Suppression of orographic noise caused by linear diffusion

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9^{th} International SRNWP Workshop on Nonhydrostatic Modelling
Bad Orb, Germany
16.–18.5.2011

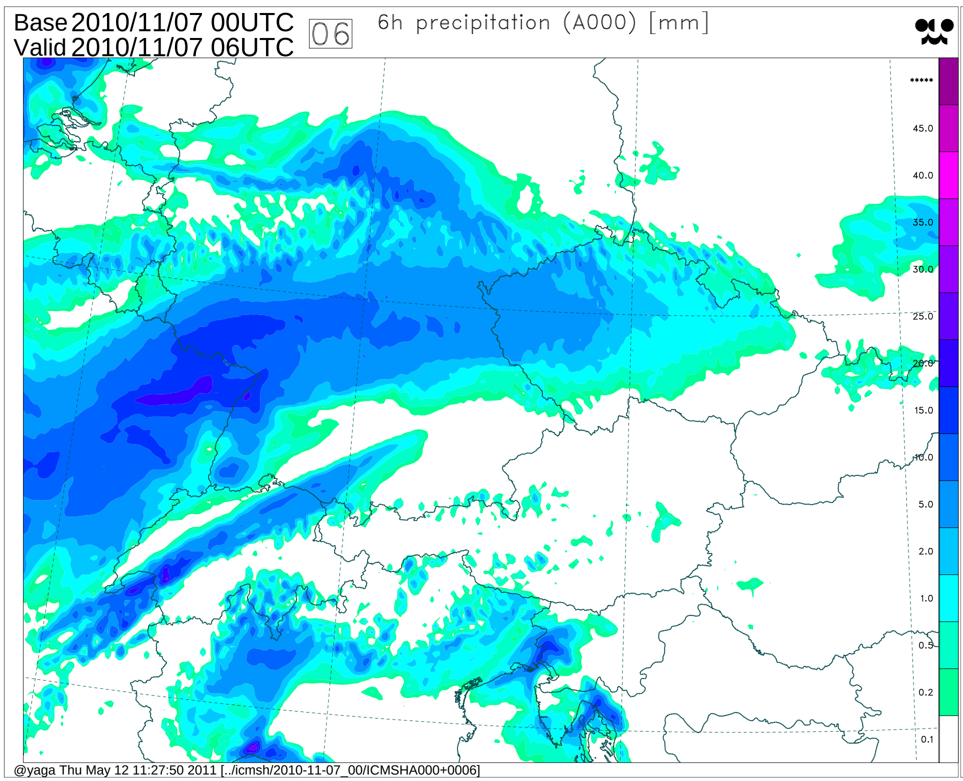
Introduction of the problem (1)

ALADIN/CHMI operational forecast

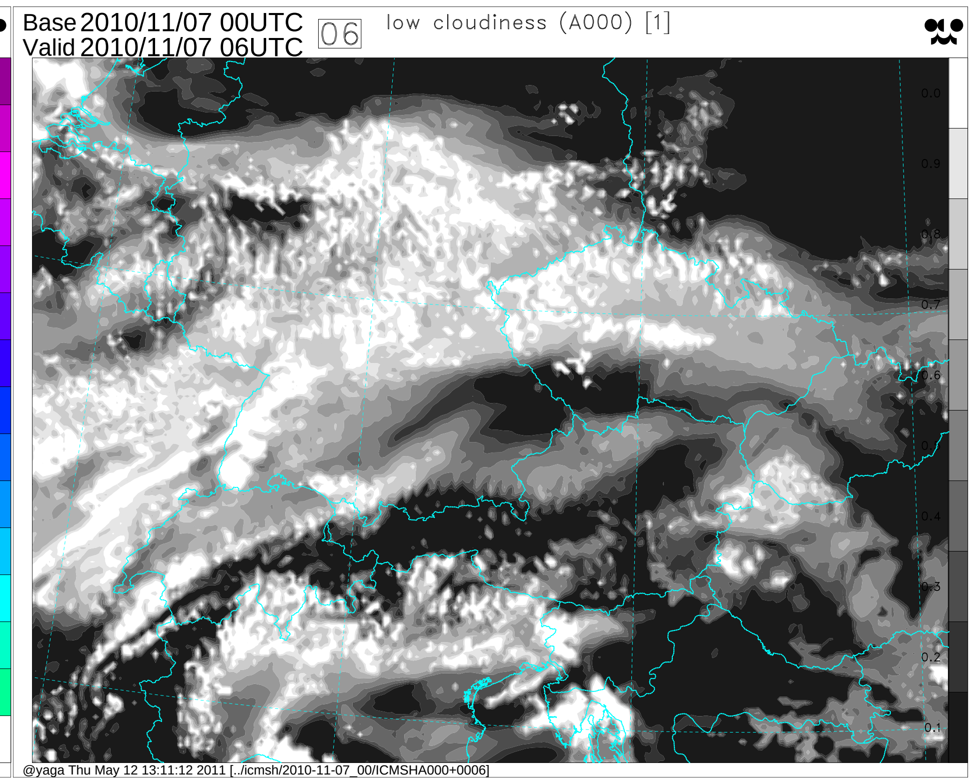
07-Nov-2010, 00 UTC + 6 h

$\Delta x = 4.7$ km, linear grid, 87L

2TL SISL scheme, $\Delta t = 180$ s, hydrostatic



cumulated precipitation



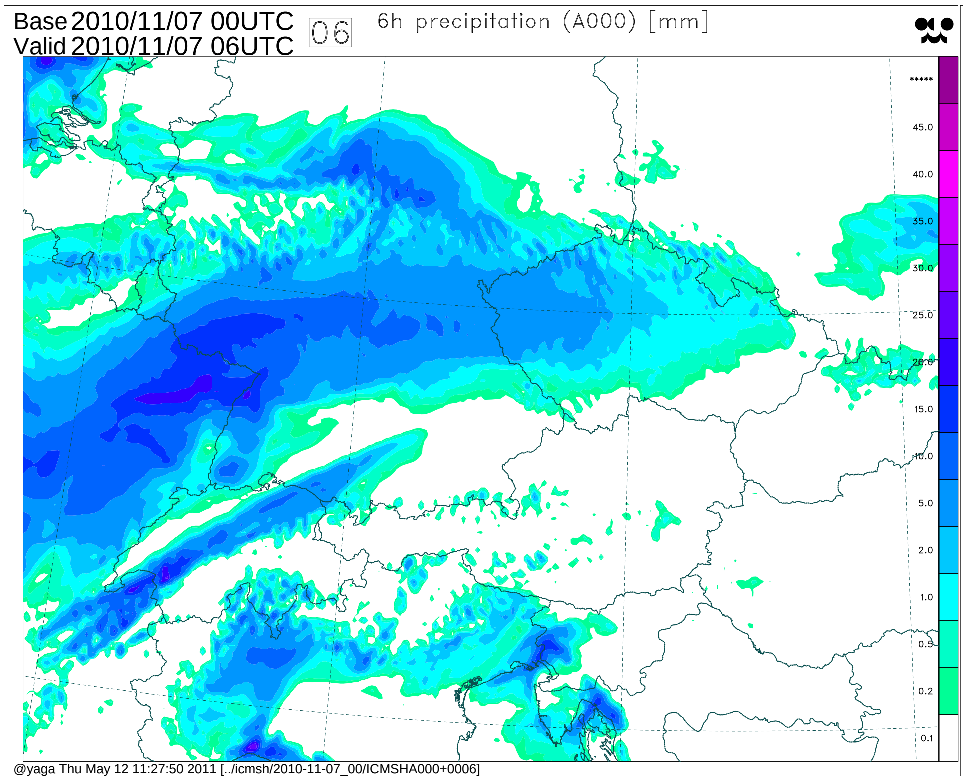
low cloudiness

Introduction of the problem (2)

