Ideal share between horizontal turbulence and numerical diffusion
Testing different parts of SLHD on 1km resolution

RC-LACE stay report

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Introduction

Horizontal diffusion is an important part of the NWP models to damp short waves that do not contain any predictive skill and to avoid the accumulation of energy at the end of the model spectrum. Furthermore, it plays a role representing the horizontal effects of turbulence and molecular dissipation, so it can be considered as a physical parameterization. Treatment of horizontal diffusion is possible with the Semi-Lagrangian horizontal diffusion (SLHD) scheme, which was developed in the ALADIN by Váňa et al. (2008). This scheme is implemented for both hydrostatic and non-hydrostatic versions of the ALADIN/ALARO/AROME model and it works well over a wide range of resolutions. However, its behavior in higher resolutions does not seem to be completely correct.

The SLHD scheme consists of three components, out of which the grid-point part is the most important. It is a flow-dependent nonlinear diffusion using Lagrangian interpolators. The other two components are spectral linear diffusions: the reduced spectral diffusion and the supporting spectral diffusion. A lot of tunable parameters belong to the three parts of the scheme. We wanted to know what can be obtained from the SLHD, so as a first step it was switched off completely, then the main grid-point part was turned up totally (through kappa=1) while keeping supporting and reduced spectral diffusion untouched. In the next step, we tried to determine the limits of diagnoses the behavior of the diffusion scheme by comparing kinetic energy spectra. We switched separately the spectral diffusion parts to see what the impact is on kinetic energy spectra at different model levels. An important and not yet answered question is how the correct behavior of the whole diffusion may be determined and whether the kinetic energy spectra can be used for this purpose.

The Czech operational model currently runs on 4.7 km resolution with 529x421 grid points over Central Europe and the hydrostatic approximation is used. In contrast to this, the experimental runs on 1 km resolution with the non-hydrostatic dynamics contain 853x489 grid points but they cover only the Czech Republic and Slovakia. Because of the different model domains the comparison with the operational run was not possible in most of the cases.

Our experiments were run on 14th October 2016 00UTC when the clouds completely dissolved in the operational run after 12h forecasts, meanwhile overcast weather was observed.

Focusing on the GP part of SLHD: kappa and deformation fields

The key part of the SLHD scheme is the grid-point part. The intensity of diffusion is calculated from the horizontal deformation field through the parameter kappa. In our first experiments kappa and deformation fields were visualized at different levels from the operational run on 4.7 km resolution

(OP01[a]) and on 1 km resolution with the same SLHD settings, as it is used operationally (CZ01[b]). Comparing these two runs we experienced big differences in the deformation values: on finer resolution deformation is bigger, as in the case of the parameter d_0, because this limit depends on the resolution:

- d_0= 0.00037369 for 1 km resolution and
- d_0= 0.000147367 for 4.7 km resolution.

As it can be read in the documentation (Váňa, 2006), d_0 is scale independent and it was chosen to be 75% quantile of the deformation. Figure 2 shows this 75% quantile of the deformation at different model levels. As it can be seen this value changes with the heights: on lower resolution it can be considered constant while on higher resolution this assumption is less applicable.

There was an idea that 3D deformation computation might help to improve the saturation of kappa. Therefore we implemented in the model the 3D formulation based on the Smagorinsky 3D scheme and we carried out an experiment (CZ07).

The current 2D formulation is the following:

$$D^2 = 0.25\,[D_{11}^2 - D_{22}^2] + D_{12}^2.$$

The 3D formulation:

$$D^2 = 0.5\,[D_{11}^2 + D_{22}^2 + D_{33}^2] + D_{12}^2 + D_{13}^2 + D_{23}^2, \text{where}$$

$$D_{11} = \frac{\partial u}{\partial x}, D_{22} = \frac{\partial v}{\partial y}, D_{33} = \frac{\partial w}{\partial z} \ll D_{11},$$

$$D_{12} = \frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right),$$

$$D_{13} = \frac{1}{2}\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right) \sim \frac{1}{2}\frac{\partial w}{\partial x},$$

$$D_{23} = \frac{1}{2}\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right) \sim \frac{1}{2}\frac{\partial w}{\partial y}.$$

Therefore

$$D = \frac{1}{2}\sqrt{2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2\right] + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2}.$$

This equation was implemented in experiment CZ07, but the results do not show too much improvement. The kinetic energy spectrum did not change at all, however, in the deformation and kappa fields the orography was outlined even at the top of the atmosphere.

