (I.Gospodinov, V.Spiridonov, J.-F.Geleyn, 2001)

corresponds to **SETTLS** discretization

(M.Hortal, 2001)

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



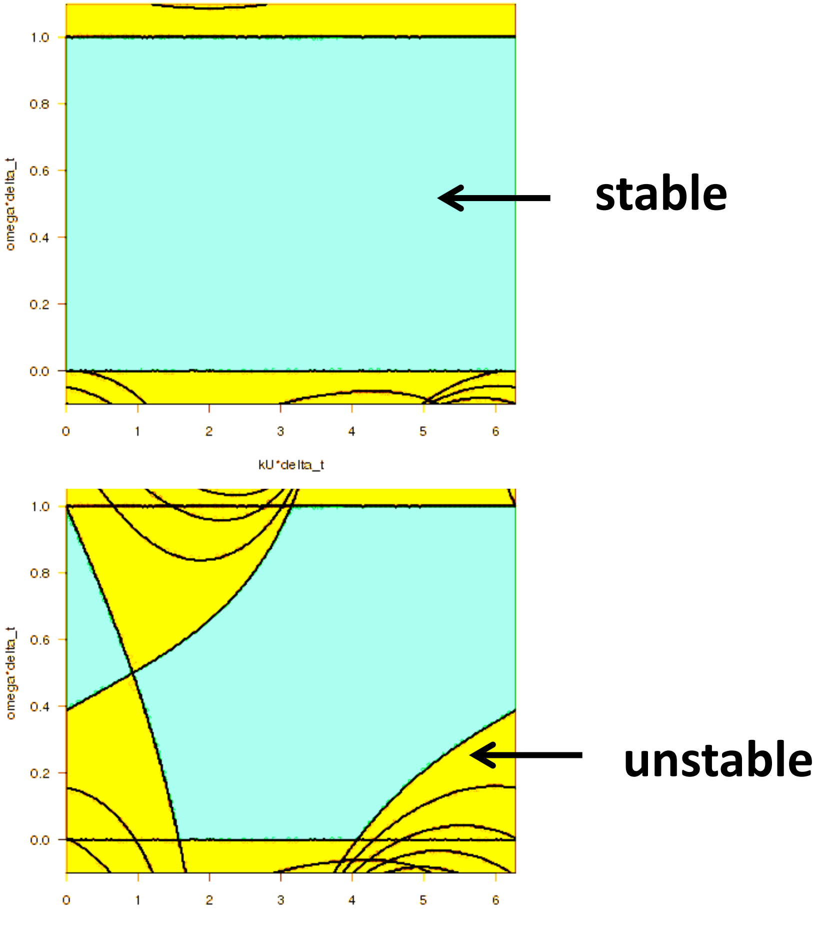
- used for non-linear terms
- we shall use it for physical tendencies

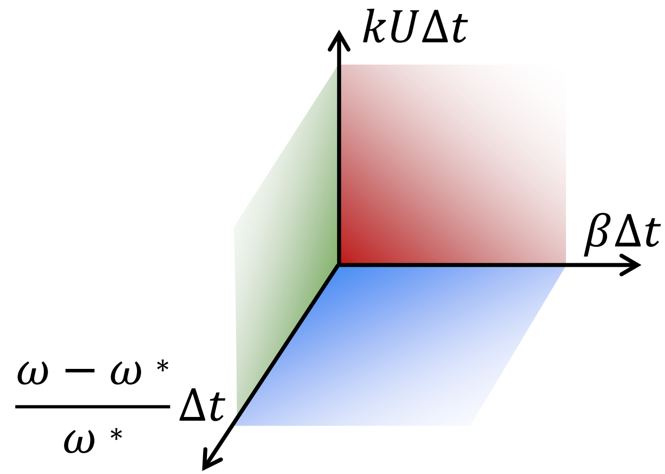
PHYSICS DYNAMICS INTERFACE

Stability: a damping physical parameterization process (β), an oscillatory dynamical process (ω), a constant advecting velocity *U*, linear terms treated SI (ω^*)

EXPLICIT

SETTLSP





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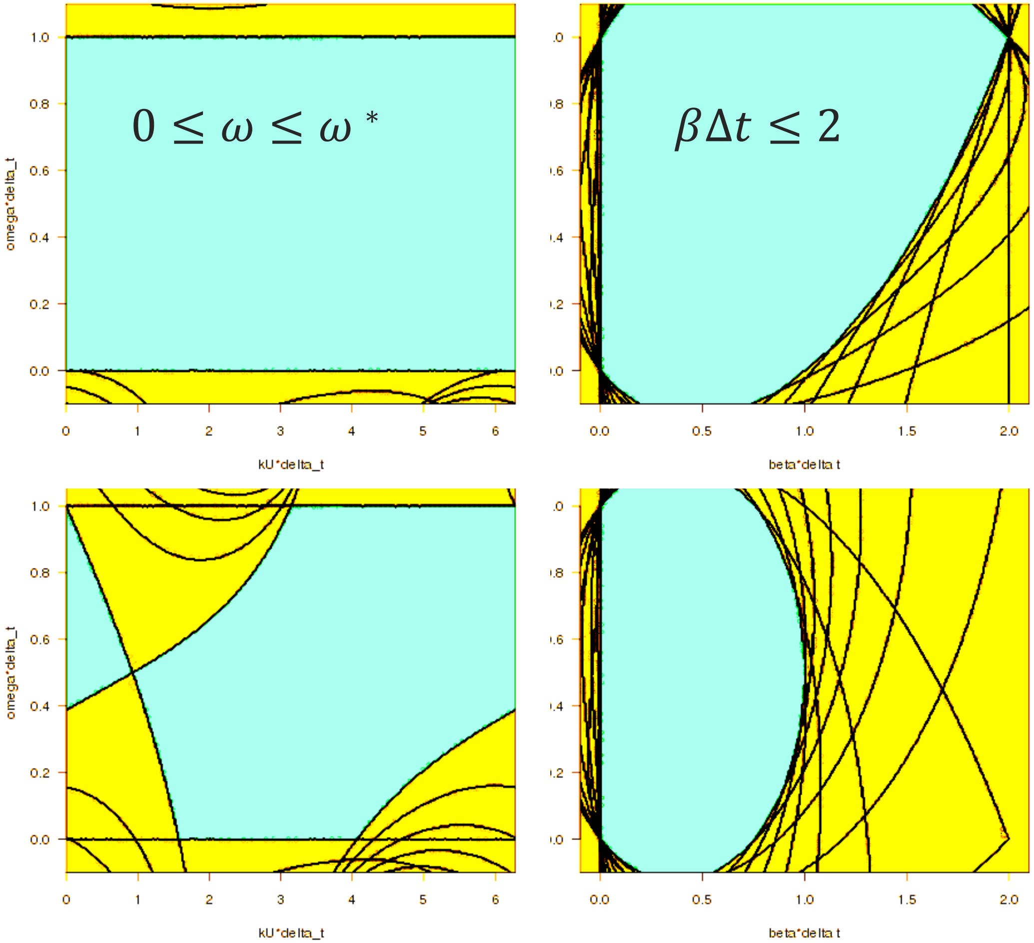