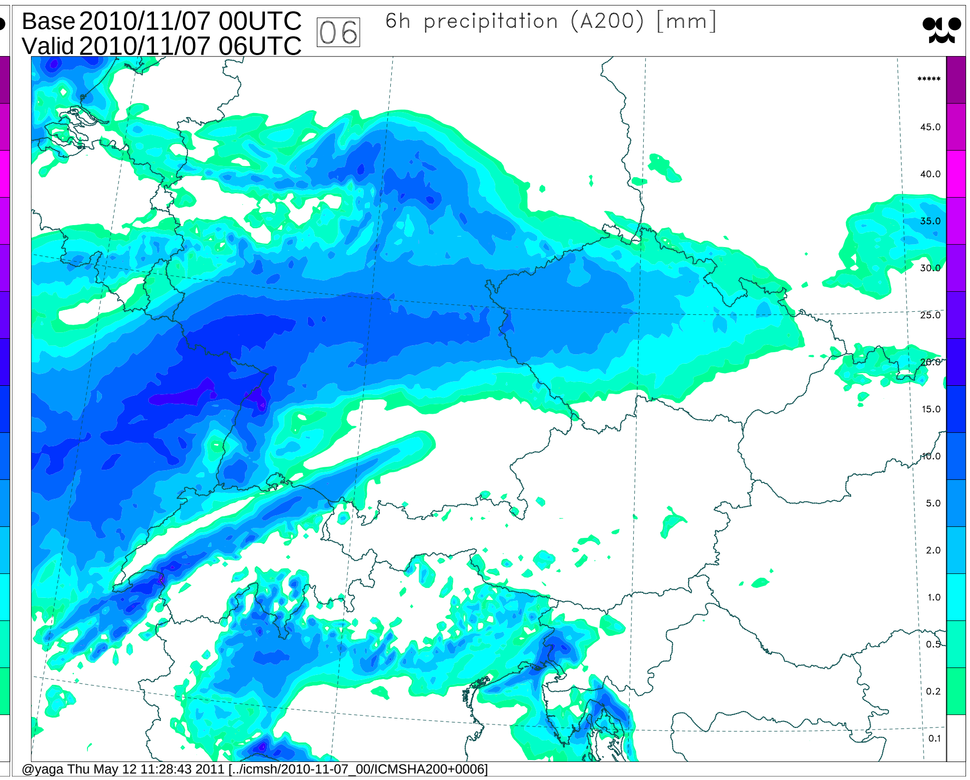
- from time to time, spurious $\approx 4\Delta x$ noise could be observed in cloudiness and precipitation fields forecasted by ALADIN/CHMI
- one of the first suspects was model physics, more specifically convection triggering based on moisture convergence
- it was believed that noise could be the result of Gibbs waves in spectrally computed moisture convergence field
- when Gibbs waves were prevented by non-oscilatory finite difference computation of moisture convergence, there was practically no impact on noise in precipitation field $\Rightarrow$ different track had to be followed

Sensitivity to timestep (1)

6h cumulated precipitation



$\Delta t = 180\,\mathrm{s}$



$\Delta t = 30\,\mathrm{s}$

Sensitivity to timestep (2)

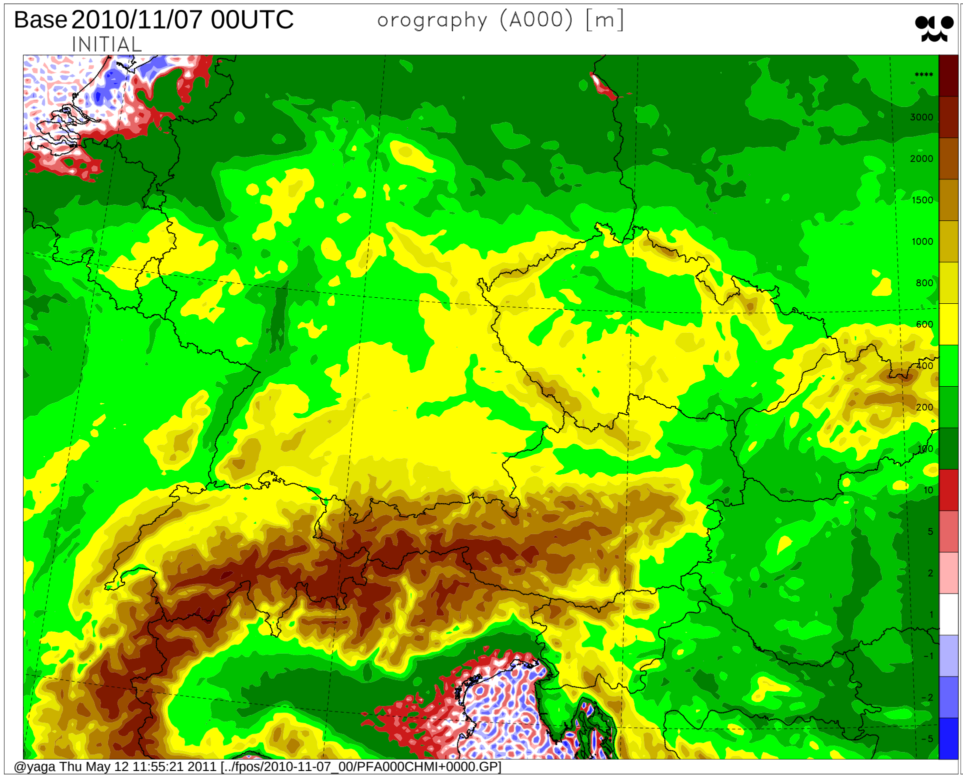
- shortening the timestep to Eulerian value significantly reduced the noise

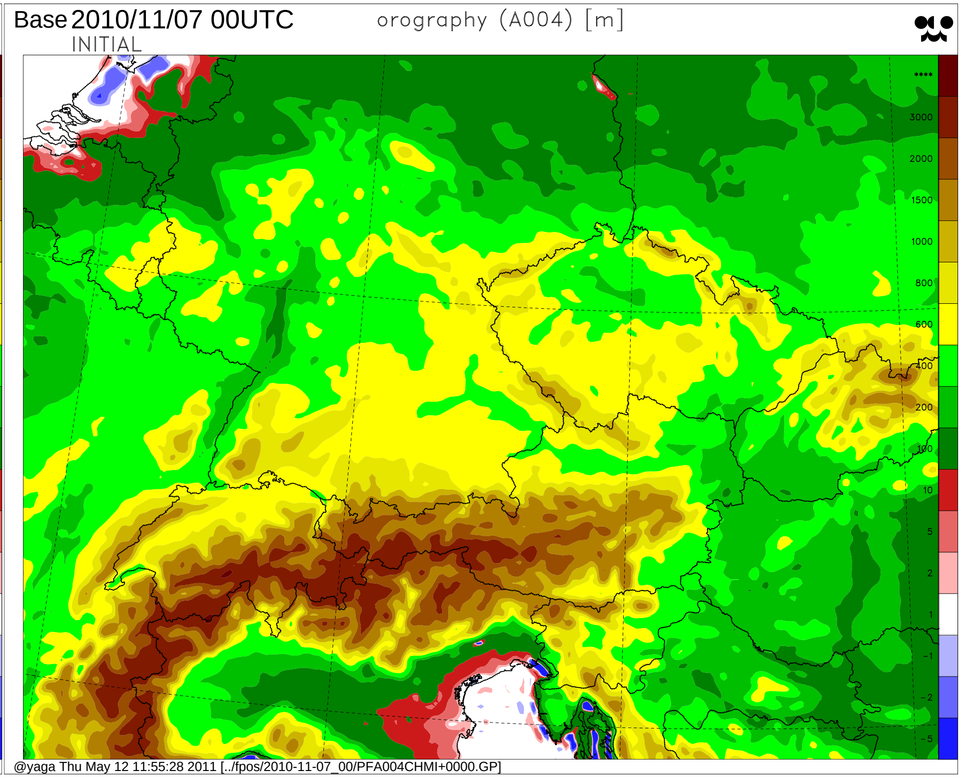
- such behaviour resembles problem of orographic resonance for SISL schemes

- however, resonant conditions were not met (wind in concerned regions was not that strong)

Sensitivity to orography filtering (1)

model orography



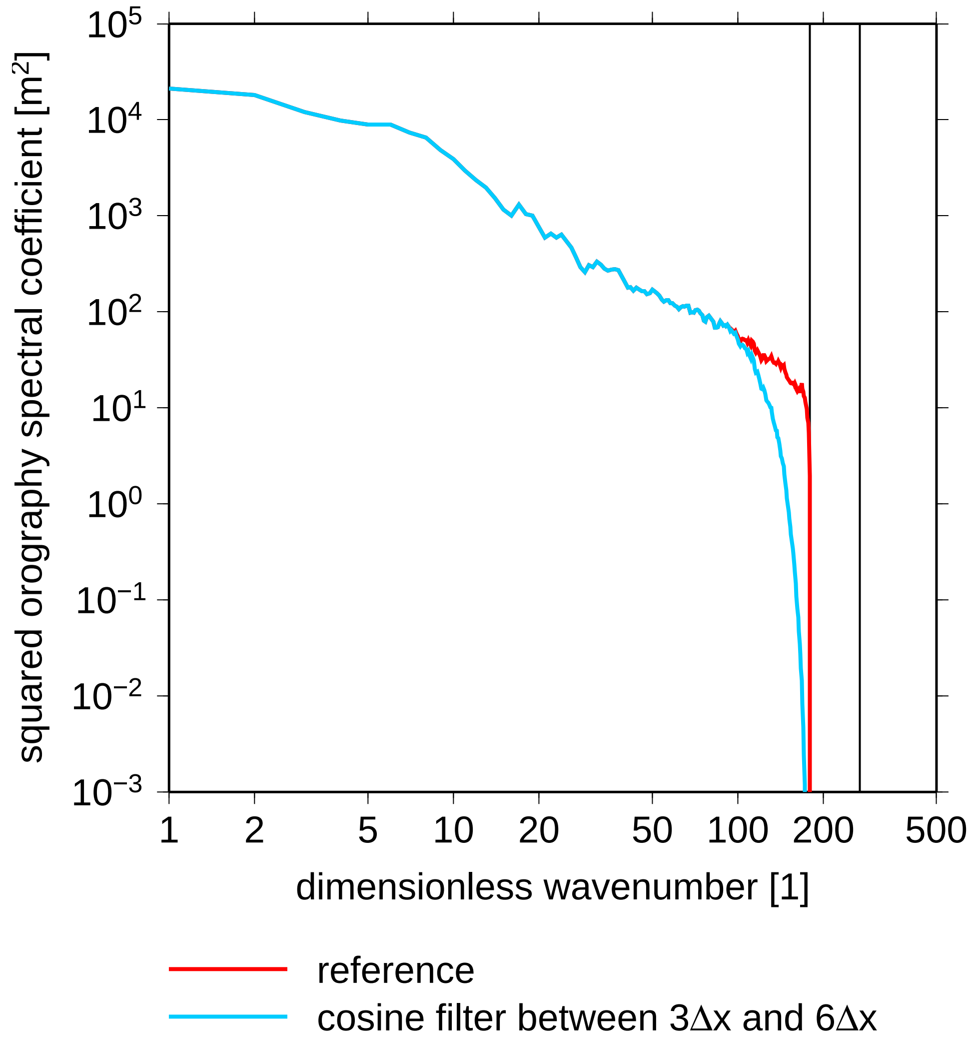


reference

filtered orography (cosine filter between $3\Delta x$ and $6\Delta x$)

