Higher order Vertical Advection

(M. Baldauf, DWD)

Motivation:

in a convection-permitting model (like COSMO-DE) the vertical advection plays a much bigger role than in a convection-parameterising model

→ try to achieve higher accuracy in the vertical advection of dynamic variables (u,v,w,T',p'), too

COSMO-model up to now: vertically implicit centered diff. 2nd order ('Old VA')

WRF: vertically explicit upwind scheme (3rd order)

- *advantages:*
  - Fits best to the explicit horizontal advection and the Runge-Kutta-scheme
  - Relatively easy to implement
- disadvantages:
  - Limitation of Courant number: $C_x + C_y + C_z < 1.4$ (*Baldauf, 2008, JCP*) →
    - WRF uses smaller time steps (~15 sec for dx=3km)
    - WRF uses a vertical 'velocity brake'

→ **Keep the vertically implicit scheme, but try a higher order of approximation (3rd order in space and time) ('New VA')**

(COSMO priority project 'Runge-Kutta', Task 8)

current use of an implicit vertical advection in every Runge-Kutta-substep reduces the temporal order of the time-split RK-scheme (*Baldauf, 2010, MWR*)

New proposal: complete operator splitting

$$\frac{\tilde{\phi} - \phi^n}{\Delta t} = R_x(\phi^n)$$

$$\frac{\phi^{n+1} - \tilde{\phi}}{\Delta t} = \beta A_z(\phi^{n+1}) + (1-\beta) A_z(\tilde{\phi})$$

R_x = complete RK3-scheme, but without vertical adv. A_z

advantages:

- no implicit scheme occurs inside of the RK
- if the numerical operators commute, then the stability properties of the single operators are passed on to the whole scheme (*LeVeque and Oliger, 1983*)
- the current ‚overdamping' in the RK-scheme is not longer needed
- ‚expensive' vertical advection is called only once / timestep

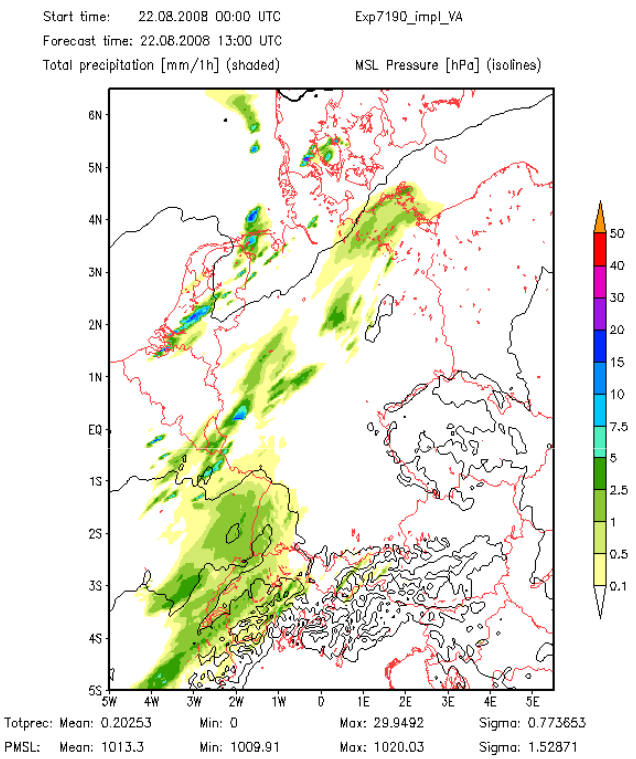
Possible problems:

- coupling between fast waves (sound, gravity) and vertical advection is weaker (but in idealised tests no problems were recognized)