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[a] OP01 SLHD namelist settings:

```
&NAMDYN
RDAMPDIV=1., RDAMPDIVS=10., RDAMPQ=0., RDAMPT=1., RDAMPVOR=1.,
RDAMPVORS=10., REXPDH=2., RRDXTAU=123., SDRED=1., SLEVDH=0.1, SLEVDHS=1.,
SLHDA0=0.25, SLHDB=4., SLHDD00=6.5E-05, ZSLHDP1=1.7, ZSLHDP3=0.6,/
&NAMDYNA
LSLHD_OLD=.F., LSLHD_T=.T., LSLHD_W=.T., SLHDEPSH=0.016, SLHDEPSV=0.,
SLHDKMAX=6., SLHDKMIN=-0.6,/
```

[b] CZ01 SLHD namelist settings (the same as OP01 supplemented with non-hydrostatic variables):

```
&NAMDYN
RDAMPDIV=1., RDAMPDIVS=10., RDAMPQ=0., RDAMPT=1., RDAMPVOR=1.,
RDAMPVORS=10., RDAMPPD=5., RDAMPVD=1., RDAMPVDS=15., REXPDH=2.,
RRDXTAU=123., SDRED=1., SLEVDH=0.1, SLEVDHS=1., SLHDA0=0.25, SLHDB=4.,
SLHDD00=6.5E-05, ZSLHDP1=1.7, ZSLHDP3=0.6,/
&NAMDYNA
LSLHD_OLD=.F., LSLHD_T=.T., LSLHD_W=.T., LSLHD_SPD=.T., LSLHD_SVD=.T.,
SLHDEPSH=0.016, SLHDEPSV=0., SLHDKMAX=6., SLHDKMIN=-0.6,/
```