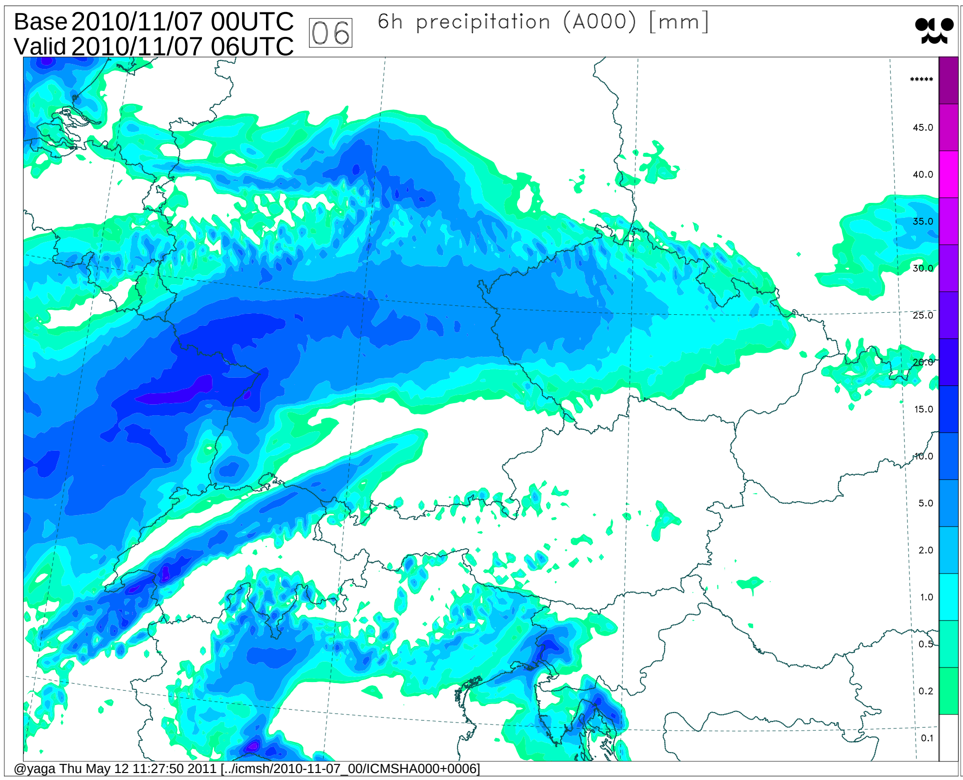
Sensitivity to orography filtering (2)

spectrum of unfiltered and filtered orography

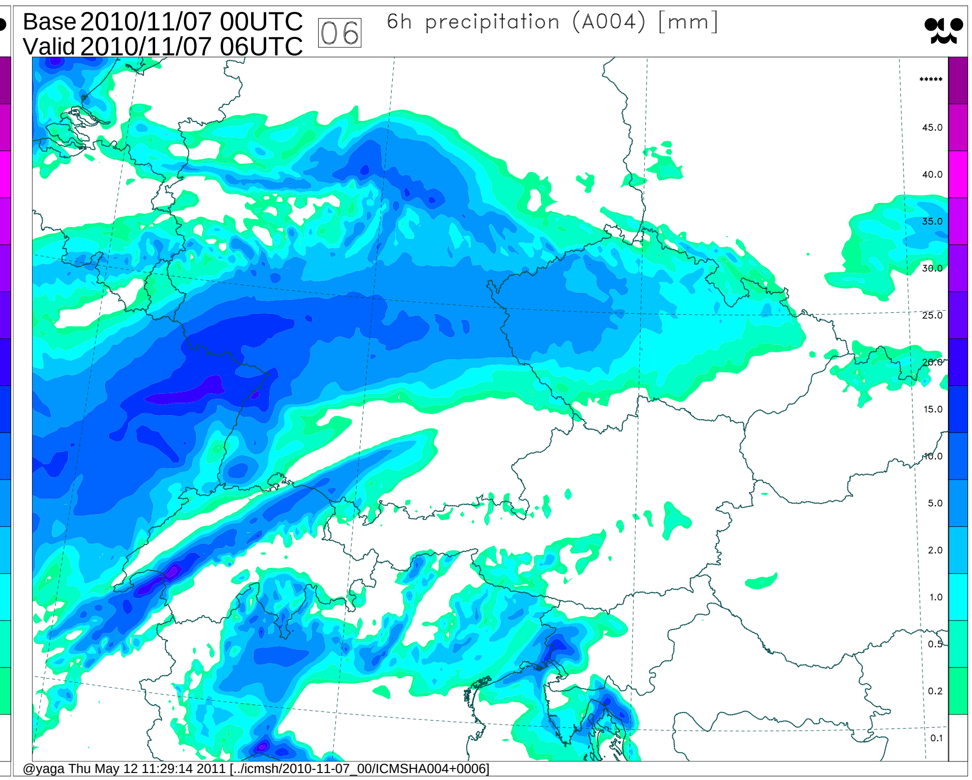


Sensitivity to orography filtering (3)

6h cumulated precipitation



reference



filtered orography (cosine filter between $3\Delta x$ and $6\Delta x$)

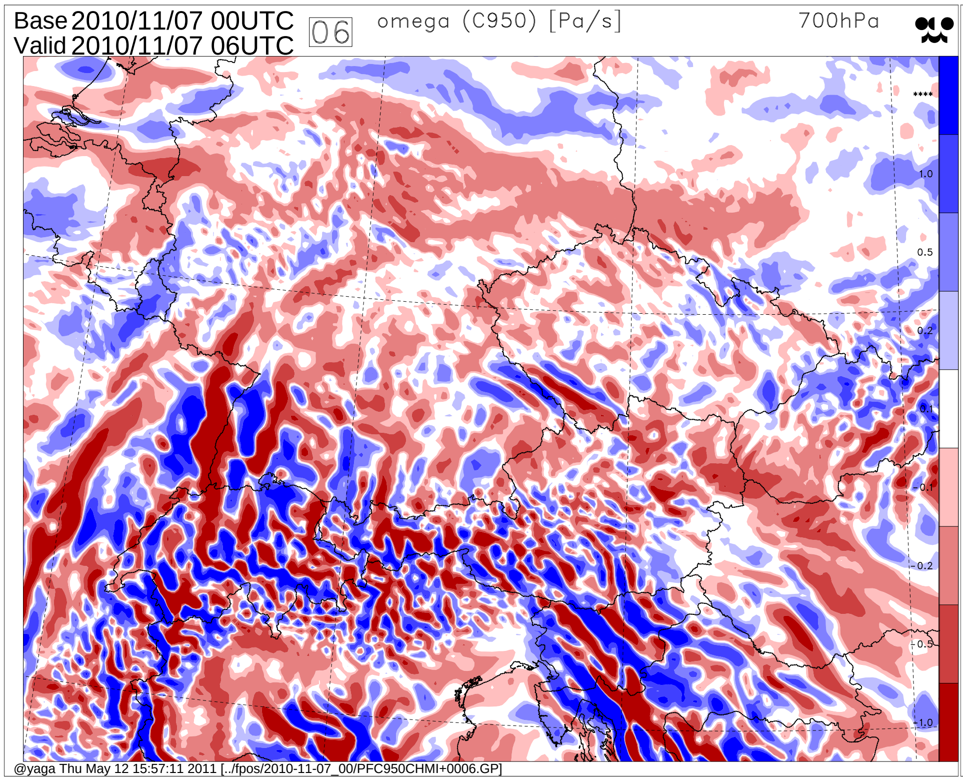
Sensitivity to orography filtering (4)

- orography filtering reduces the noise $\Rightarrow$ like resonance, problem is orographically induced