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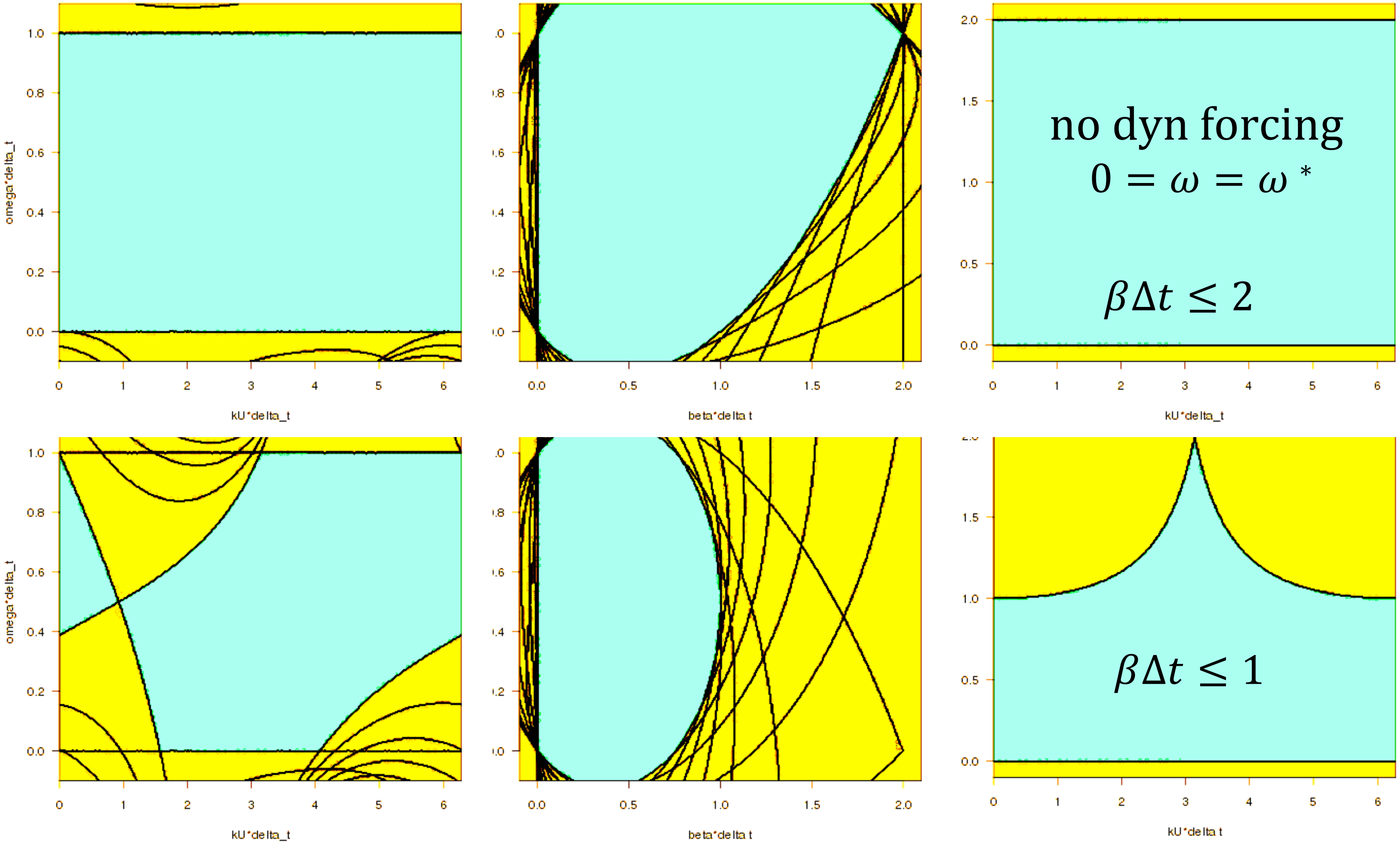

- implemented in CY36t1 of ALARO
- experiments with the operational settings (Cz 4,7km, 87 vertical levels, 2TL SI-SL HYD, Δt=180s):

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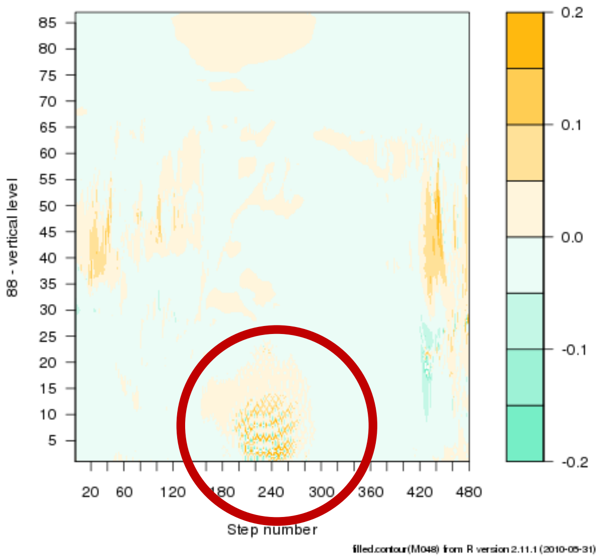
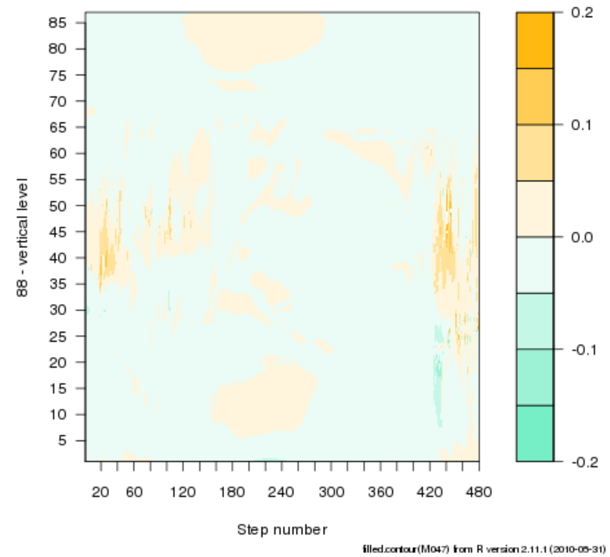
- experiments with the operational settings (Cz 4,7km, 87 vertical levels, 2TL SI-SL HYD, Δt=180s):

