Examination of vertical diffusion of vertical velocity in 2D experiments with ALADIN-NH

LACE stay report
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1) Introduction

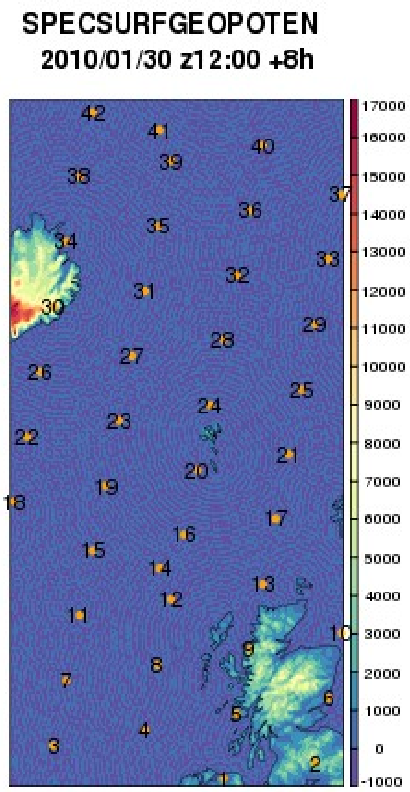
This work is the continuation of the last year's LACE stay in Prague with the topic: "Feasibility study to add the physical tendency of vertical velocity to the adequate prognostic (NH) variable". At that time we made the needed modifications in the model to count with the vertical diffusion of vertical velocity variable (VDW). The details are described in the report from that stay.

This time we looked at the effect of VDW in vertical 2D experiments. We also wanted to know the influence of the resolutions so we made series of runs with various vertical (dz = 10, 20, 40 m) and horizontal (dx = 10, 20, 40, 100 m) grid-sizes. The scale of the impact of the VDW was then observed through vertical mean profiles of the differences of potential temperature and horizontal wind.

2) Vertical velocities in a real case

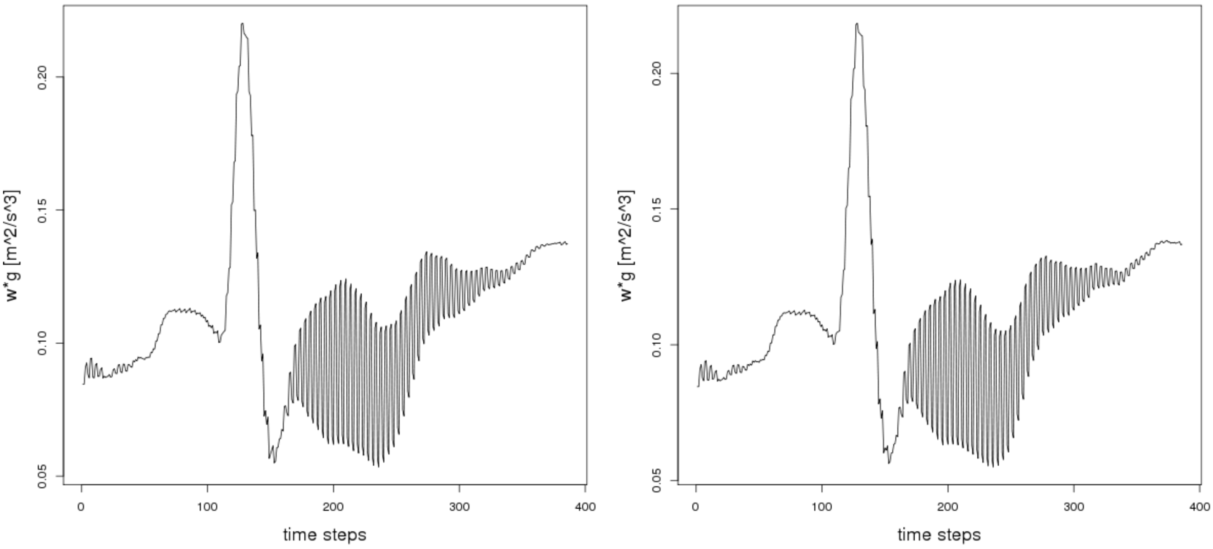
Before the 2D experiments, we checked the development of the vertical velocity. We were looking for instability to be sure, that our modification doesn't have any negative effect on the vertical velocity.