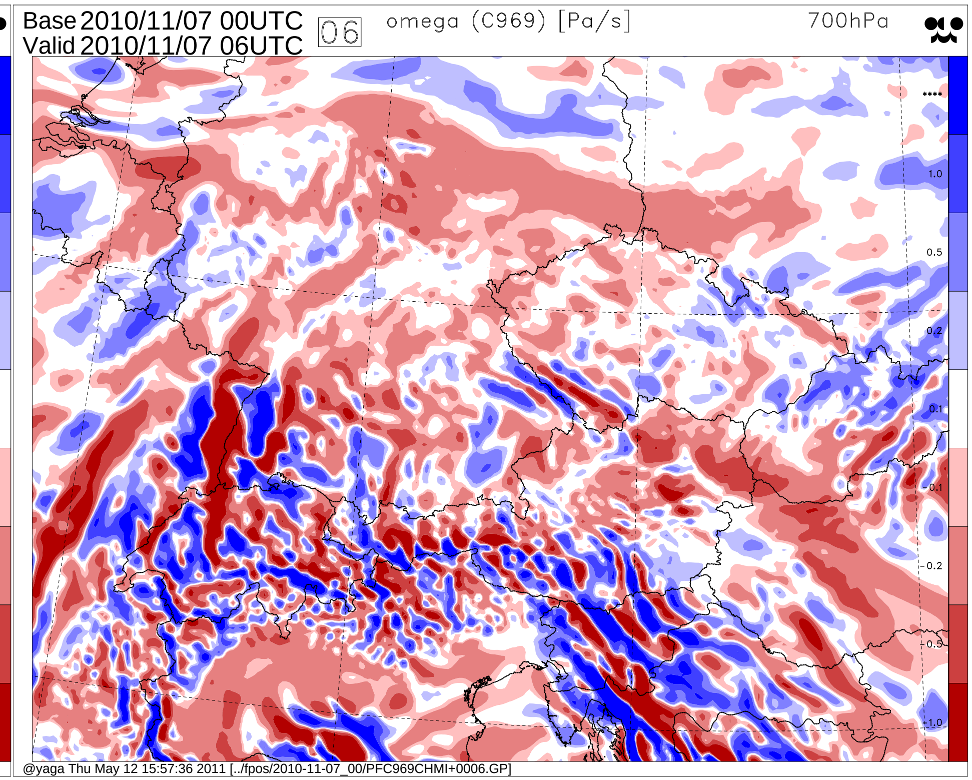
- removal of fine scale orography is not a solution, since we lose scales we are interested in

Reproducing the problem in adiabatic model

vertical velocity ω at 700 hPa level



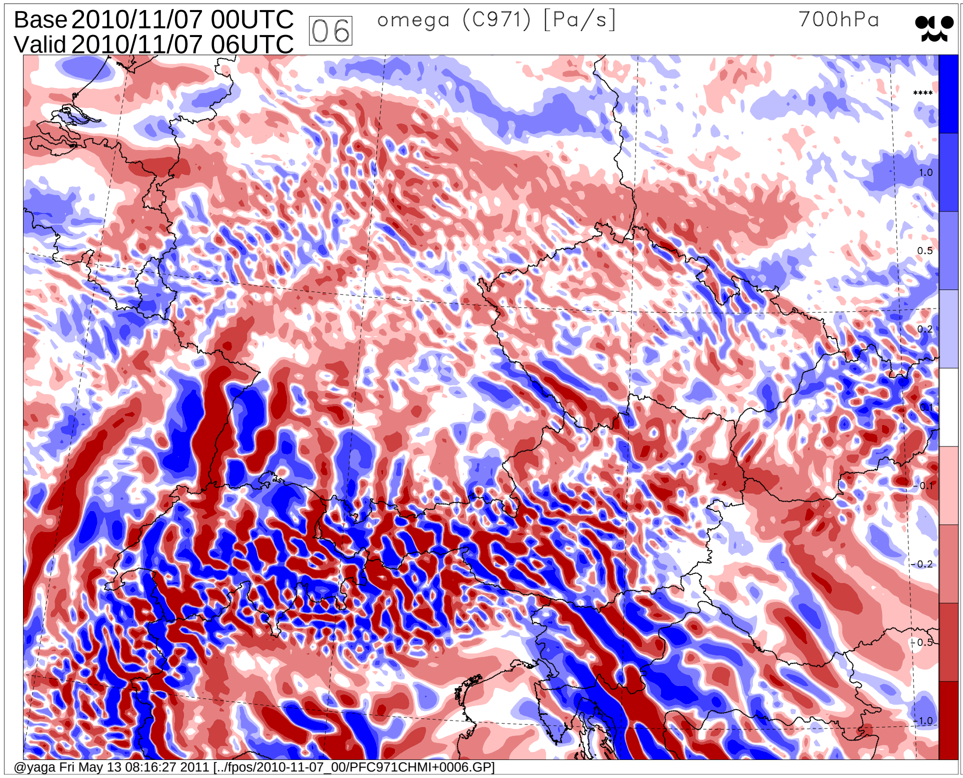
$\Delta t = 180\,\mathrm{s}$

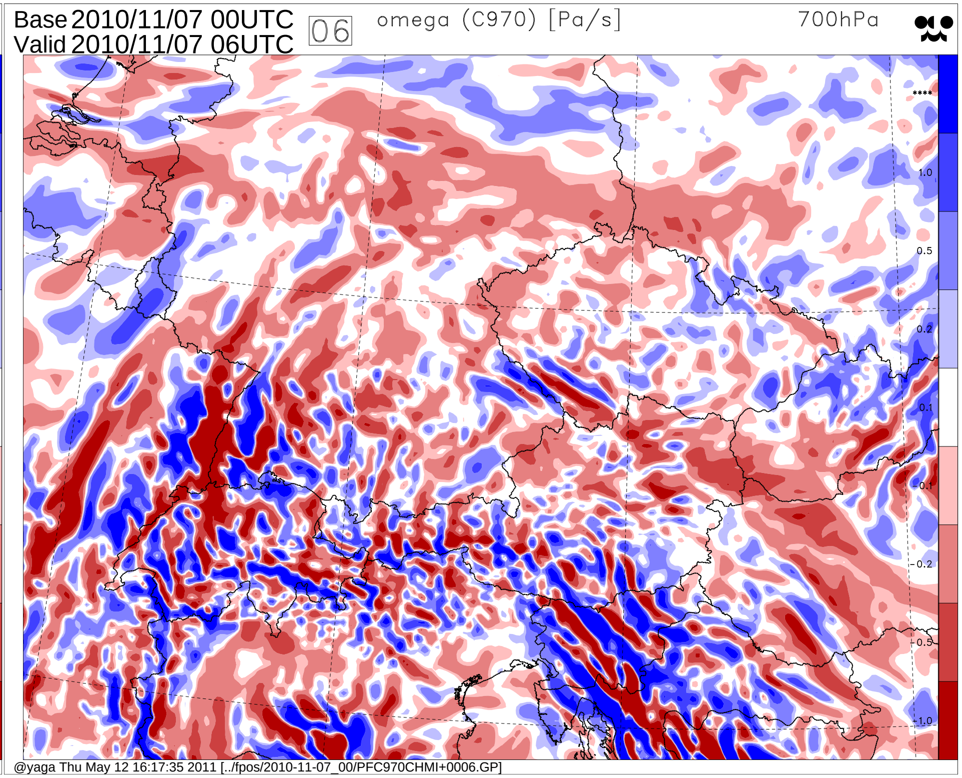


$\Delta t = 30\,\mathrm{s}$

Sensitivity to diffusion strength (1)

vertical velocity ω at 700 hPa level





5x stronger spectral diffusion

no spectral diffusion

Sensitivity to diffusion strength (2)

- surprisingly, stronger spectral diffusion amplified the noise
- when spectral diffusion was turned off, noise disappeared
- further tests showed that it is **too strong** diffusion on horizontal divergence D which causes the problem

Basic mechanism – explanation in 1D linearized shallow water equations (1)

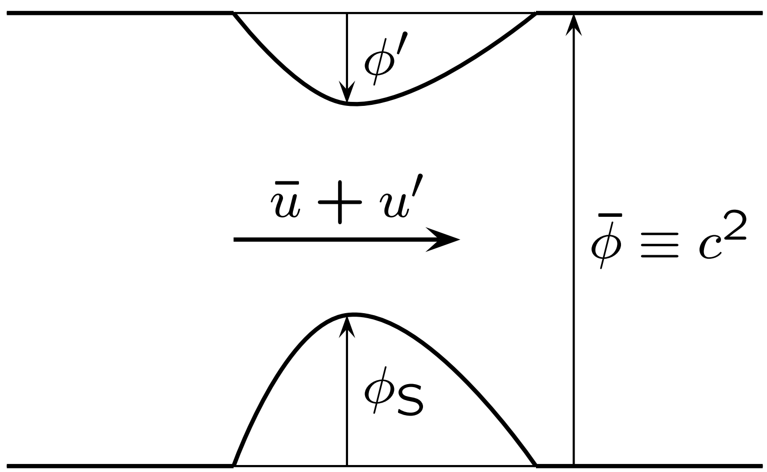
$$\frac{\partial D'}{\partial t} + \bar{u}\frac{\partial D'}{\partial x} = -\Delta\phi' - \nu_D \nabla^4 D'$$

$$\frac{\partial \phi'}{\partial t} + \bar{u}\frac{\partial \phi'}{\partial x} = -c^2 D' + \bar{u}\frac{\partial \phi_S}{\partial x}$$

$$D'(x,t) \equiv \frac{\partial u'(x,t)}{\partial x}$$

$$u(x,t) \equiv \bar{u} + u'(x,t)$$

$$\phi(x,t) \equiv \bar{\phi} + \phi'(x,t)$$



Basic mechanism – explanation in 1D linearized shallow water equations (2)