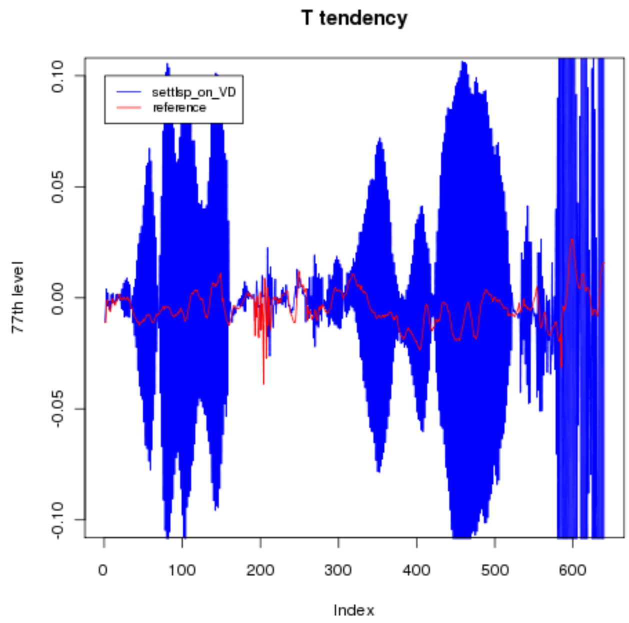
⇨ problems with vertical diffusion parameterization

⇨ removal of VD from SETTLS type phys-dyn coupling

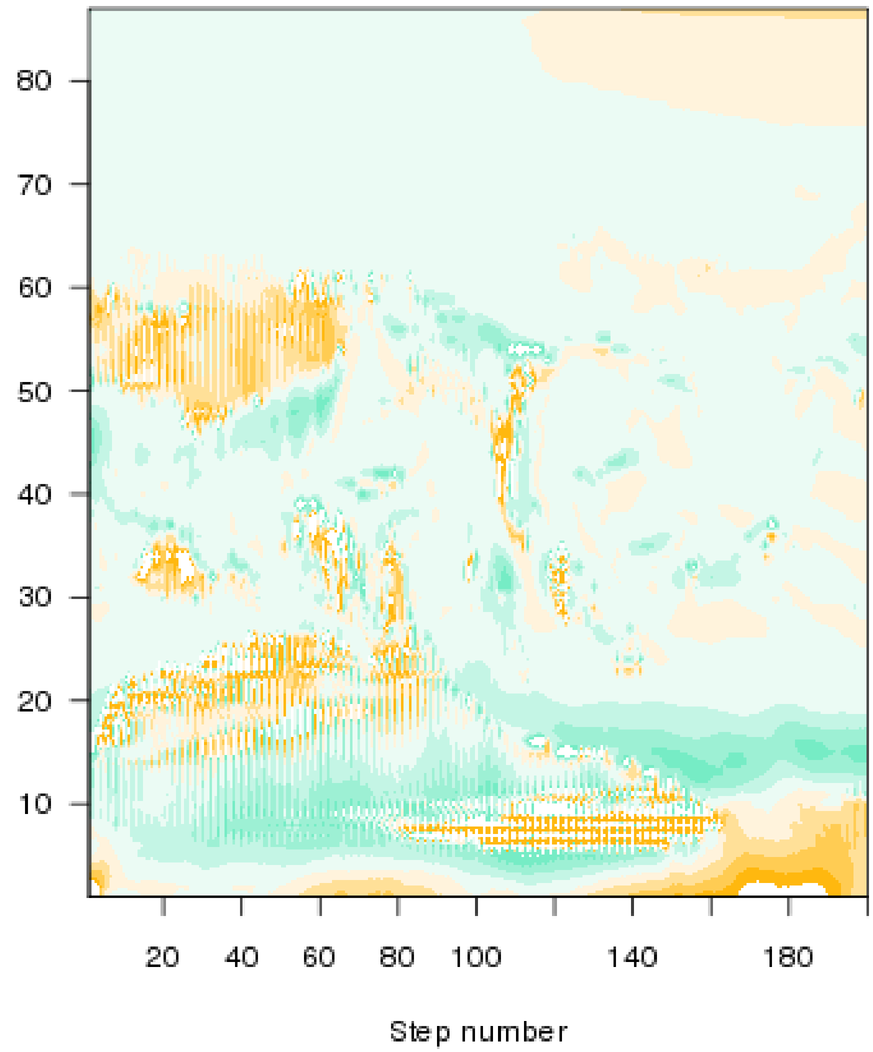
⇨ elimination of some noise near the surface