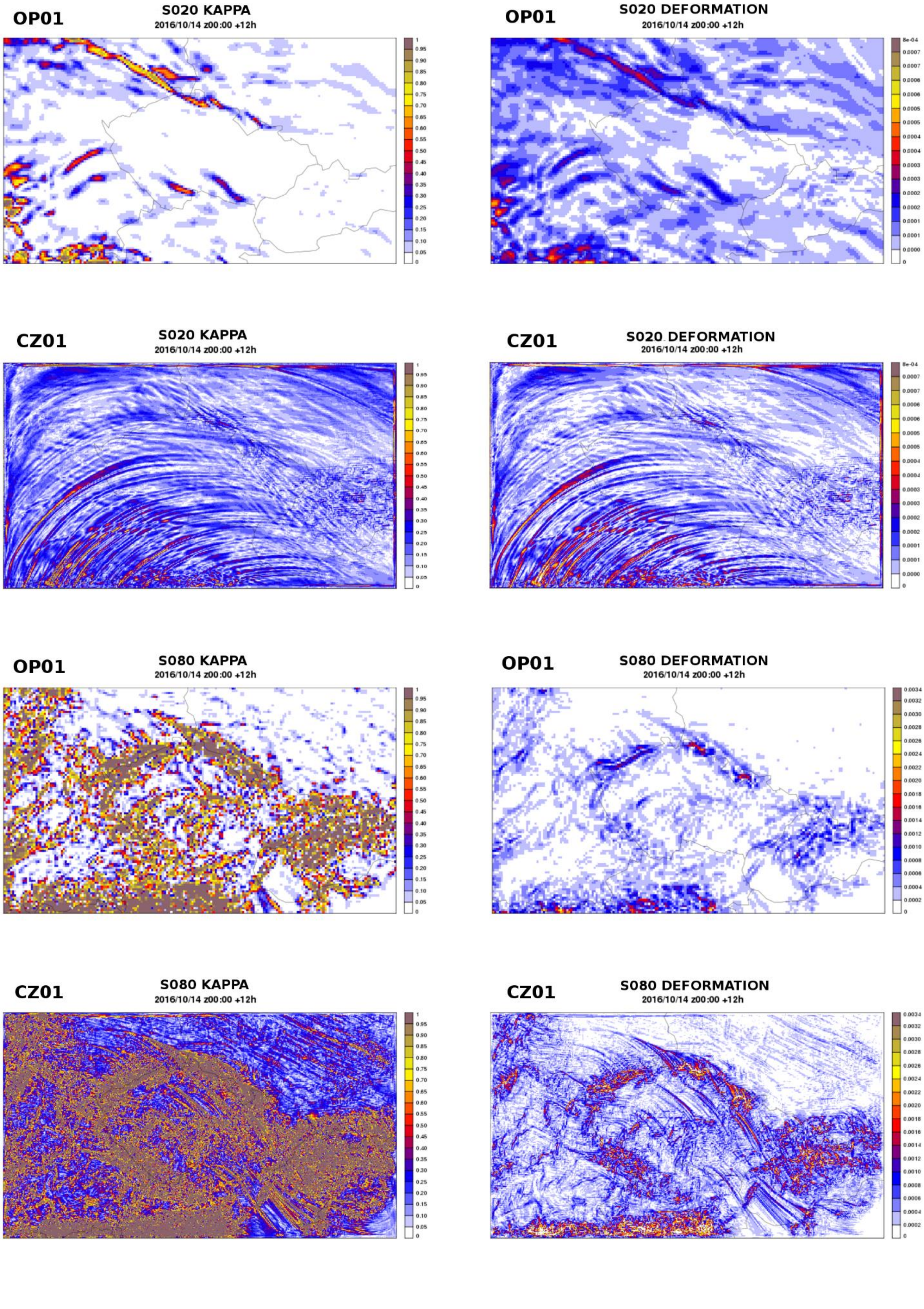

Figure 1: Kappa and deformation fields at different model levels on 4.7 km (OP01) and 1 km (CZ01) resolution

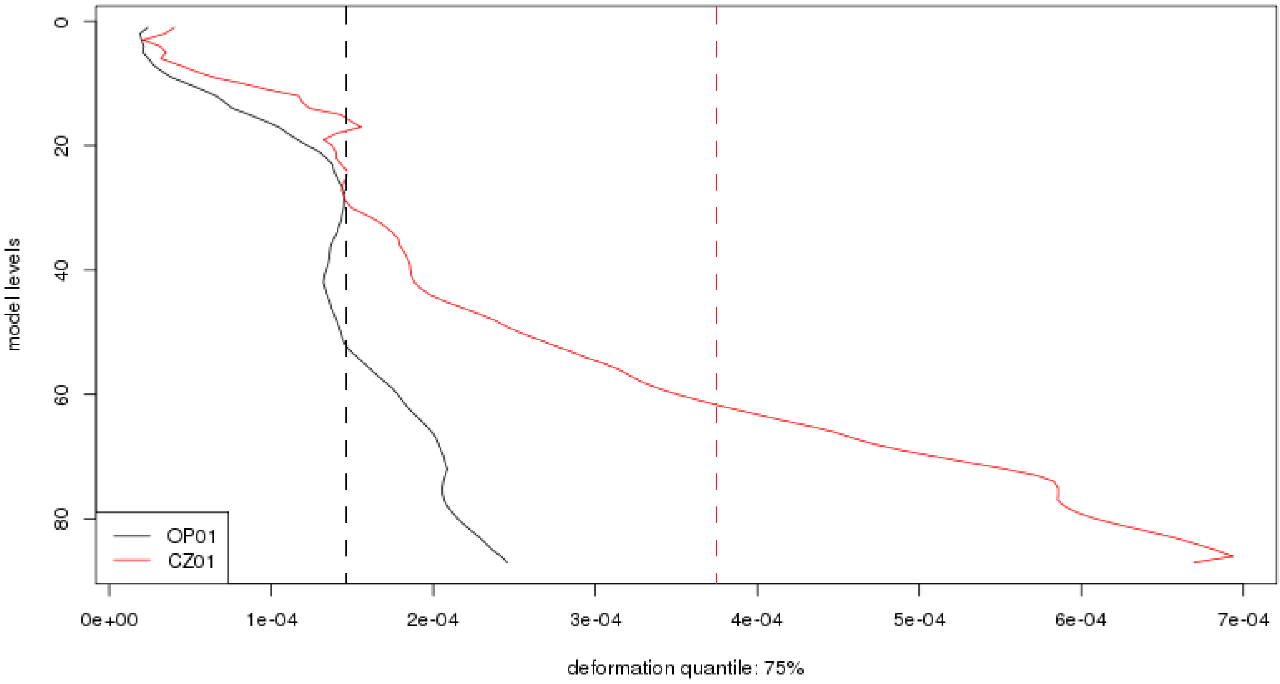

Figure 2: The 75% quantile of deformation at different levels in the experiment OP01 and CZ01 (different resolution). Dashed line indicates the d_0 value on 4.7 km resolution (black) and on 1 km resolution (red).