- two limit cases for stationary response far from resonance ($|\bar{u}| \ll c$):

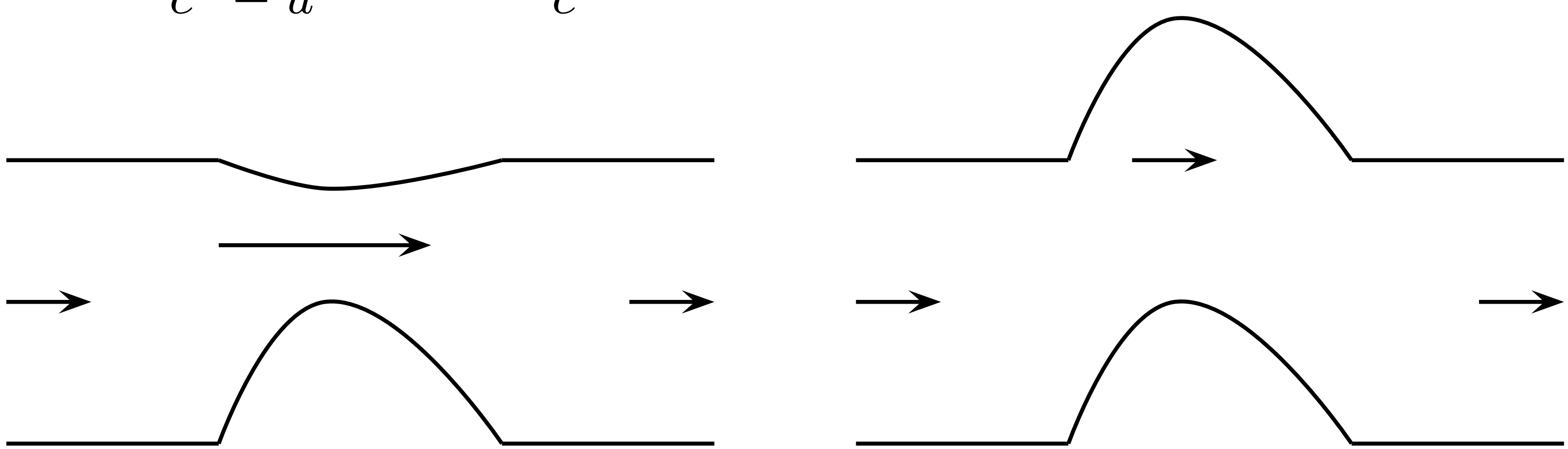
$\nu_D = 0$

$$u' = \frac{\bar{u}}{c^2 - \bar{u}^2} \cdot \phi_S \approx \frac{\bar{u}}{c^2} \cdot \phi_S$$

$$\phi' = -\frac{\bar{u}^2}{c^2 - \bar{u}^2} \cdot \phi_S \approx -\frac{\bar{u}^2}{c^2} \cdot \phi_S$$

$\nu_D \to +\infty$

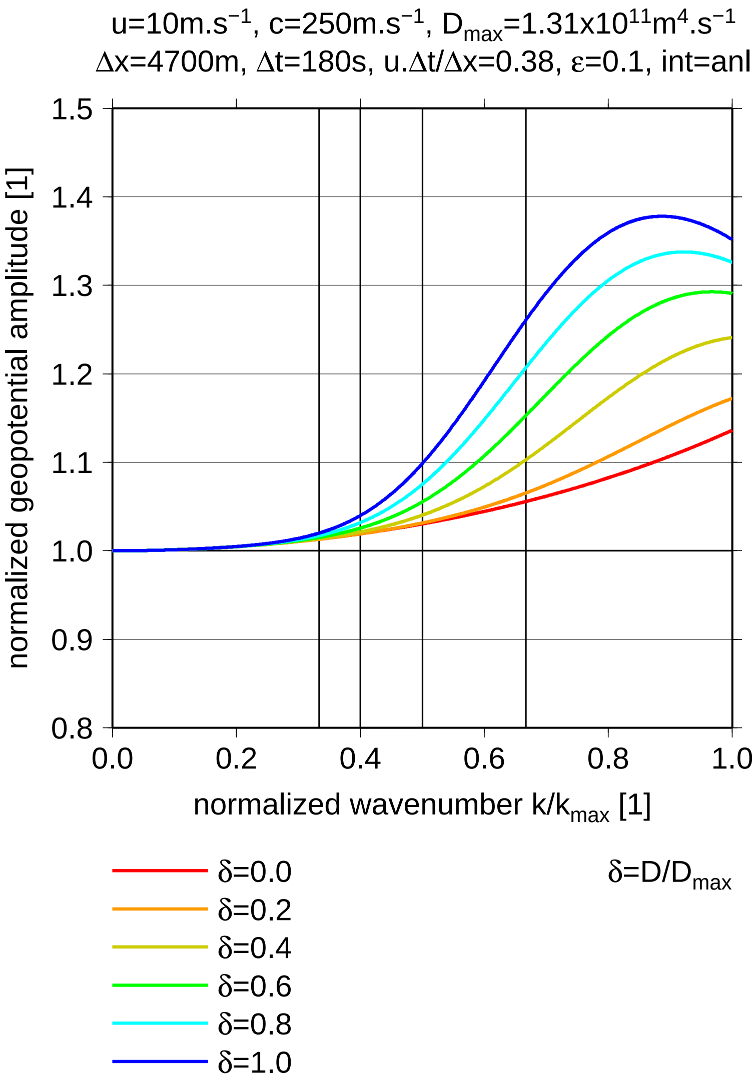
$$D' \to 0$$
$$u' \to 0$$
$$\phi' \to \phi_S$$



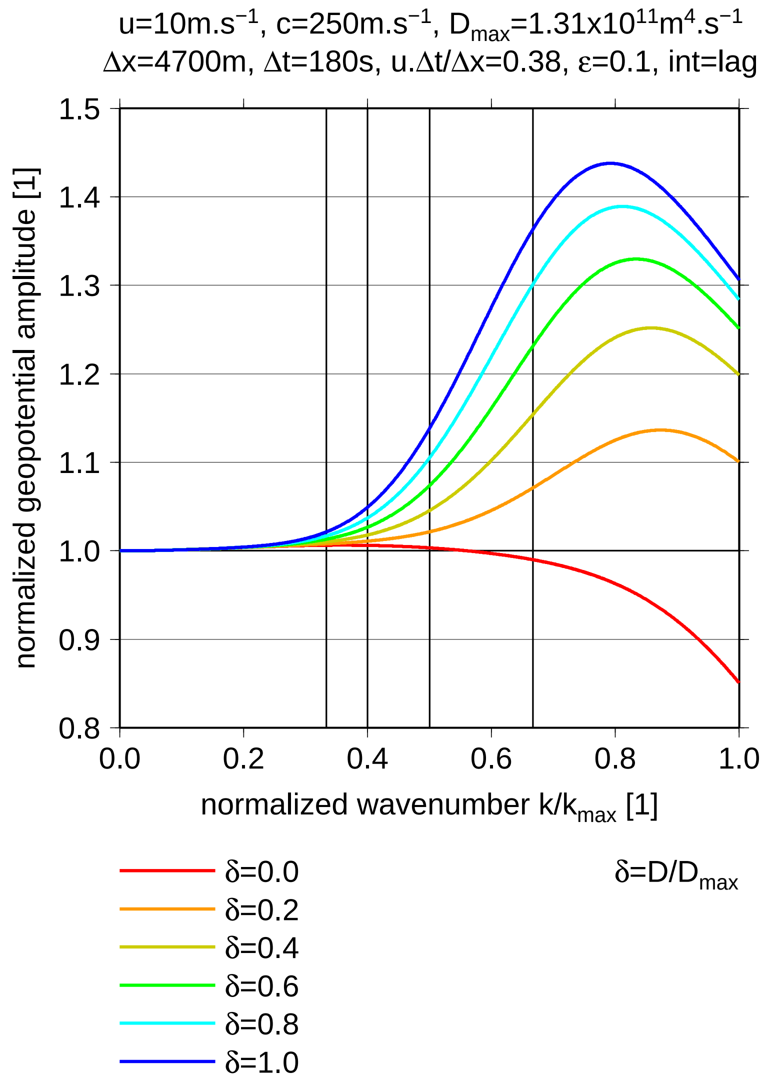
- sufficiently strong ν_D reverts sign of ϕ', eventually increasing its amplitude by factor $c^2/\bar{u}^2$ with respect to undiffused solution