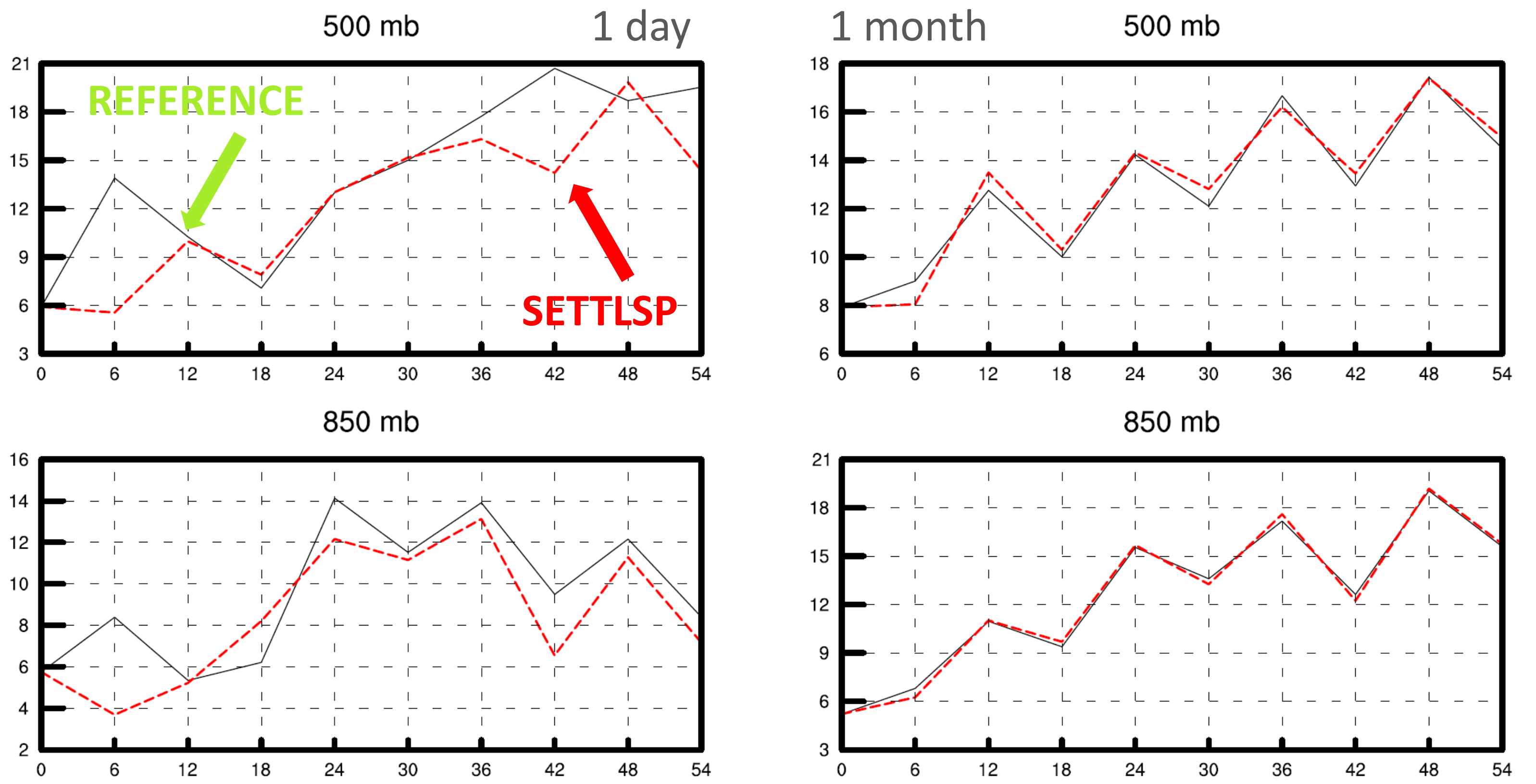


Time evolution of *phys(T)* in a single point: $2\Delta t$ oscillations (not restricted to lowest level only)

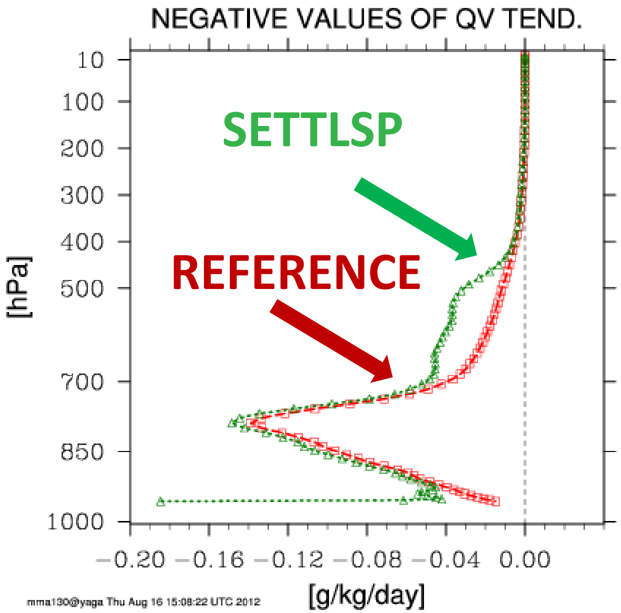


T on the lowest model level, the difference SETTLSP – REF; after 32 hours

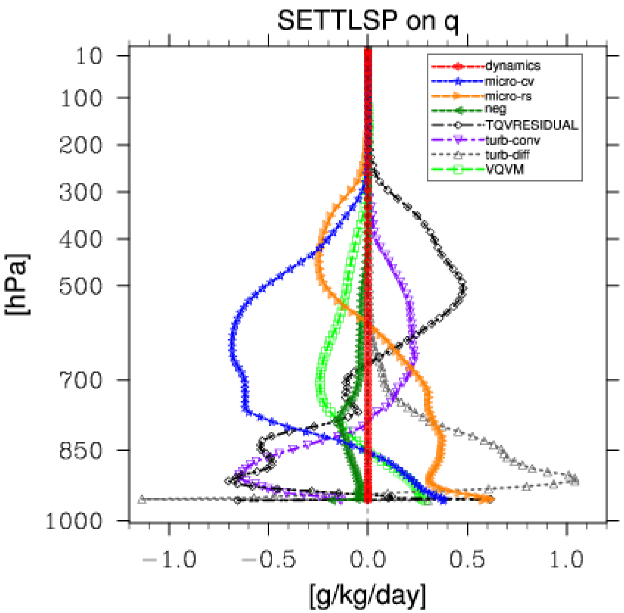
Applied on GMV (*u*, *v*, *T*) variables only: **similar accuracy**
(verification of the geopotential scores (STDE))



M.Hortal: More negative values of q_v are created using SETTLSP



DDH : negative values of q_v



and all tendencies

But:

- negative values are created by advection as well
- standard procedure to get rid of it
- their values are of similar or smaller magnitude then for other tendencies

SETTLS in physical tendencies coupling

- applied on all advected variables ⇒ time oscillations, poor stability
- 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