Previously in the last year's work we examined the impact of the VDW in a real case near the British Isles from 2010. We wrote out the *wg* (*w* vertical velocity multiplied by the *g* gravity acceleration) values from some grid-points (every grid-point with index NPROMA=955) in every time-step on the 85. vertical model level (the total number of levels was 87):



1) Points where the development of the wg was examined (on the 85. model level).

In a couple of these grid-points we detected some instability (*figure 2)*), but this instability occurred both times, whether we added or didn't add VDW, so it wasn't the reason of them. We also tried it with vertical velocity (LGWADV=T) and with vertical divergence (LGWADV=F) as the vertical velocity variable and we got the same result.



2) The wg on the 85. model half-level in the point number 27. Left: without VDW (LGWADV=T), right: with VDW (LGWADV=T).

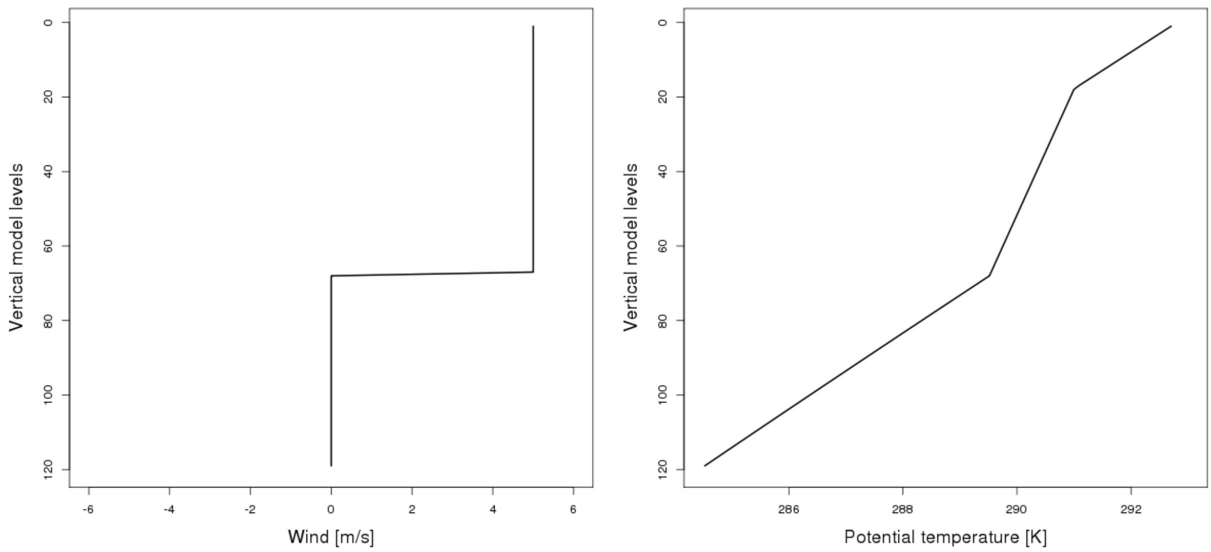
3) 2D experiments

In our vertical 2D experiments we wanted to simulate eddies, to see how the VDW influences the results in a highly turbulent case. To get these eddies we set the initial conditions containing strong wind shear and stratified temperature profile, ideal for the Kelvin-Helmholtz instability. The 2D field was 1200 m high and the height of the horizontal wind shear was 520 m, where the wind-speed changed from 0 m/s to 5m/s (*figure 3) left*). In the same height is a break in the potential temperature profile (*figure 3) right*), under which the profile is isotherm. We built in a small orographic disturbance to trigger the eddies. Without it no eddy was generated.

Note that in every case we used vertical velocity as the vertical velocity variable (LGWADV=T), and we applied constant lateral boundary conditions (not cyclical).

If we want to use the VDW modification, we have to run our experiments with the parametrization the of the turbulence, because the VDW is estimated from the values which appear during the computation of the turbulent kinetic energy in the part of the code called TOUCANS (Third Order moments Unified Condensation Accounting and N-dependent Solver for turbulence and diffusion). However, in case the turbulence is turned on, it inhibits the development of the eddies. We tested a case, where we initialized the run with an output from an other experiment in which the eddies had been already there and turned on the turbulence. In this case the eddies were washed away.