Sensitivity to diffusion strength far from resonance

normalized geopotential amplitude ($\Delta t = 180\,\mathrm{s}$, $u = 10\,\mathrm{ms}^{-1}$)



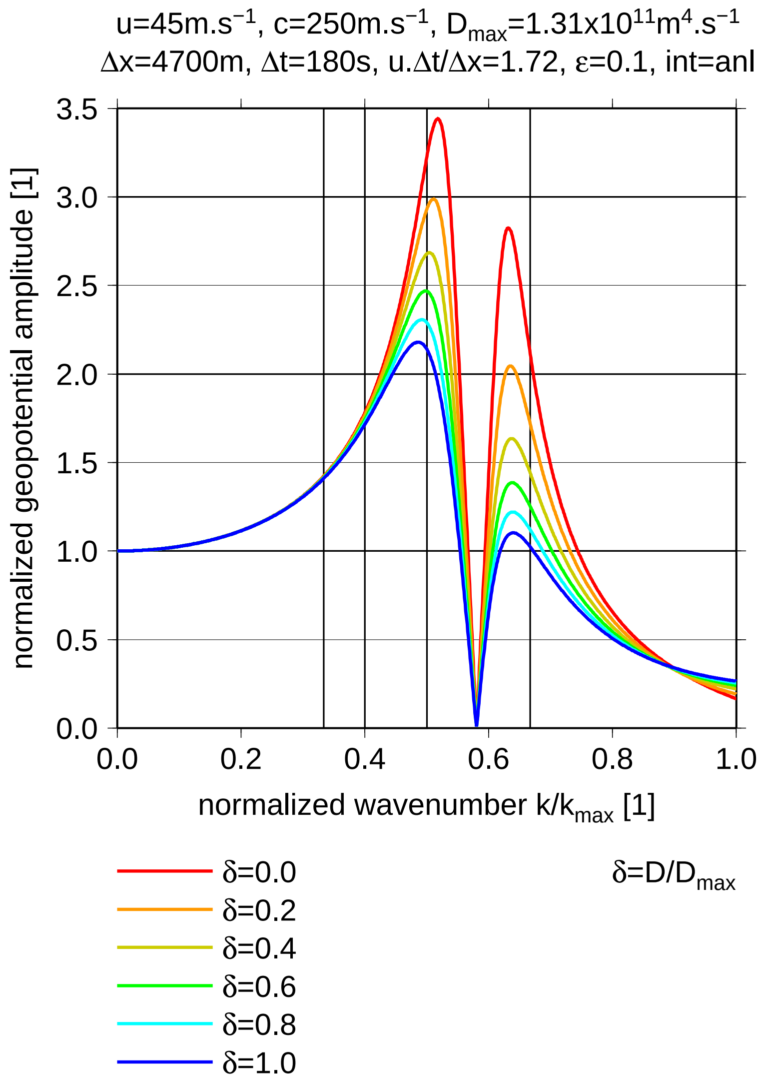
exact interpolator



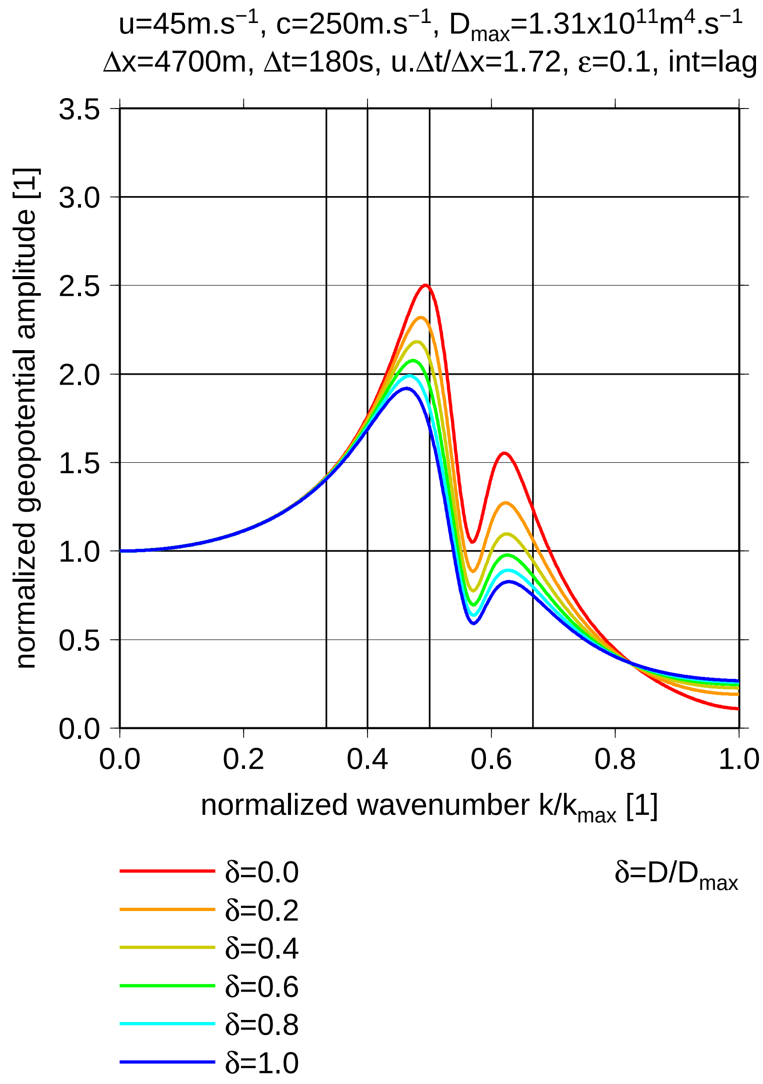
cubic Lagrange interpolator

Sensitivity to diffusion strength near resonance

normalized geopotential amplitude ($\Delta t = 180\,\text{s}$, $u = 45\,\text{ms}^{-1}$)