Vertical Finite Elements in Non Hydrostatic system

– implemented successfully in hydrostatic IFS (A.Untch, M.Hortal, 2003)
– in NH studied since 2004 (P.Bénard, J.Vivoda and others)
– as close to HYD VFE as possible (basis functions, vertical integral operators)
– two times higher accuracy then VFD on the same stencil (cubic B-splines)
– more accurate vertical velocities for SL scheme

Previous work:
P.Bénard – compatibility with existing model choices
J.Vivoda – stability analysis for linear model, “draft” implementation to ALADIN, stuck on problems (instability appeared when using dense NWP like vertical level distribution, iterative solver in spectral space)
cooperation with J.Simarro (HIRLAM)

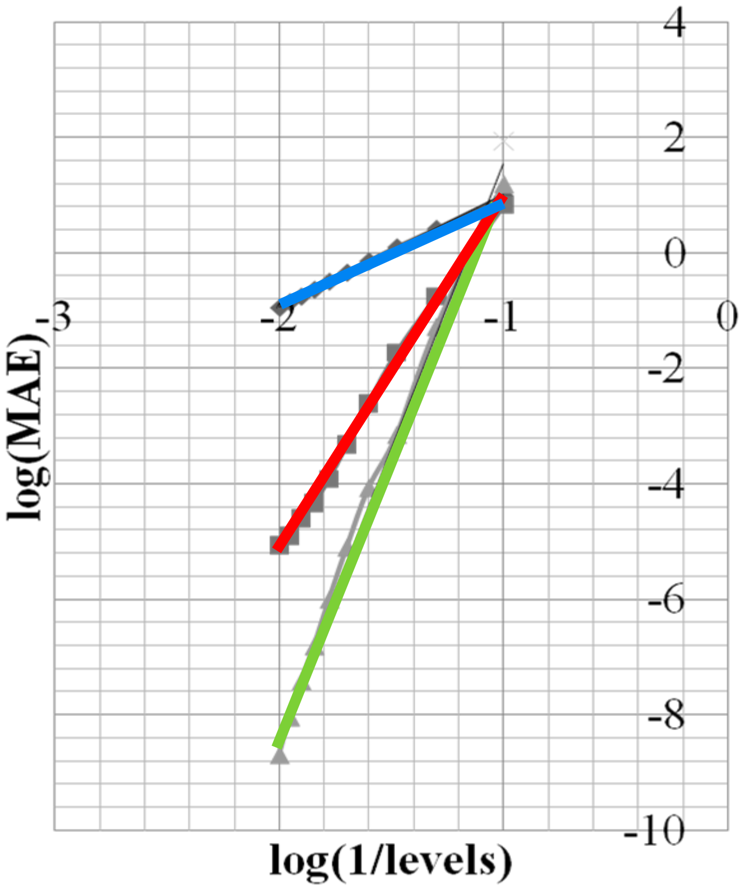
Starting point – Untch and Hortal,2003

– basis functions – cubic B-splines with compact support
– no staggering – all variables are defined on model full levels
– only integration/derivation is performed in FE space, products of variables done in physical space

Towards NH

– vertical integral and derivative operators (vertical Laplacian)
– not satisfied (C1), (C2) constraints for integral operators
– requires definition of derivatives of A and B functions on full levels (for vertical coordinate η definition)

log, log diagram of MAE of discretization of Laplacian of function f=sin(6η)



FD 2nd order accurate

FE with 4th order spline
4-5th order of accuracy

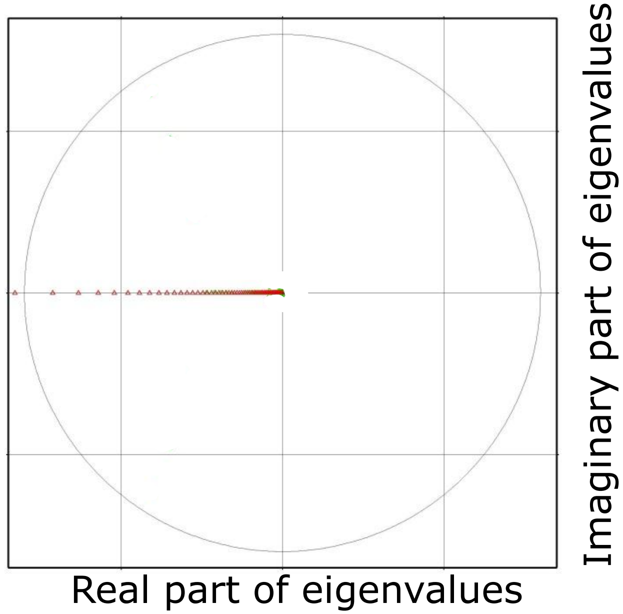
FE with 8th order spline
9-10th order of accuracy

Laplacian formulation (eigenvalues of Laplacian in complex plain)

- inner domain formulation

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

- due to stability conditions the FD formulation BCs are kept



Eigenvalues of Laplacian operator (red dots) are pure real and negative – condition for stability of SI time stepping without nonlinear residual

$$(I - \tau L)X^{t+dt} = (I + \tau L)X^{t}$$

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

$\Longrightarrow$ algebraic elimination of all variables but one (*d*) not possible to get Helmholtz equation

The implicit problem

– linear inversion
– formulated for a couple of variables (*d*,*D*)
– a system of 2L equations solved in spectral space (2x larger, performed once in setup) – not feasible for horizontally varying map factor (LESIDG)
– stationary iterative method used (predictor with (C1) satisfied + corrector)
– convergence ?