In this experiment we saw much bigger values in deformation, which means kappa became 1 on a larger domain than before, especially at higher levels (e.g. above S020) where kappa is usually already smaller than 1 on the whole domain, but in this case the structure at higher levels is similar to the structure at lower levels (as it follows the terrain). Meanwhile, there are no changes in the kinetic energy spectra at different levels.

Impact of the SLHD on different variables

Another thing that we tried during the stay was some experiments where SLHD for different variables was switched off separately. Table 1 shows the setup of these experiments and in Figure 3 low cloud cover can be seen in these different runs. As a reference picture satellite image shows the actual cloud cover in Figure 4. The most of these experiments do not give more cloud, except for the last one, when SLHD was not applied on horizontal wind (CZ05). When comparing the kinetic energy spectra for our experiments, we may see that SLHD not being applied on non-hydrostatic variables (CZ03) produces noise of short wavelengths, while the case when SLHD not being applied on horizontal flow (CZ05) gives more pronounced damping in lower model levels. It seems that the changes in the SLHD setup of hydrometeors and temperature give the smallest impact.

Table 1: SLHD settings for the different experiments. Checkmarks indicate those namelist variables that were set to TRUE and crosses indicate the FALSE logical variables whose names are at the top of the columns.

	Nonfalling hydrometeors (YQ_NL%LSLHD, YI_NL%LSLHD, YL_NL%LSLHD)	Pressure departure (LSLHD_SPD), vertical divergence (LSLHD_SVD)	Temperature (LSLHD_T)	Horizontal flow components (LSLHD_W)
CZ01	✓	✓	✓	✓
CZ02	✗	✓	✓	✓
CZ03	✓	✗	✓	✓
CZ04	✓	✓	✗	✓
CZ05	✓	✓	✓	✗

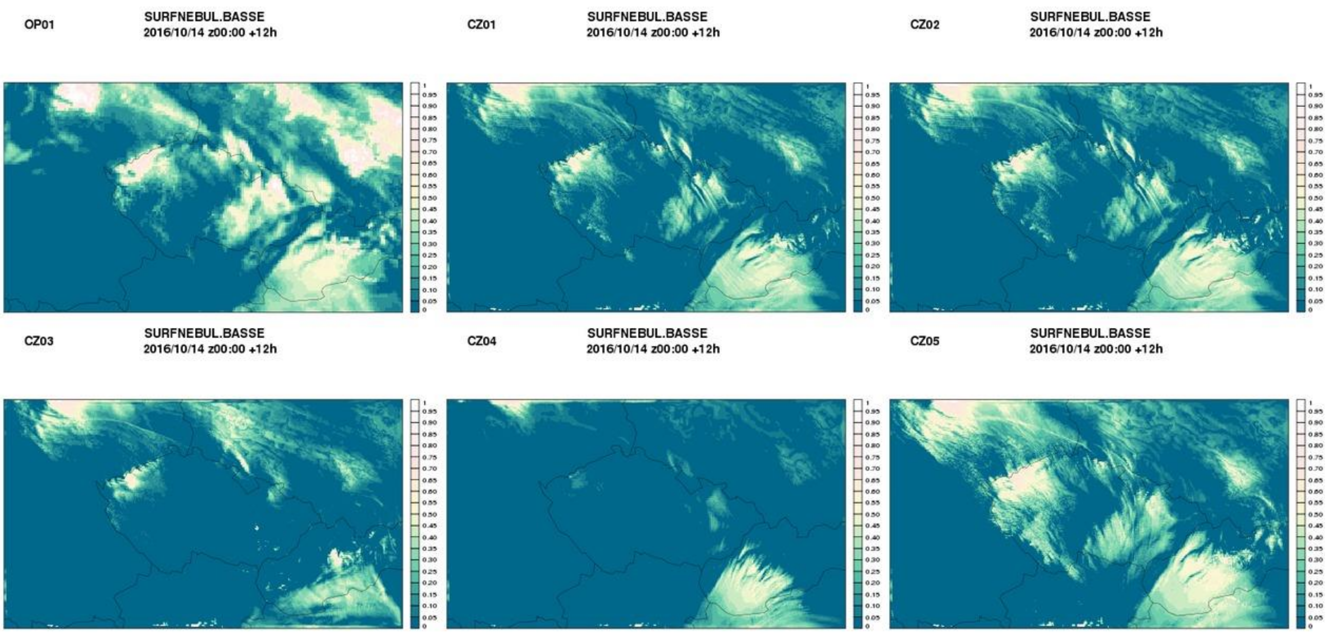

Figure 3: Low cloud cover over the Czech Republic according to different model runs (CZ01-CZ05: see Table 1 for settings) on 1 km resolution. OP01 shows operational version.