So we had to modify the code. We set the turbulent fluxes to zero in the CPTEND_NEW. This way the VDW is computed and used while the turbulence does not have effect on the results. So we compared the outputs from the experiments without the VDW and turbulence and the outputs with the VDW and the unused but turned on turbulence.

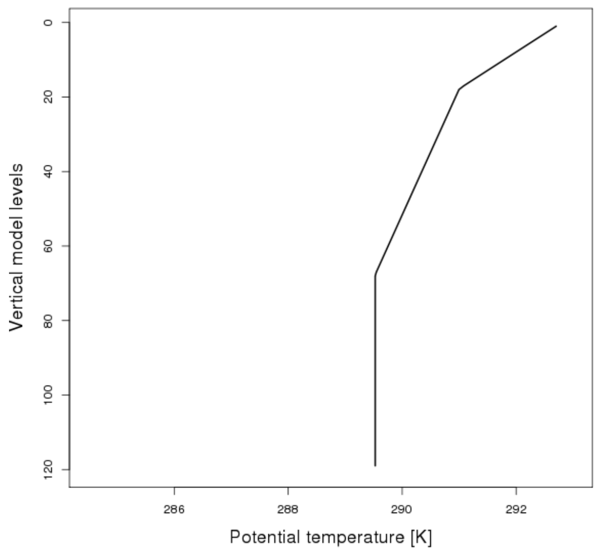


3) The initial profile of the wind and the potential temperature in the 2D experiments.

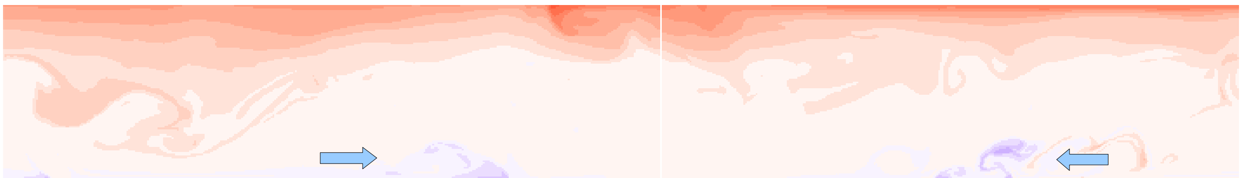
We made series of experiments with various vertical and horizontal resolutions to see the dependency on the resolution (the time step was 0.5 s in every case):

Experiment	Number of vertical levels	Number of grid-points in 1 level	Vertical resolution [m]	Horizontal resolution [m]
1)	120	800	10	10
2)	120	400	10	20
3)	120	200	10	40
4)	60	800	20	10
5)	60	400	20	20
6)	60	200	20	40
7)	30	800	40	10
8)	30	400	40	20
9)	30	200	40	40
10)	120	200	10	100
11)	60	200	20	100
12)	30	200	40	100

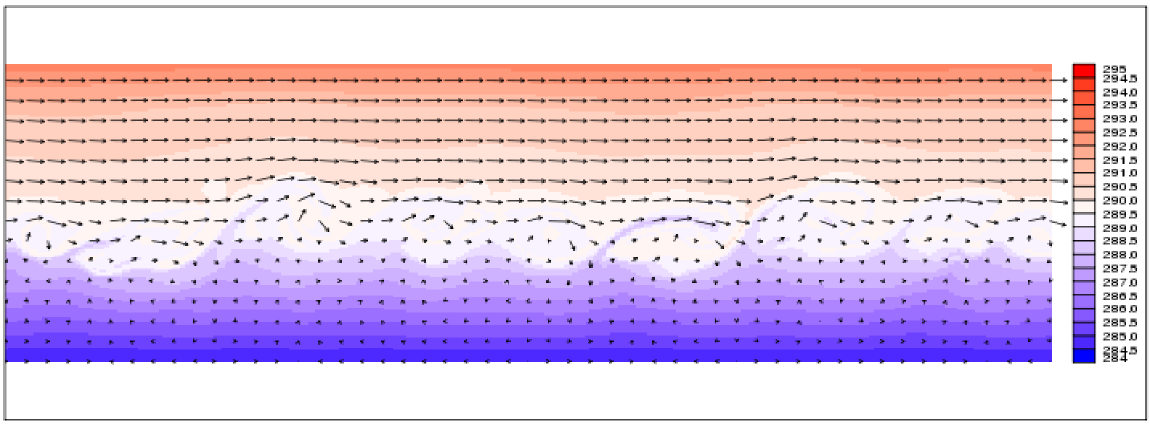
We also tried what happens, if we use constant potential temperature in the lower part of the field instead of isotherm profile (*figure 4)*). In this case the mixture was too strong and false reflected movements appeared form the lateral boundaries (*figure 5)*), so we stayed at the much more stable isotherm profile.