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

– $\mathbb{T}$ is not tridiagonal as for FD (nor identity as for continuous case)

Main findings:

1. **Knots positions** are crucial for stability

- regular distribution is not sufficient for stability
- the same findings done by J.Simmaro
- experimental study of optimum positioning
  (looking for needle in pile of hay)
- experiments are computed with following definition of eta level distribution (**α** represents the "density" of eta levels close to boundaries)
- full level eta coordinates computed as average from half levels
- knots positions are identical to full level eta except that two levels closest to boundary are skipped

$$\sigma_i = \frac{i}{L} \qquad \beta = 3(1-\alpha) \qquad \eta_l = \sigma_i\left(\alpha + \sigma_i\left(\beta + \sigma_i\left(1-\alpha-\beta\right)\right)\right)$$

VFE IN NH (AFTER J.VIVODA)

$\alpha = 1$

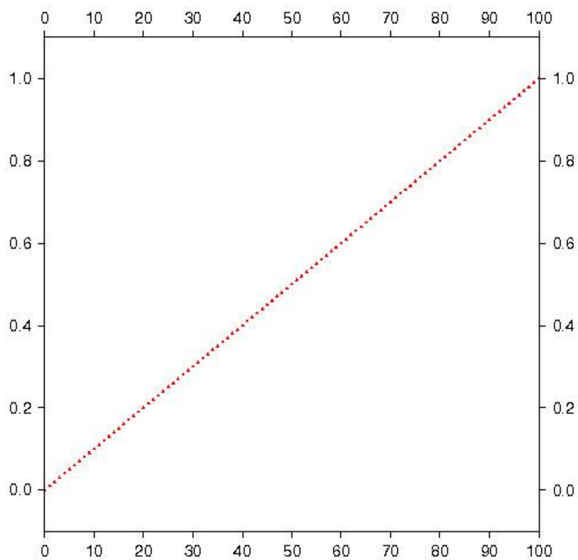
regular eta levels distribution

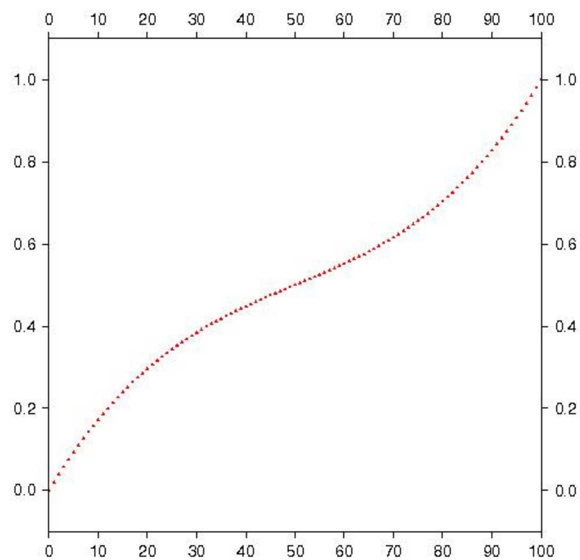
$\alpha = 2$

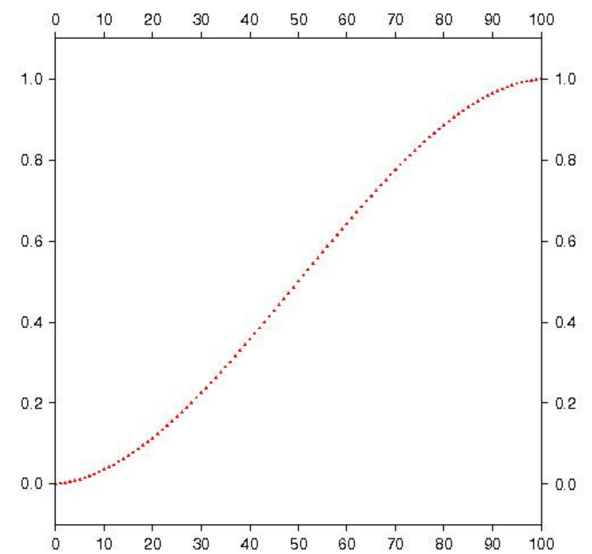
eta levels dense in the middle

$\alpha = 0.5$

eta levels dense close to boundaries







Vertical hybrid functions (*b* parameter determined from conditions that *A>0* and *B* is monotonous):

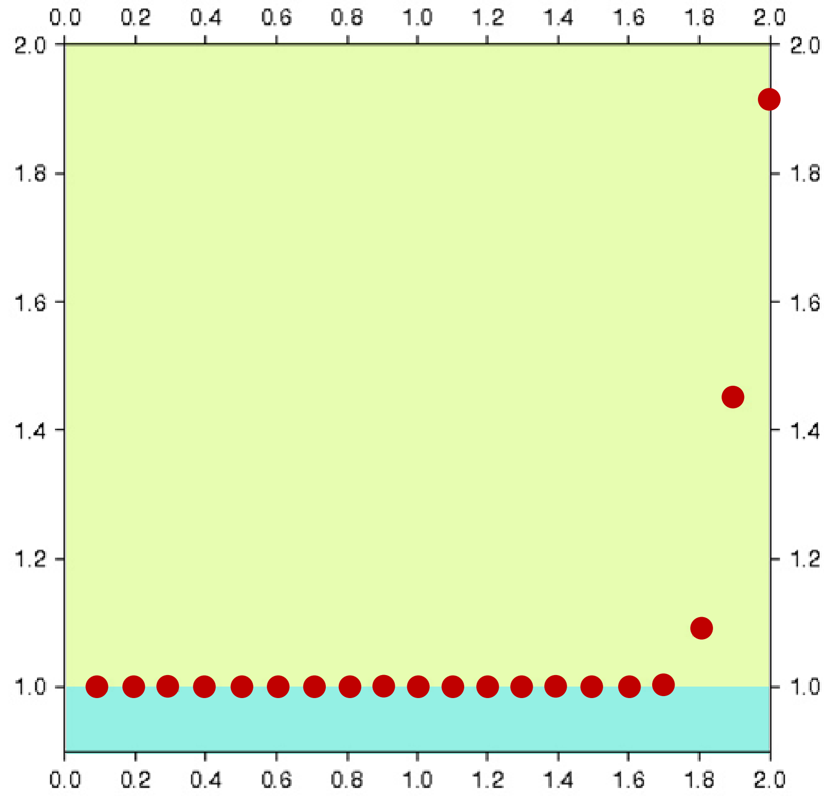
$$B_i = b\eta^2 + (1-b)\eta^3$$

$$A_i = \eta - B_i$$

Stability of SI time stepping without NL residual

$$(I-\tau L)X^{t+dt}=(I+\tau L)X^{t}$$

stability factor



α

Main findings:

2. Stability analysis of VFE method

- developed in Mathematica
- stability factor (eigenvalues of operators) in dependence of breakpoints (knots) position
- minimum levels to express discretisation of model is 5
- simplified, symmetrized positions of knots

Conclusion: **NOT TRACTABLE**

Main findings:

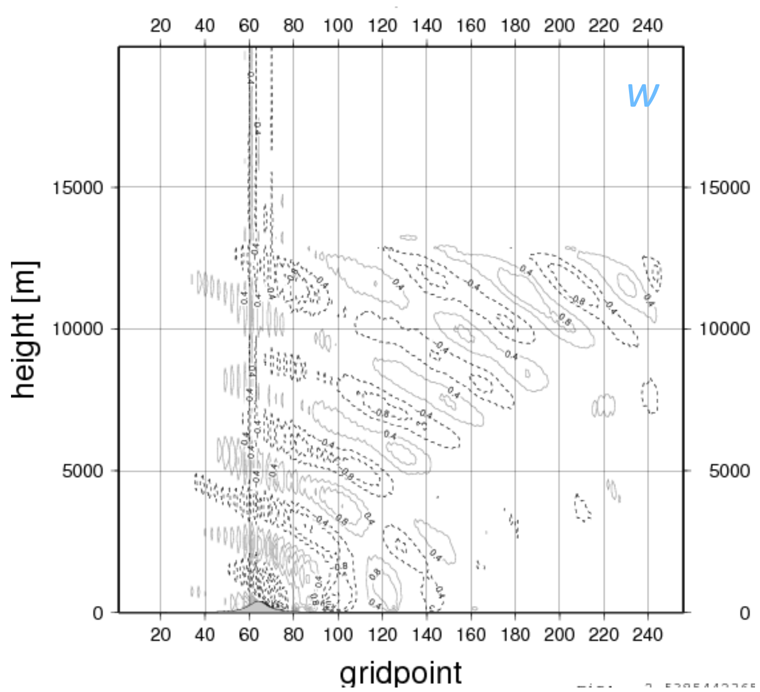
3. A stable configuration can be achieved (2D tests)

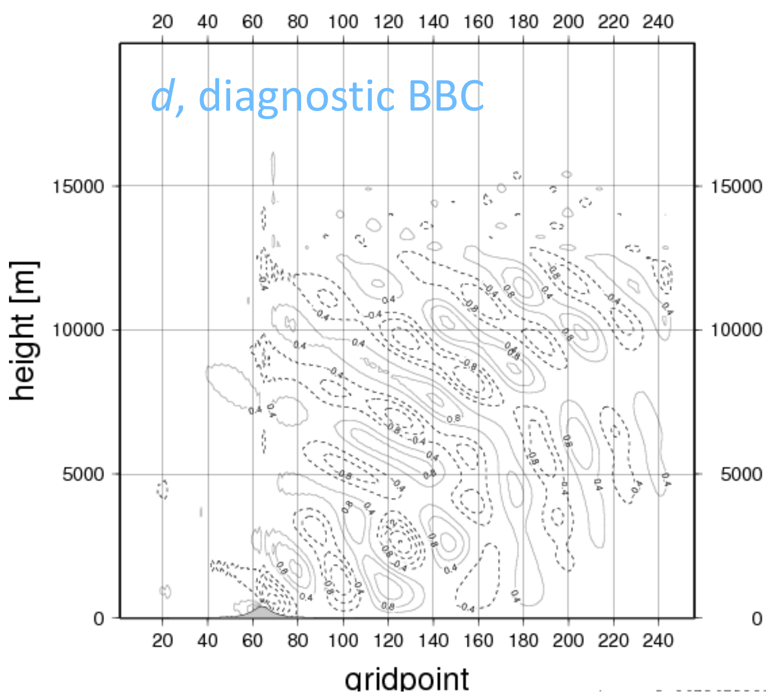
- with an irregular distribution of knots, denser close to boundaries ($\alpha < 1$)
- the full levels chosen freely - there is at least one full level in support of each basis function

2D vertical slice tests:

1.NL NH of Bubnová (1995), flow over Agnesi mountain

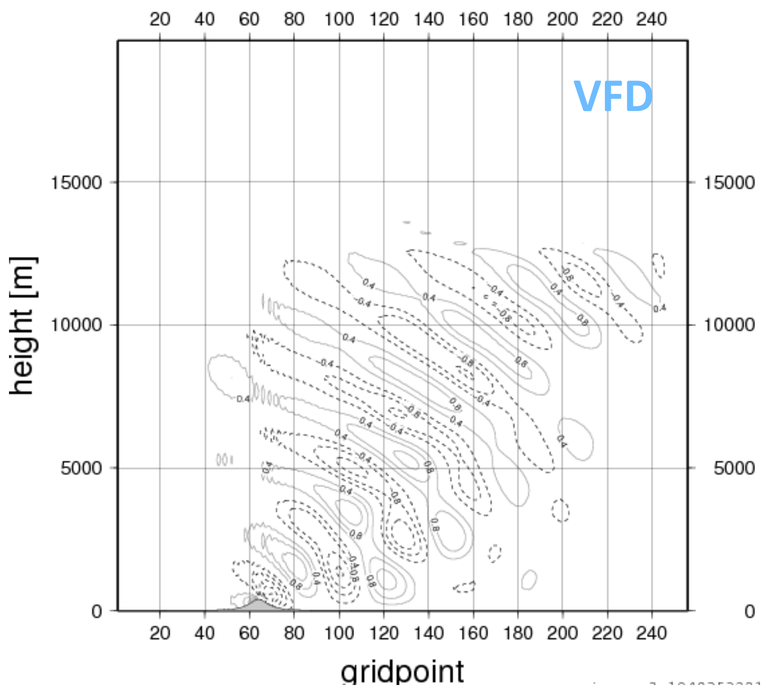
$$\alpha = 0.7$$

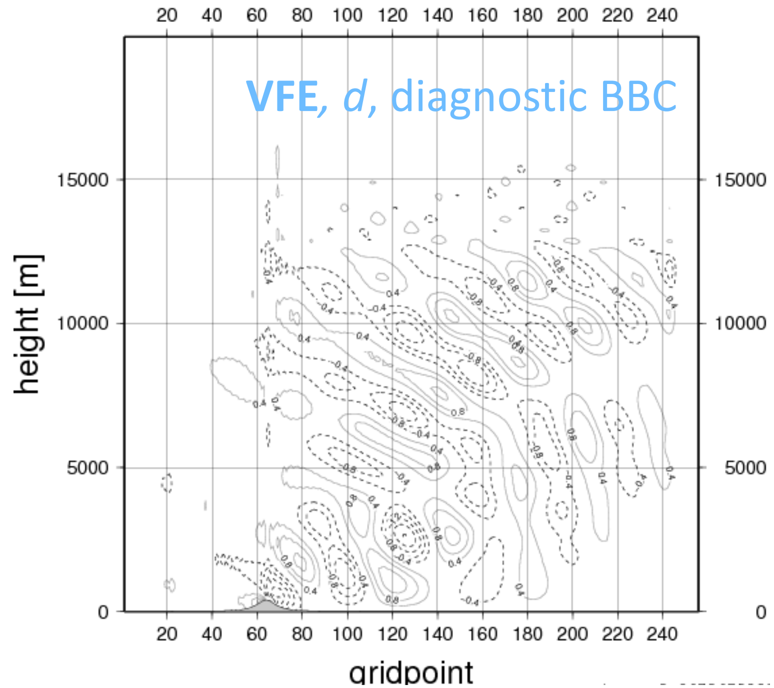




2D vertical slice tests:

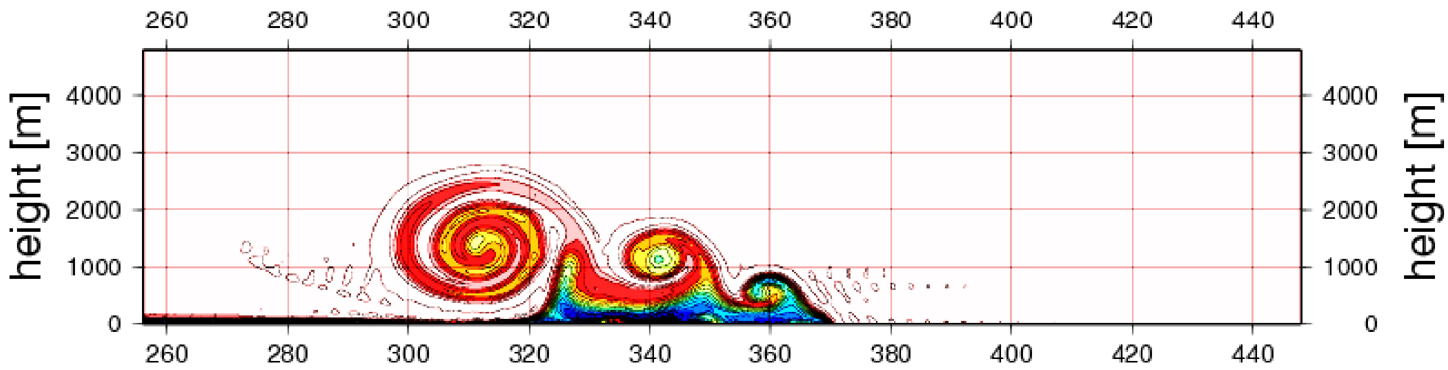
VFD is computed with the same level distribution as VFE (remaining issues concerning discretization accuracy)



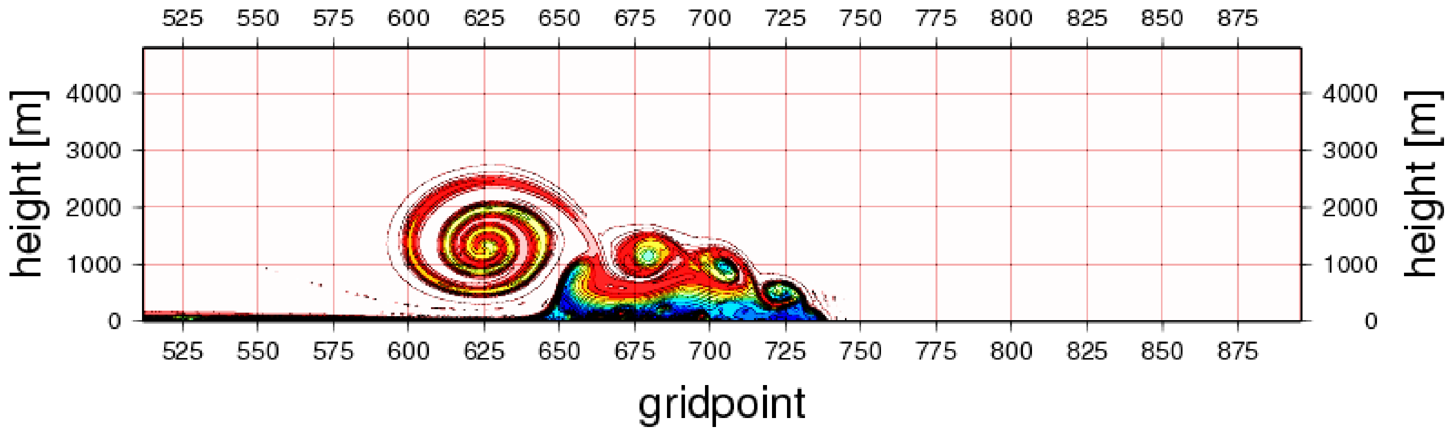


VFE IN NH (AFTER J.VIVODA)

2. **Straka test** (1993), density current, with $\alpha = 0.7$



Δt = 3s, 200steps



Δt = 1.5s, 400steps

Plan for 2013: TOWARDS (SUB)KILOMETRIC SCALES

- 1D2D turbulence scheme (horizontally extended vertical turbulence scheme TOUCANS)
  - Scientific validation
  - Tests in <1km resolution ALARO
- Physics-dynamics interface
  - Numerical diffusion – after 1D2D turbulence
    - multiscale testing
    - diagnose energy and entropy in the system
    - SLHD tuning
  - SLHD for <1km resolution AROME
  - Physical tendency of w
  - SL interpolations – ENO technique
- VFE in NH – to be continued …

Plan for 2013: TOWARDS (SUB)KILOMETRIC SCALES

- Extensive testing in <1km resolutions
  - HYD x NH
  - Time schemes - main weaknesses
  - Sharp slopes
  - Academic experiments (2D, 3D ALPIA etc.)
  - Comparison with other dynamical cores ?
  - Well prepared physics needed

- Coupling for <1km resolutions
  - Detecting rapid changes in pressure, precipitation field of the leading model, consequencies on the coupling zone positioning
  - Coupling of variables from physics – needed?, how?

THANK YOU FOR YOUR ATTENTION !