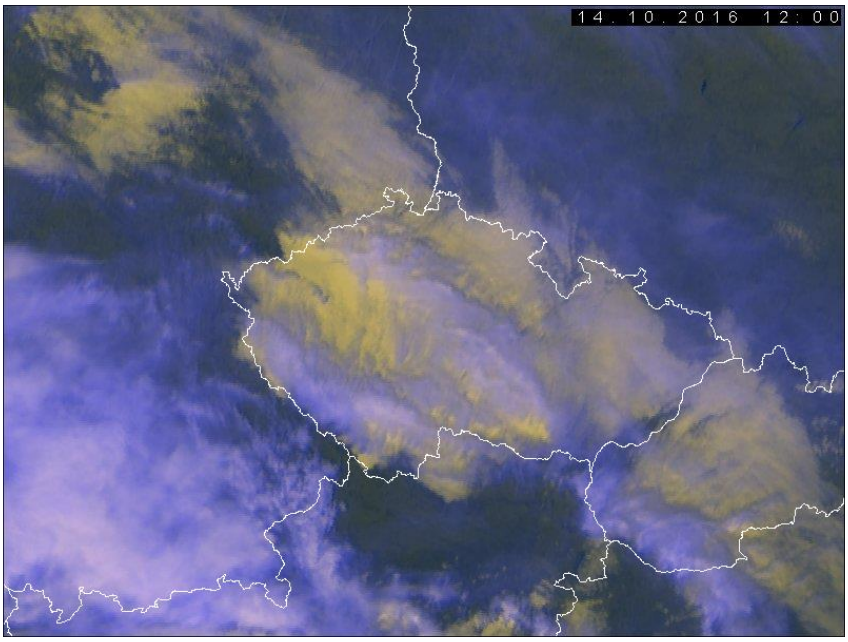

Figure 4: Satellite image about the clouds over the Czech Republic on 14/10/2016 at 12UTC.