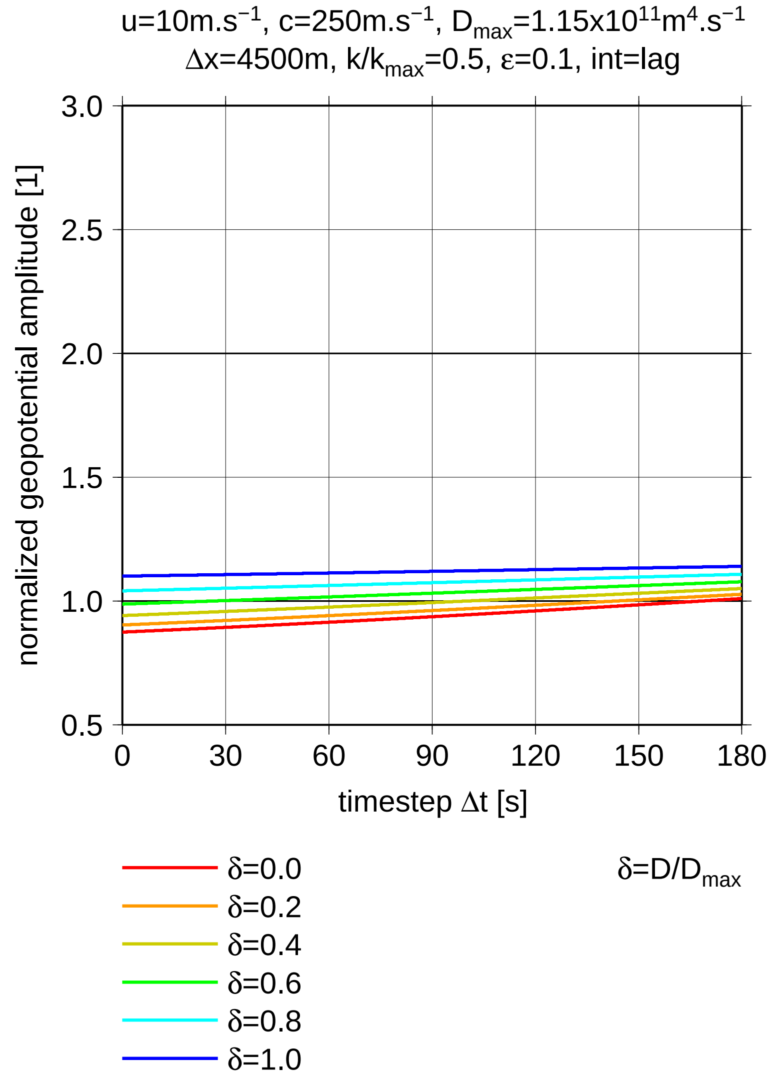
exact interpolator



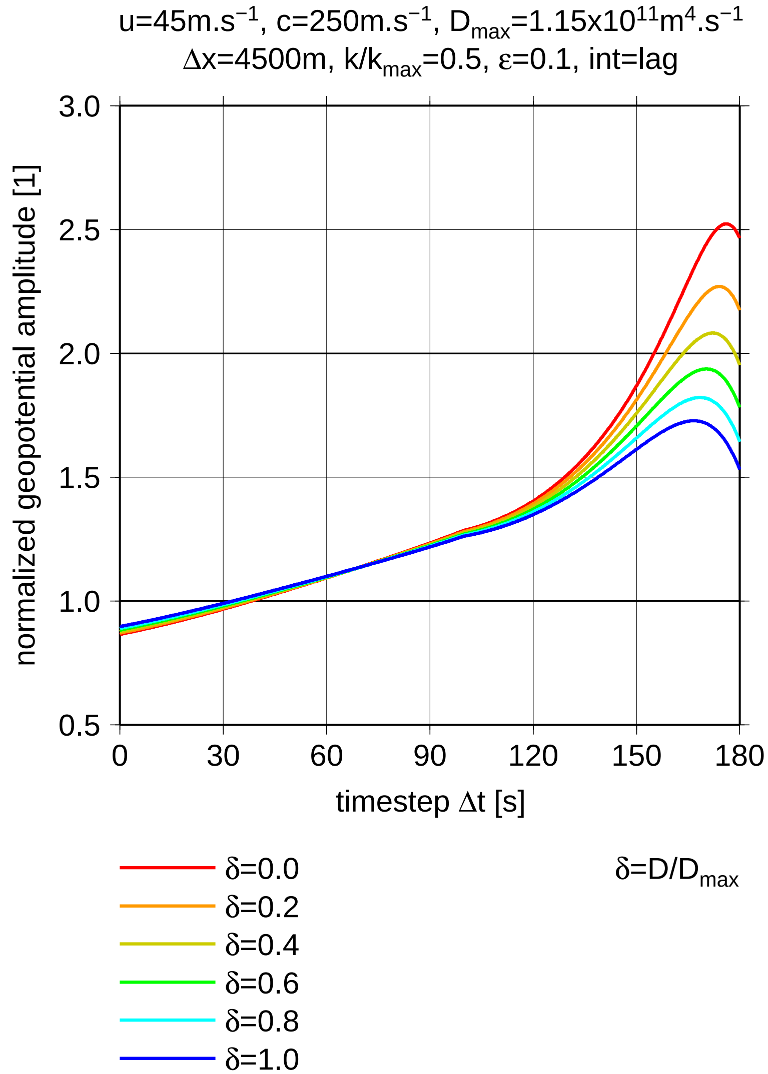
cubic Lagrange interpolator

Inability to explain Δt dependency far from resonance

normalized geopotential amplitude ($4\Delta x$ wave, cubic Lagrange int.)



$u = 10\,\mathrm{ms}^{-1}$



$u = 45\,\mathrm{ms}^{-1}$

Horizontal diffusion in ALADIN/CHMI

- ALADIN/CHMI uses so called SLHD scheme, which contains two diffusions – gridpoint (nonlinear) and spectral (linear)

- gridpoint diffusion employs damping properties of SL interpolators, its strength being modulated by horizontal flow deformation rate

- spectral diffusion is used for two purposes:

  1) 4^{th} order **reduced diffusion** acts mainly as sponge layer, eliminating spurious reflections from model top caused by unphysical elastic upper boundary condition

  2) 6^{th} order **supporting diffusion** controls orographic terms evaluated in final points of SL trajectories, which are thus not subject to gridpoint diffusion

- spectral diffusion on divergence is 5 times stronger than on vorticity and other fields

Retuning of spectral diffusion in ALADIN/CHMI (1)

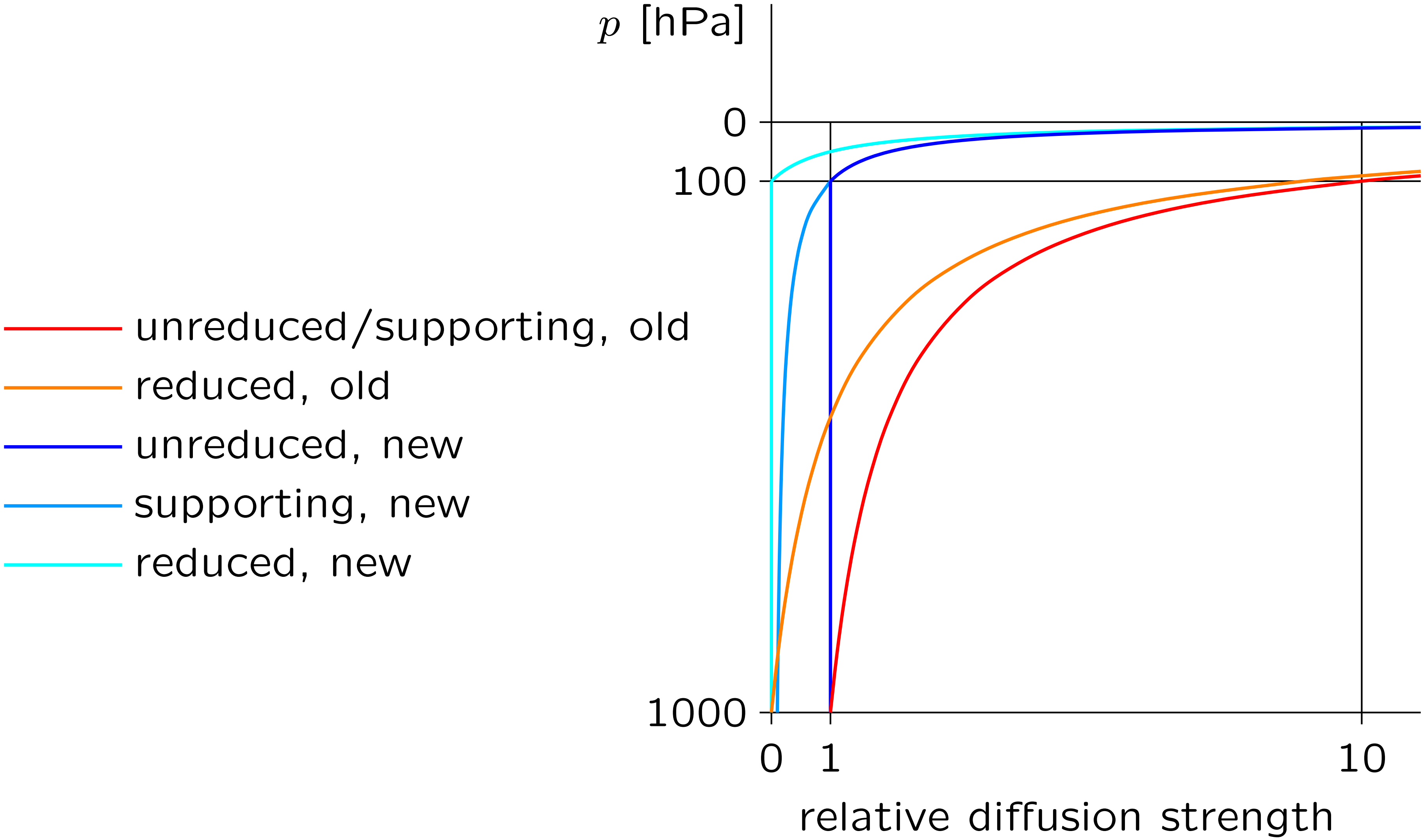
- reduced diffusion on divergence was completely turned off below 100 hPa level and its stregth above this level was weakened 10 times

- order of reduced diffusion was decreased from 4 to 2 (less scale selectivity of sponge layer improved its absorbing properties)

- supporting diffusion on divergence was weakened 10 times

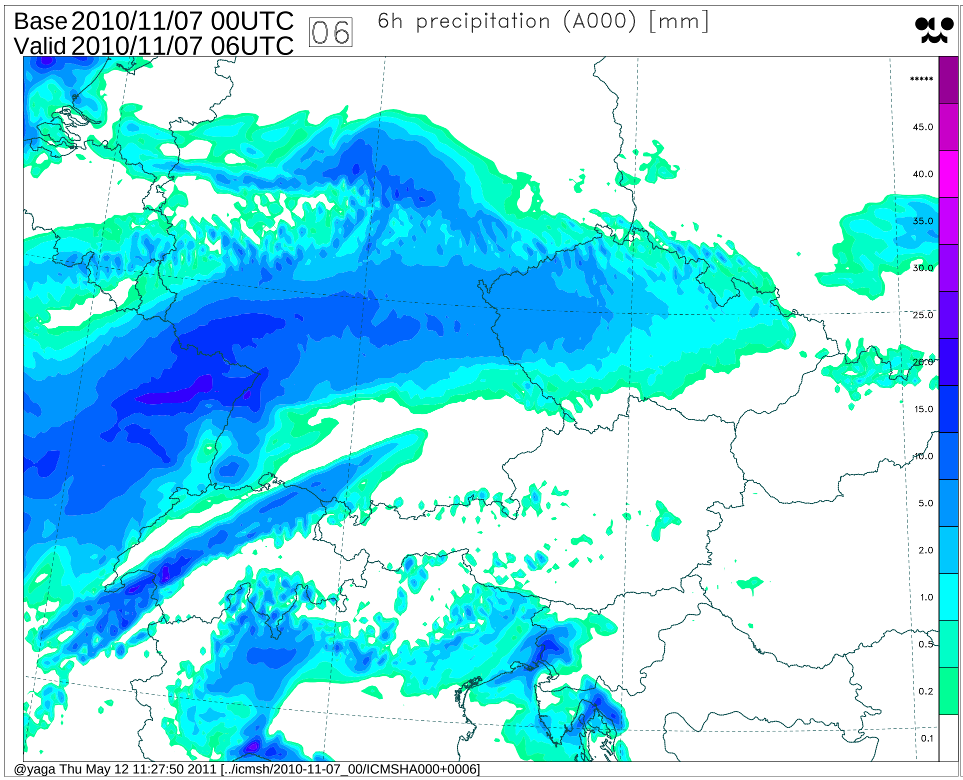
- strength of spectral diffusion on other fields was equalized with that on divergence