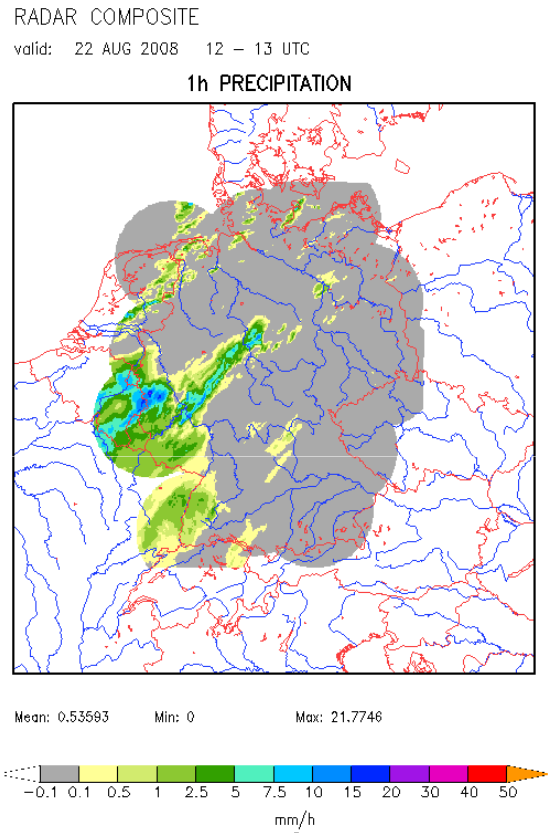
'Typical' behaviour in precipitation is not easy to determine ...

example '22.08.2008':