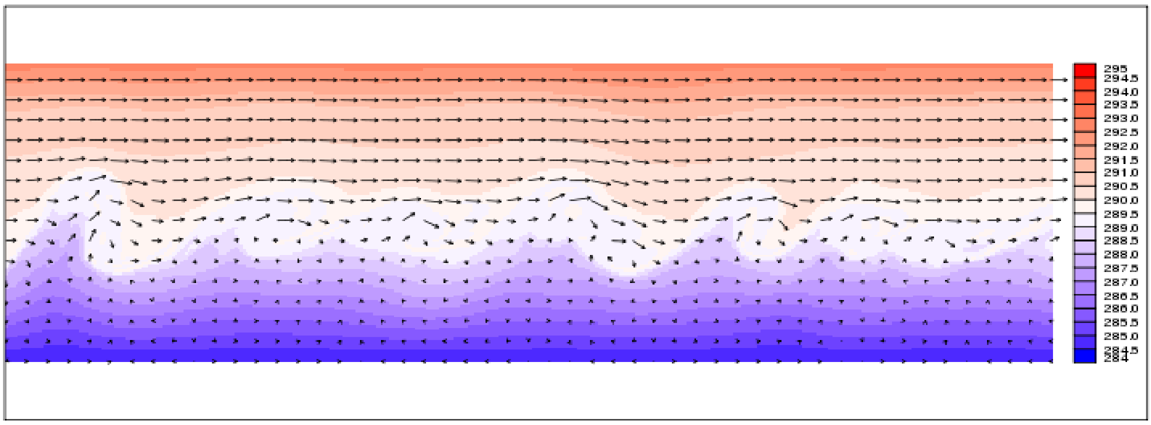
4) The initial profile of the potential temperature in the 2D experiment with constant potential temperature at the lower part of the field.



5) The potential temperature field in the 6000. time step of the experiment with constant potential temperature at the lower part of the field. Check the false "cold fronts" moving from the sides.



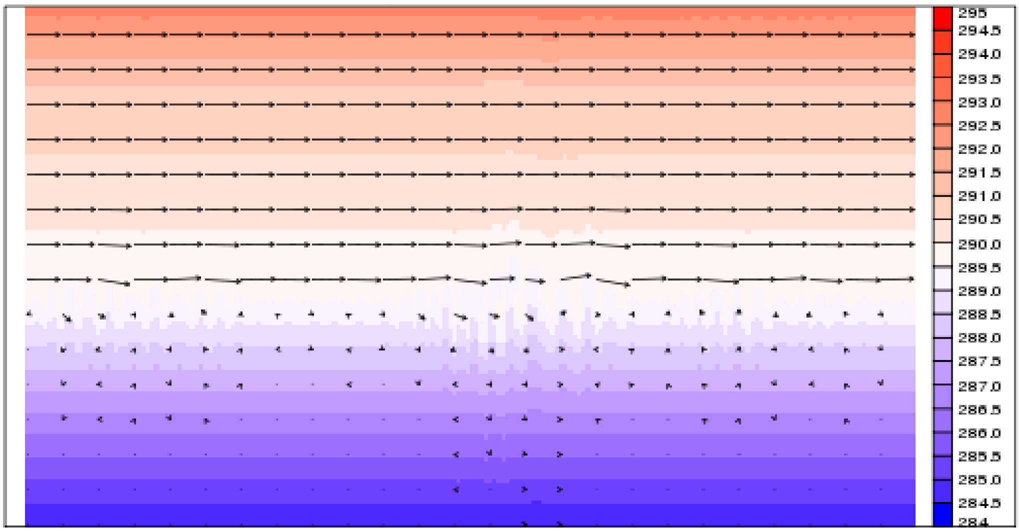
6) The potential temperature field [K] with wind arrows in the 2000. time step of the experiment with dx = 10 m, dz = 10 m, without VDW (from 200. to 600. horizontal grid-point).



