Examination of vertical diffusion of vertical velocity with ALADIN-NH CY38

LACE stay report
Prague – Czech Hydrometeorological Institute,
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1) Introduction

This work summaries and complements the previous two LACE stays concerning the vertical diffusion of vertical velocity variable. On the first stay the needed modifications were made in the ALADIN-NH CY36 model and tried on real cases. During the second stay it was tested with idealized vertical 2D experiments. Unfortunately the physical parametrization (TOUCANS - Third Order moments Unified Condensation Accounting and N-developement Solver for turbulence and diffusion) had not been completely finished that time. So this time we implemented this modification into the ALADIN-NH CY38 model and tested it with 2D experiments and real case experiments with full TOUCANS modification.

The vertical velocity variable (VDW) can be the vertical divergence (*d*) or the vertical velocity (*w*). The basic idea of the resolving of the vertical diffusion of VDW is to get the turbulent diffusion flux of the vertical velocity (F_w) from the turbulent kinetic energy (*e*), which is computed in TOUCANS. The F_w can be estimated by the equation:

$$F_w = -\rho \overline{w'w'} \approx -\frac{2}{3}\rho e \quad , \quad (1)$$

where ρ is the density of the air and w' is the turbulent part of vertical velocity. The tendency from the vertical diffusion (in the following just 'tendency') of *w* is then:

$$\left(\frac{\partial w}{\partial t}\right)_{diff} = -\frac{g}{m}\frac{\partial F_w}{\partial \eta} \quad , \qquad (2)$$

where g is the gravity acceleration constant, η is the vertical hybrid coordinate and $m = \partial\pi/\partial\eta$, where π is the hydrostatic pressure. This tendency is then passed to the dynamical core of the model.

Moreover, we have tested a more precise version of the second order momentum of the turbulent vertical velocity in our experiments defined by

$$\overline{w'w'} = e\frac{2}{3}\left[1 - \frac{(3\lambda_3 - \lambda_2)\left(1 + \frac{4\lambda_4 Ri_f}{(3\lambda_3 - \lambda_2)}\right)}{1 - Ri_f}\right] \quad , \quad (3)$$

where λ_2, λ_3, and λ_4 are constants of the turbulent scheme and Ri_f is the flux Richardson number (*Ivan Bašták Ďurán, Jean-François Geleyn, and Filip Váňa: TOUCANS documentation (2012), 13, eq. 80*).

2) Modifications

A new module was created with the name: yomwtend_extra.F90 in which we defined a global switch called LRWTEND, which may be used to turn on/off the effect of our modification. If LRWTEND = TRUE, the modification is applied. The default value is FALSE and it is listed in the namelist NAMWTEND_EXTRA:

```
&NAMWTEND_EXTRA
LRWTEND=.TRUE.
/
```

The F_w values are obtained on the level of the routine APLPAR from the routine ACPTKE. Then the routine CPTEND_NEW calculates from F_w the tendencies of w according to (2). In case LGWADV = FALSE (which means, the vertical velocity variable is d) the tendencies of w are transformed in the routine GNHGW2SVDAROME to tendencies of d. These tendencies are then passed to the routine CPUTQY. There they are multiplied by the time step and added to the main buffer, where the variables are stored.

The structure of CPG routine:

```
                  ┌─ ...             ┌─ ...             ┌─ ...
                  ├─ MF_PHYS ────────┼─ APLPAR ─────────┼─ ACPTKE
CPG ──────────────┼─ CPG_PT          ├─ CPTEND_NEW      └─ …
                  ├─ CPG_DYN         ├─ CPUTQY
                  ├─ ...             └─ …
                  └─ ...
```