Retuning of spectral diffusion in ALADIN/CHMI (2)

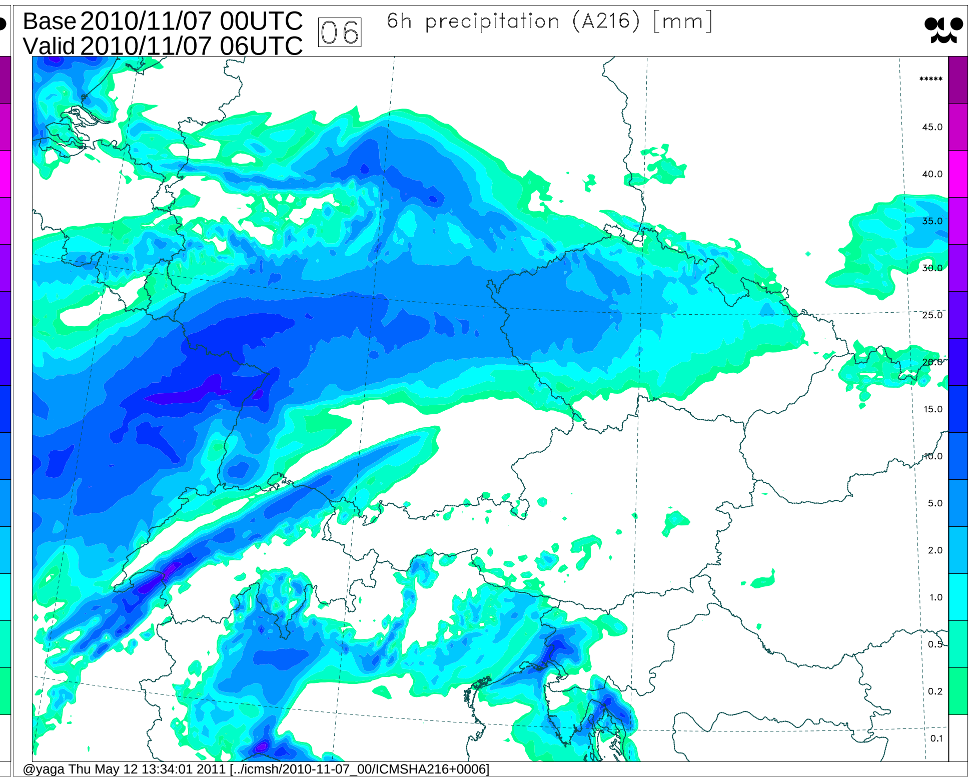


Results with retuned spectral diffusion (1)

6h cumulated precipitation



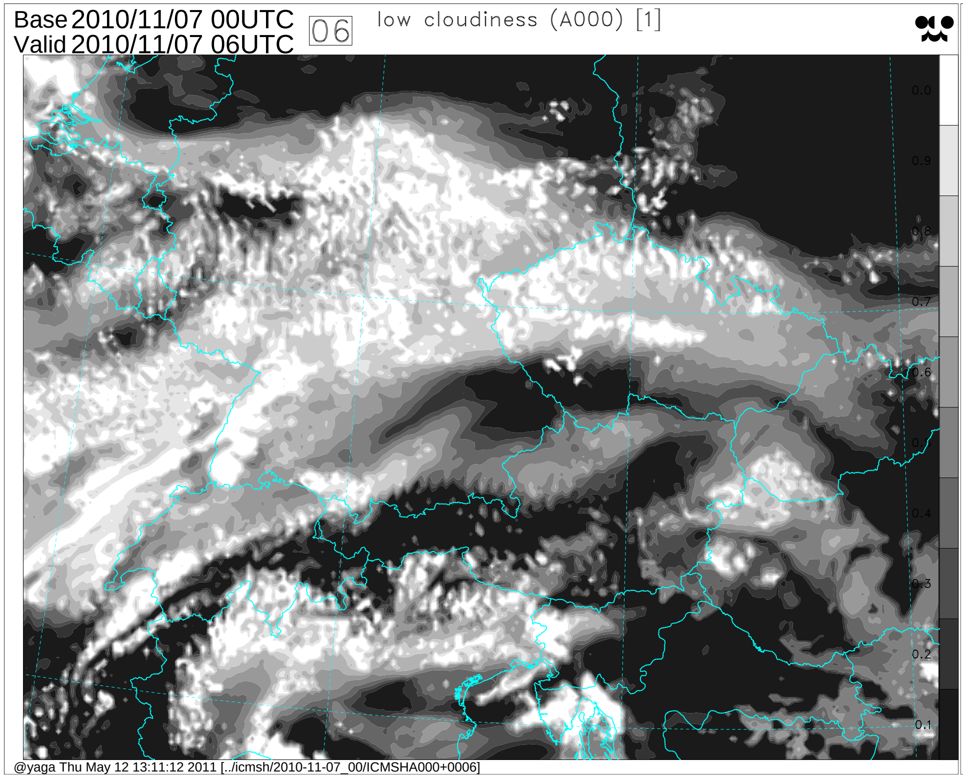
old diffusion tuning

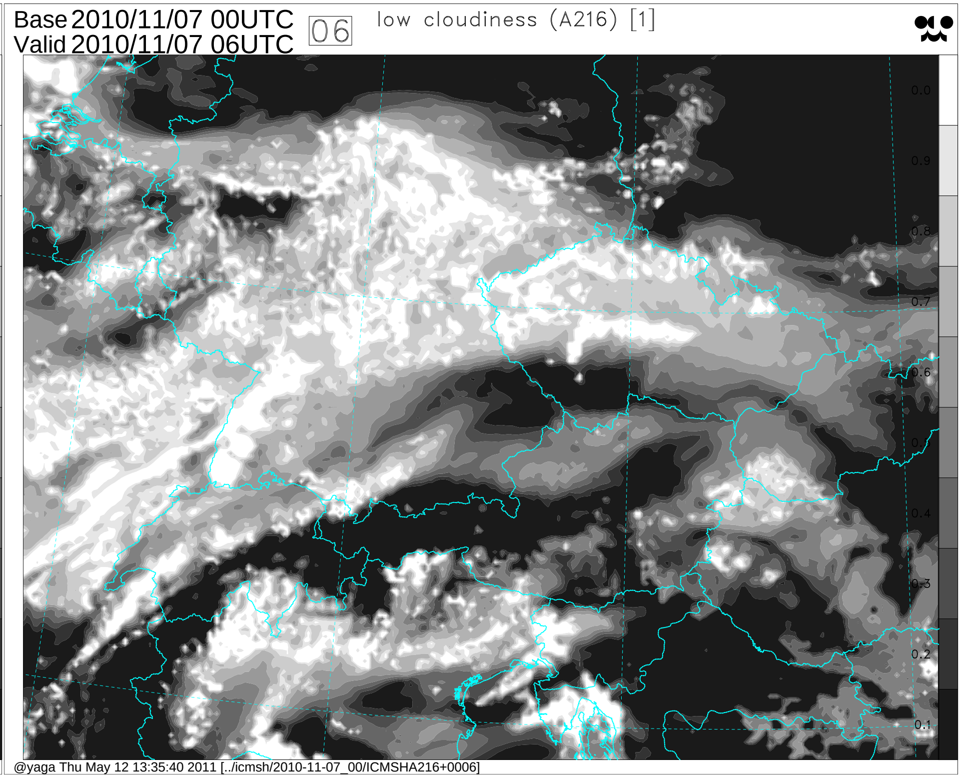


new diffusion tuning

Results with retuned spectral diffusion (2)

low cloudiness





old diffusion tuning

new diffusion tuning

Conclusions

- use of numerical diffusion as a noise filter in coupled system of equations can have surprising consequences

- too strong linear diffusion on horizontal divergence can cause spurious orographic response due to feedback between momentum and continuity equations

- satisfactory solution is to weaken (or completely prevent) linear diffusion on divergence in tropopause, leaving all the work to more physical nonlinear diffusion

- nonlinear diffusion modulated by horizontal flow deformation rate is softer thanks to the fact that it does not affect dominant linear part of orographic response