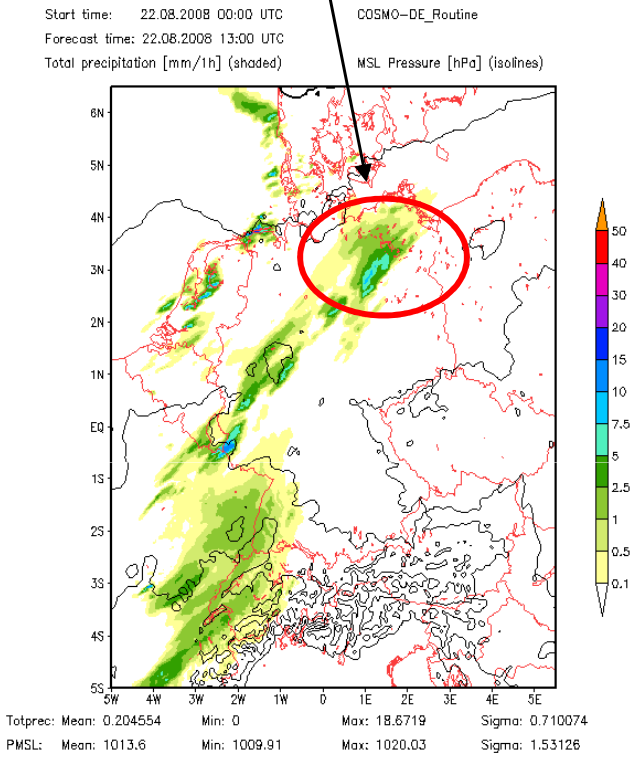
over estimation



New VA



Radar

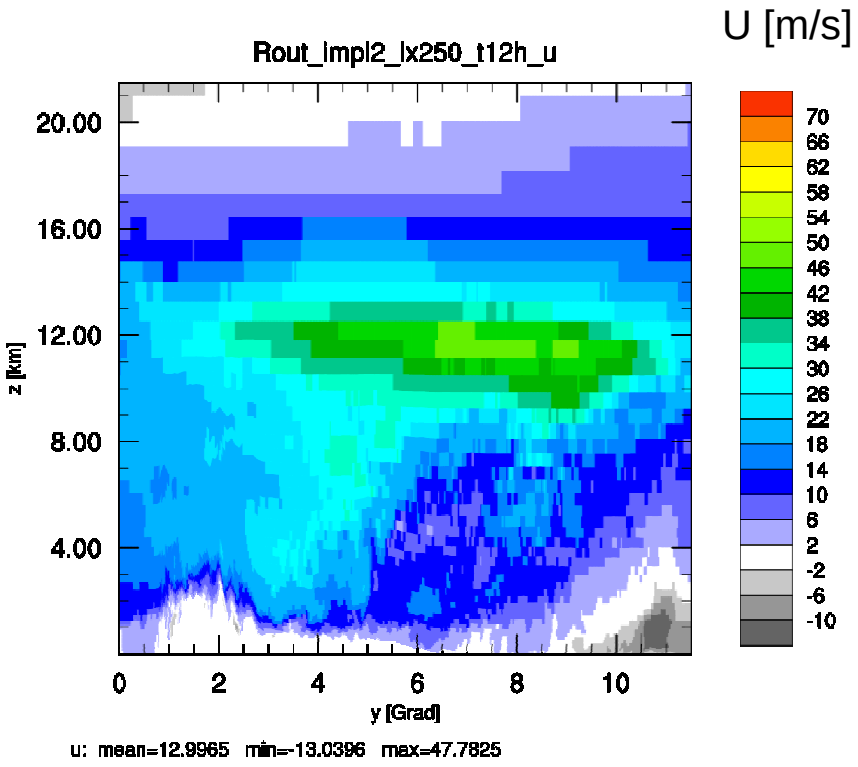


Old VA
Routine COSMO-DE

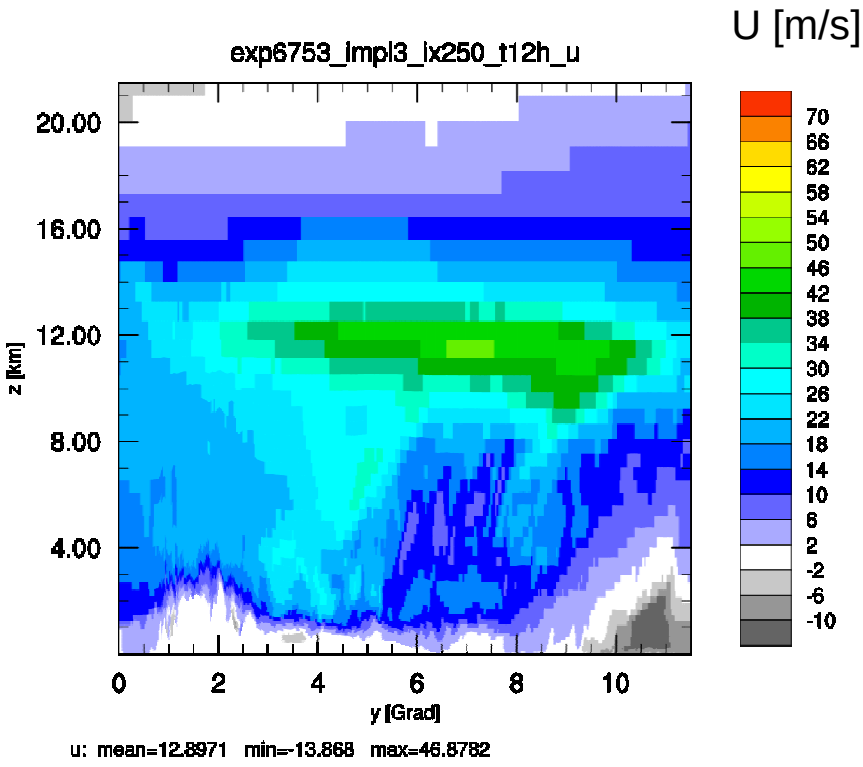
Vertical cross section of zonal velocity