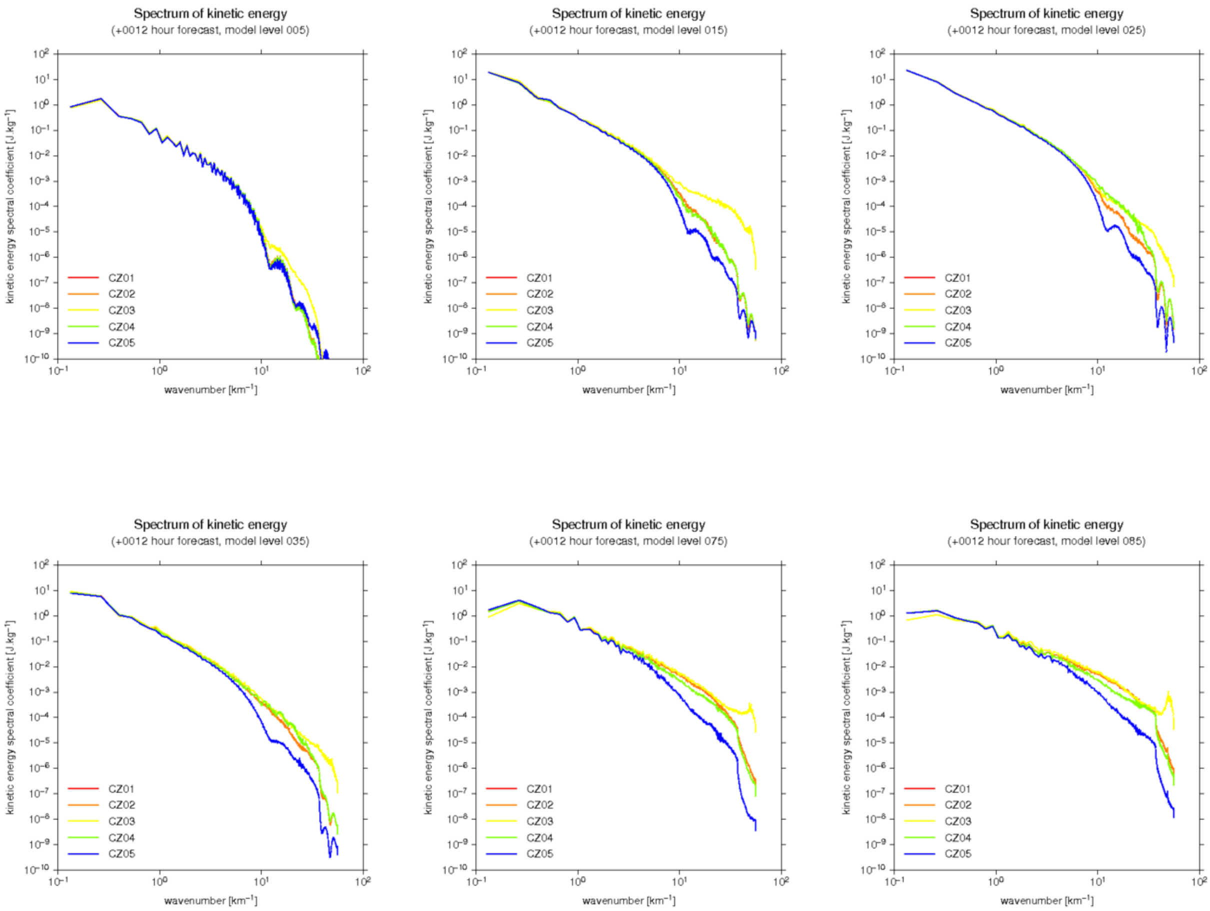

Figure 5: Kinetic energy spectra at different model levels according to different model runs (CZ01-CZ05: see Table 1 for settings)

Impact of the reduced and supporting spectral diffusion

The most important component of SLHD is the grid-point part but two spectral diffusions were also introduced to avoid some undesirable effects (Váňa et al, 2008). In the following experiments we tried to switch on and off the different components and in order to compare the result we ran an experiment with the classical spectral diffusion settings without grid-point diffusion (CZ08[c]) and another experiment without any diffusion at all (CZ10). We tried an experiment with smaller RRDXTAU (CZ11) to keep the spectral coefficients on the same value as on lower resolution, so the original value (126) was divided by the resolution changes (4.7) and this is why in experiment CZ11 RRDXTAU was set to 26.

The spectra of kinetic energy can be seen on Fig 6. Reduced spectral diffusion works only at the higher levels (S001-S011), so at lower levels the spectra are the same in experiments CZ01 and CZ16, as in the case of CZ14 and CZ15.When we changed the definition of kappa and it was set to the constant value 1 to maximize the effect of the grid-point part, we did not see any impact in the energy spectra in these cases.

Table 2: The settings of the three parts of SLHD in the different model runs.

	Grid-point	Supporting spectral	Reduced spectral
CZ01	kappa from deformation	✓	✓
CZ14	kappa from deformation	✗	✗
CZ15	kappa from deformation	✗	✓
CZ16	kappa from deformation	✓	✗
CZ17	kappa=1	✓	✓
CZ18	kappa=1	✗	✓
CZ19	kappa=1	✓	✗
CZ20	kappa=1	✗	✗

Summary

The experiments run during the stay have proved the need for the retuning of the SLHD settings. The runs showed that kappa is almost 1 everywhere, which is not the feature that we expect. Besides, reduced spectral diffusion seems too strong on finer resolution. From among our experiments it was experiment CZ11 with smaller RRDXTAU value which gave the most acceptable result, but further investigation is still needed concerning the tuning of the scheme.

New experiments with different resolutions have been prepared on a similar domain so that better comparison is possible to gain more information about the behavior of SLHD. This is what we are going to continue to work with next year.

Acknowledgment

I would like to thank Petra Smolíková for all her help and guidance during my stay.

[c] CZ08 relevant namelist settings: `RDAMPDIV=20. RDAMPQ=20., RDAMPT=20., RDAMPVOR=20., RDAMPPD=200000., RDAMPVD=20.; RDAMPDIVS, RDAMPVORS, RDAMPVDS, REXPDH, RRDXTAU` used as default and SLHD logical variables were set to false.