7) The potential temperature field [K] with wind arrows in the 2000. time step of the experiment with dx = 10 m, dz = 10 m, with VDW (from 200. to 600. horizontal grid-point).

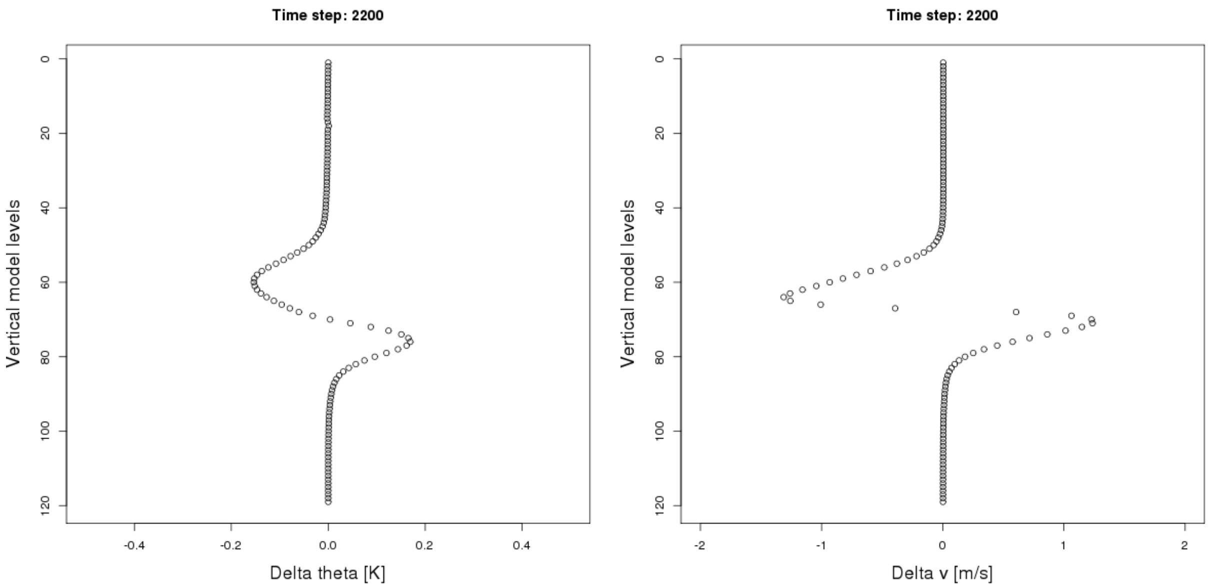
As can be seen in the *figure 6)* and 7*)*, due to the chaotic behavior, the VDW modification makes the eddies develop elsewhere then if the VDW is turned off. It would be quite difficult to compare the vertical velocities in two fields full of eddies which are not in the very same place, because the amplitudes of the differences would be as high as the values itself, while the average values wouldn't differ so much. So we rather decided to compare the mean profiles of the potential temperature and horizontal wind. We also studied the differences of the standard deviations of the vertical velocity.

Our simulations were 4500 s long with 0.5 s time step. We followed the development of the profiles of differences via .gif animations to deduce the effect of the VDW and the resolution. Note that the horizontal means (and standard deviation) for the profile were calculated from the 75 % of one level (without the 12.5 % from both sides) to leave out the unrealistic boundary effects.