'12.08.2008 0 UTC run' after 12 h

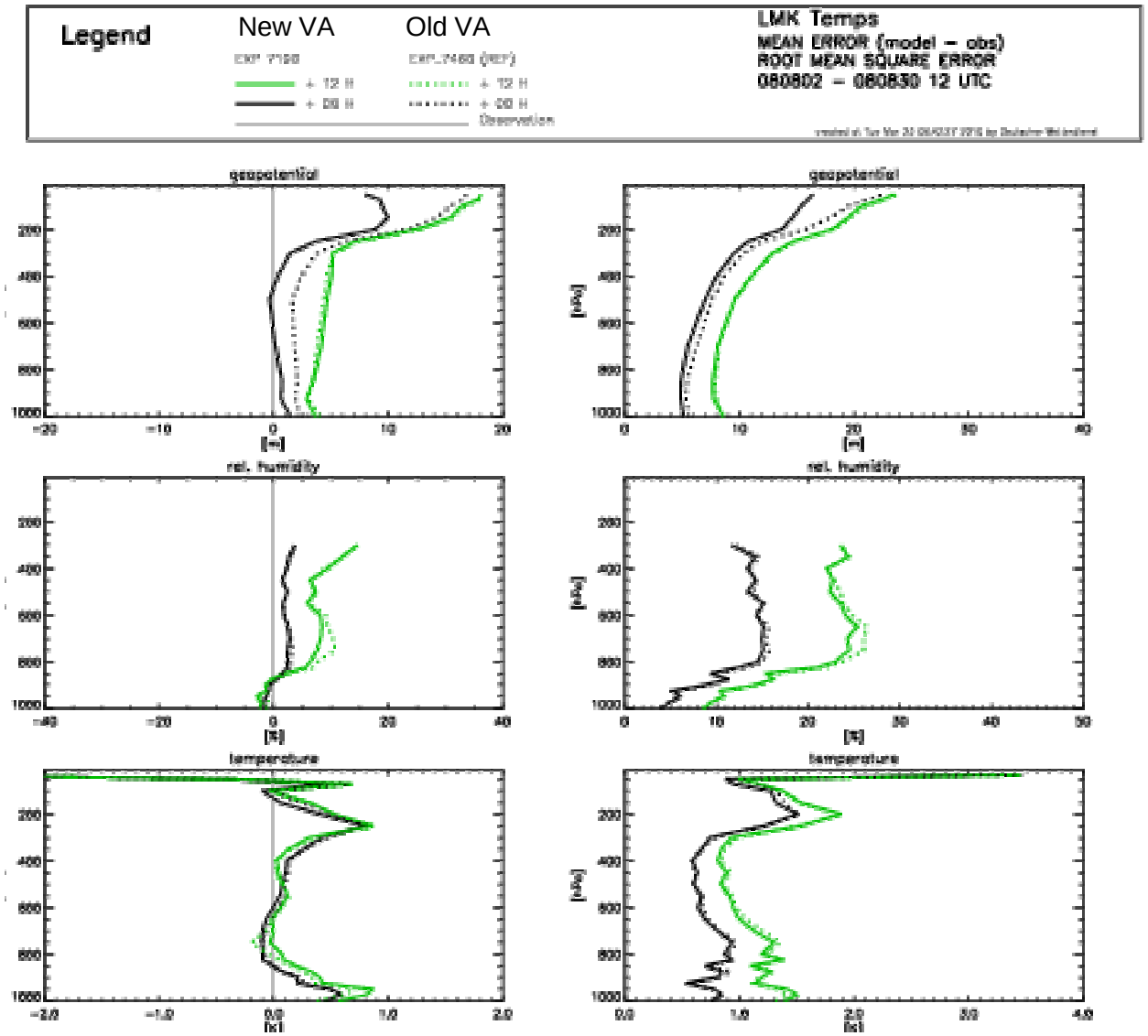
Old VA



New VA



slightly less noisy velocity field



Bias RMSE

upper-air-verification
against radiosondes
at 0 UTC

improvement of new VA
against routine is visible in
all variables

Summary

The current implicit vertical advection scheme possess a relatively strong damping and is formally not unconditionally stable.

From all of the tested alternatives only the 'complete operator splitting' (= vertical advection outside of the RK-scheme) with a 3rd order implicit vertical advection operator has proven to be superior:

- improved advection properties in idealized advection tests
- unconditionally stable in C_z
- works also in combination with fast waves
- plausible results in idealized and real cases
- runs stable for several COSMO-DE (2.8 km) simulations (summer period);
- computational amount is only slightly increased