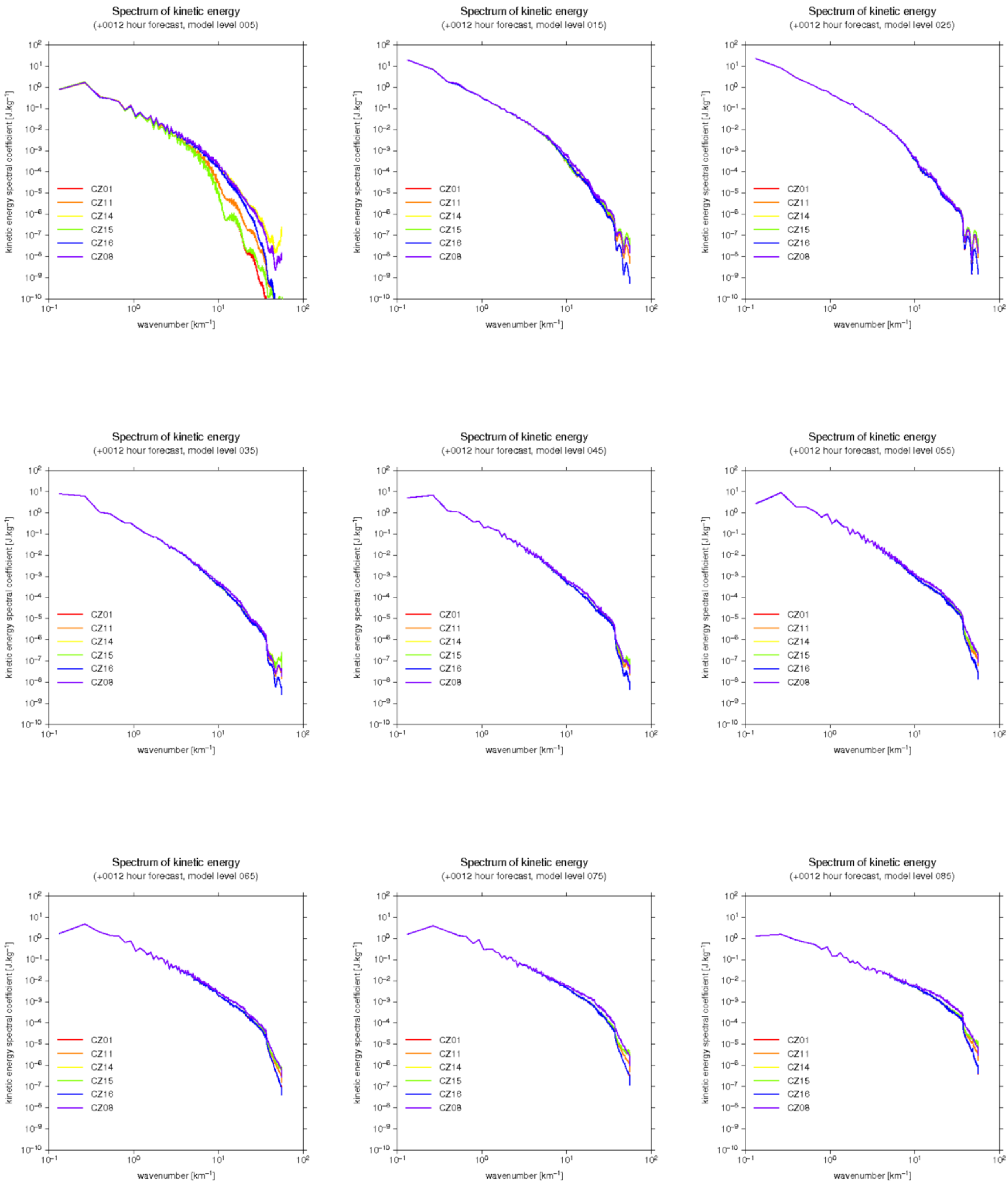

Figure 6: Kinetic energy spectra at different model levels according to different model runs

References

Váňa, F., (2006): Semi-Lagrangian horizontal diffusion in ALADIN/ARPEGE, http://www.umr-cnrm.fr/gmapdoc/spip.php?article145

Váňa, F., Bénard, P., Geleyn, J.-F., Simon, A. and Seity, Y. (2008): Semi-Lagrangian advection scheme with controlled damping: An alternative to nonlinear horizontal diffusion in a numerical weather prediction model. Q.J.R. Meteorol. Soc., 134: 523–537. doi:10.1002/qj.220