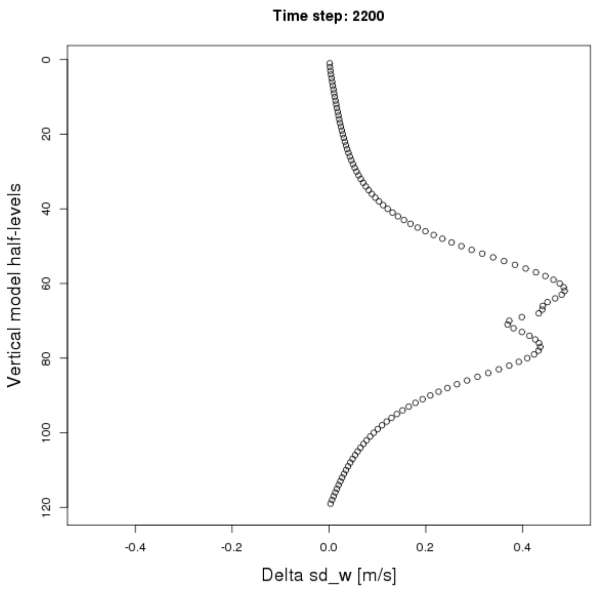


8) The potential temperature field [K] with wind arrows in the 2200. time step of the experiment with dx = 100 m, dz = 10 m, without VDW.

Experiments *1) - 9)* were made in a physical domain with the same size (1200 m high and 8000 m long) but the resolutions were changed. The developments of the profiles of potential temperature differences do not vary very much in this range of resolution (dx & dy = 10 - 40 m). At various horizontal resolutions they have similar amplitude, usually around 0.2 K. Only the smoothness and the variability in time is higher at higher resolution. The same is true for the vertical resolution, but there is a little bit lower amplitude at lower vertical resolutions.



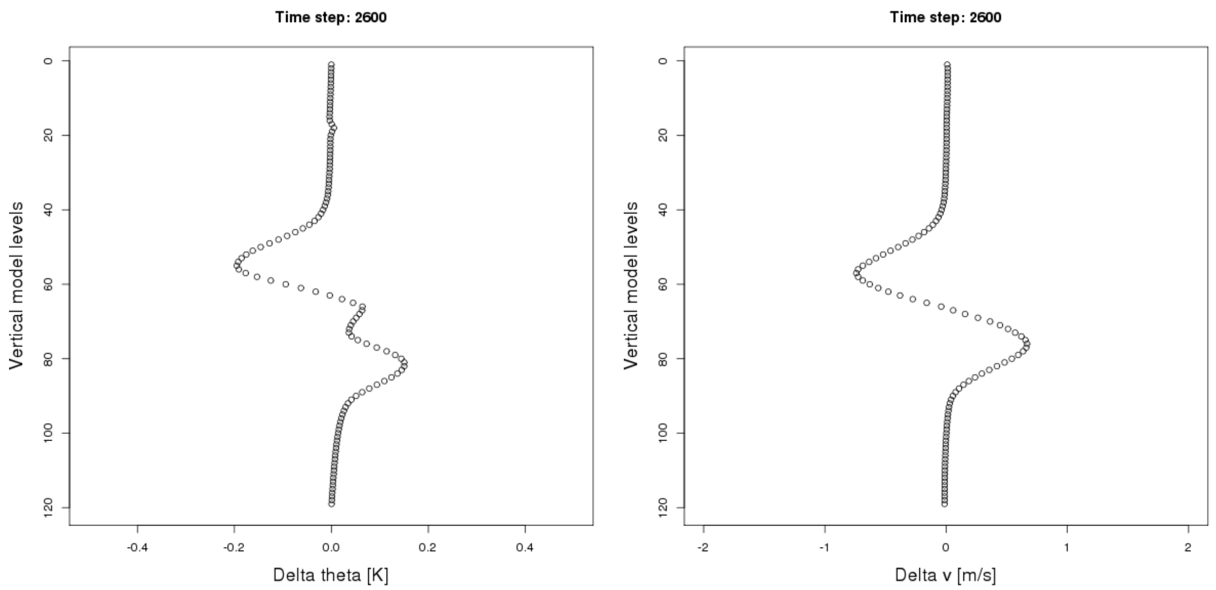
9) Profile of the differences of the mean potential temperature (left) and horizontal wind (right) between the cases with and without VDW at the 2200. time step in experiments with dx = 100 m and dz = 10 m.



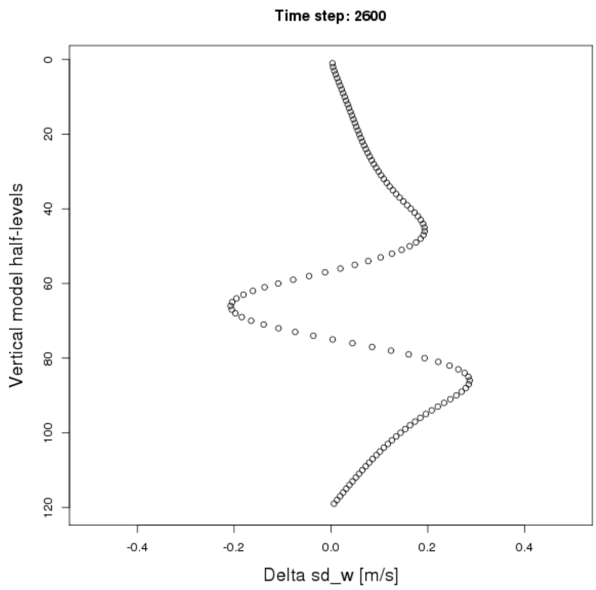
10) Profile of the differences of the standard deviation between the cases with and without VDW at the 2200. time step in experiments with dx = 100 m and dz = 10 m.

We also can say that the profiles of potential temperature differences at lower vertical resolutions develop slower because the eddies in this case develop slower too.

The experiments *10) -12)* were run in a domain which is 1200 m high and 20000 m long, the horizontal resolution was dx = 100 m, the vertical resolution was dy = 10 - 40 m. The developments of the profiles of potential temperature differences here were much more stable and the differences between the experiments with various vertical resolutions were more conspicuous.

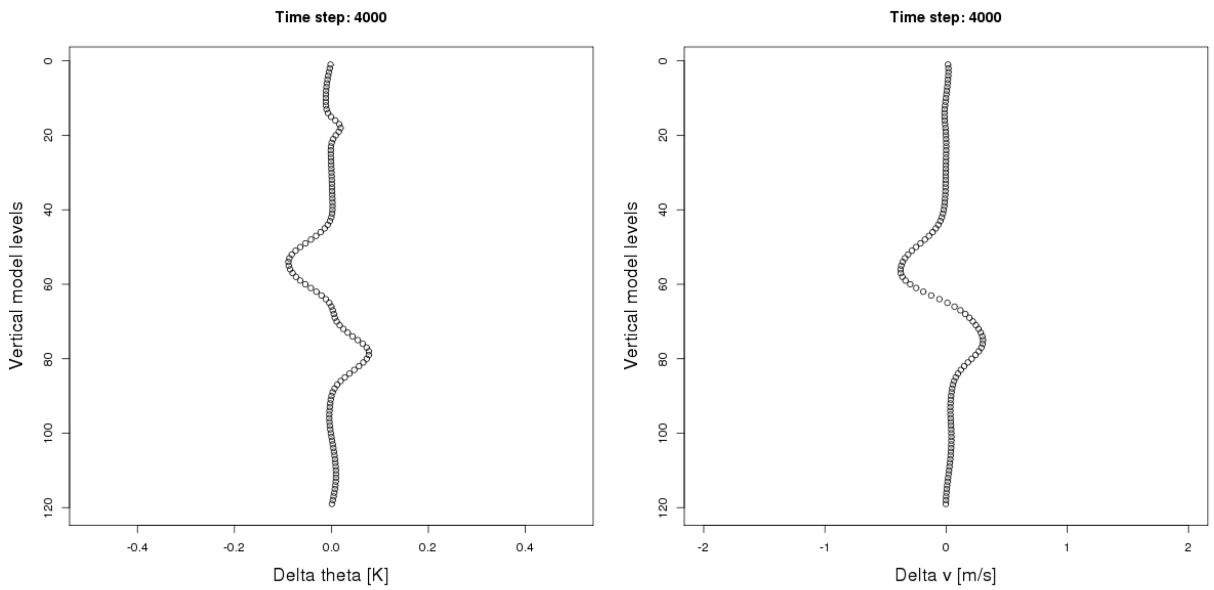


11) Profile of the differences of the mean potential temperature (left) and horizontal wind (right) between the cases with and without VDW at the 2600. time step in experiments with dx = 100 m and dz = 10 m.

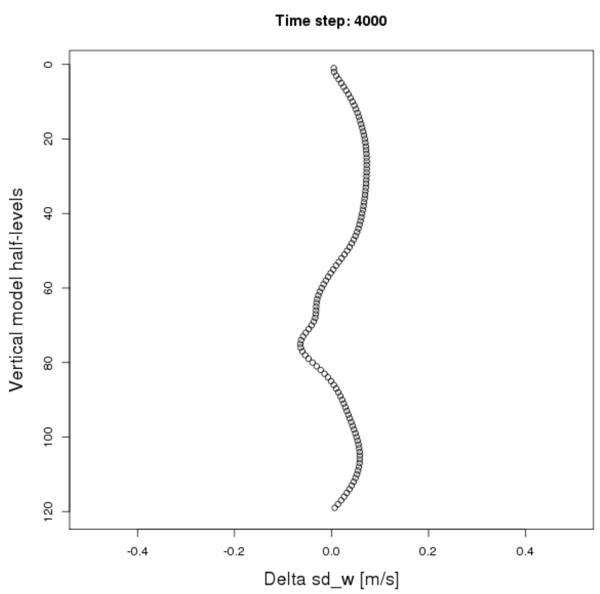


12) Profile of the differences of the standard deviation between the cases with and without VDW at the 2600. time step in experiments with dx = 100 m and dz = 10 m.

In the *figures 9) - 14)* can be seen the differences of the profiles between the runs with VDW and without VDW (the value with VDW minus the value without VDW) at times 1100, 1300 and 2000 s of the experiment *10)* (dx = 100 m and dz = 10 m). Around 1100 s (2200. time step) the amplitude of differences of the mean horizontal wind reaches the maximum (*figure 9 right)*) and it is more than 1 m/s. In the upper part of the region with eddies the difference is negative and in the lower part is positive, because the VDW brings up the low momentum and brings down the high momentum.



13) Profile of the differences of the mean potential temperature (left) and horizontal wind (right) between the cases with and without VDW at the 4000. time step in experiments with dx = 100 m and dz = 10 m.



14) Profile of the differences of the standard deviation between the cases with and without VDW at the 4000. time step in experiments with dx = 100 m and dz = 10 m.

The ±1 m/s could seem as quite high difference, but do not forget, that there is huge wind-shear, the wind-speed jumps up from 0 to 5 m/s inside one grid-size.

For the potential temperature the maximum difference comes around 100 s later and it is more than 0.2 K. Note that the difference between the top and the bottom of the potential temperature profile is around 8 K.

After the differences of potential temperature and horizontal wind reach their maximum, they start to slowly decrease, and then stabilize around one profile (*figure 13)*).

The maximum in the profile of the standard deviation of vertical velocity shows us the place of the center of the eddies. We can see in the *figure 10)* and *11)* how this maximum divides into two maximums. This is because between the two main layer with different horizontal wind-speed occurs an interlayer and the eddies start to be created on its two new boundaries upside and downside.

4) Summary

We tested the effect of the VDW with vertical 2D runs in the ALADIN-NH model. To achieve a really turbulent environment we set the initial and lateral conditions ideal for the Kelvin-Helmholtz instability. The small difference coming from the VDW modification resulted in the shift of eddies when compared to runs without the VDW. For this reason we compared not the whole fields but the mean profiles.

The experiments were made with various vertical and horizontal resolutions to see how the VDW depends on the grid-size. We found that in the range dx & dy = 10 - 40 m the resolution has impact on the variability in time and that at lower resolutions there are lower differences. For horizontal resolution dx = 100 m the differences in all fields are better developed.

The amplitude of differences in the mean potential temperature is in this case about ±0.2 K (at a profile with ~8 K difference between the top and the bottom) and near a wind-shear, where the wind-speed jumps up from 0 to 5 m/s, the mean wind-profile can differ by ±1 m/s.

5) Acknowledgments

Many thanks for the comfortable atmosphere during my stay in Prague at CHMI to everyone I have met there, especially to Perta Smolíková and Ivan Bašták Ďurán. Their precious help was indispensable for this job.