3) 2D experiments

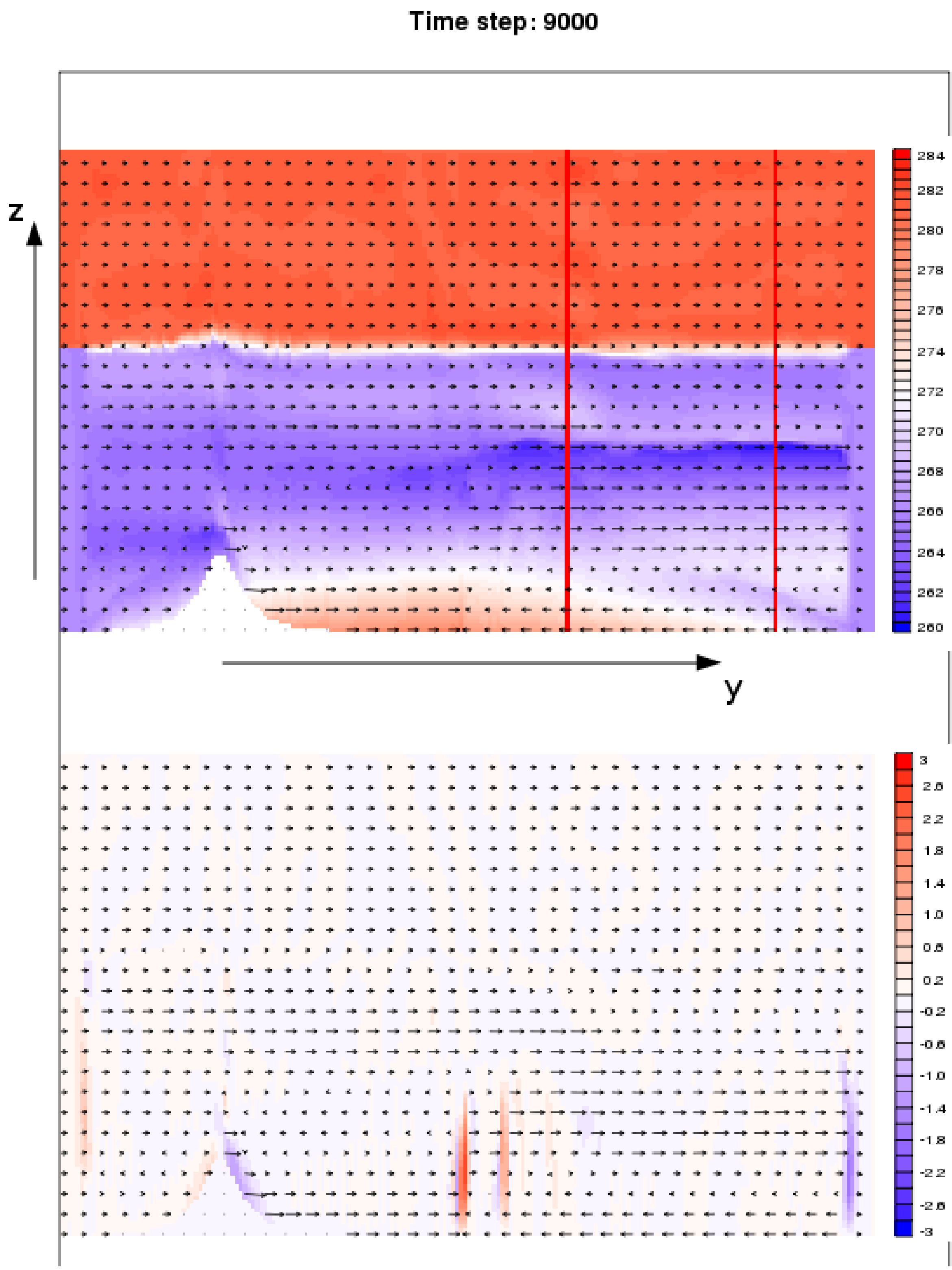
In the vertical 2D experiments we simulated lee waves behind a hill. The arrangement of the simulation is in the figure 1. The height of the hill is 1000 m. The seize of the domain is: 120 vertical levels (dz = 50 m) and 200 grid-points in the y direction (dy = 1000 m). The initial profile of the temperature and the potential temperature are in the figure 2. There are two isothermal layers divided by a strong inversion. The initial profile of the horizontal wind is homogeneously 3 m/s. The lateral conditions during the simulations are the same as the initial. The length of the simulation was 50 h (9000 time steps) and the used time-step was dt = 20 s. The VDW was set to w.

An important factor is that these simulations were made with physical parametrization set according to the actual Czech operational setting. As a consequence a convective updraft was generated in the middle of the domain. When we switch off the whole physical package, this updraft does not appear.

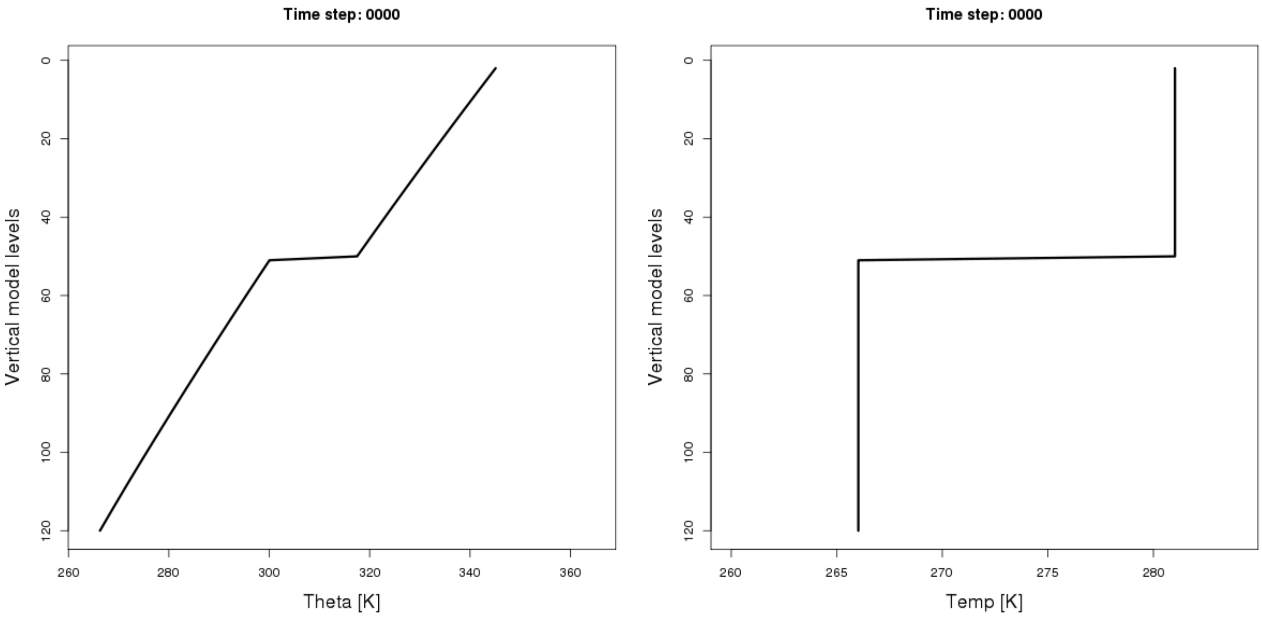
We prepared the mean profiles of the potential temperature, temperature and horizontal wind in the central domain between the two red lines in the figure 1 (horizontal grid-points from 126 to 175). These profiles at each time step from the beginning to the end of the simulation can be seen in the figure 3. To determine the range of the modification's effect we plotted the differences of the mean profiles of the potential temperature and the standard deviation of the vertical velocity from the previously used region. The difference-profiles are in the figure 4.

We also tested the setting with VDW being set to d in 2D experiments. The results were quite similar to the results with w (figure 5).

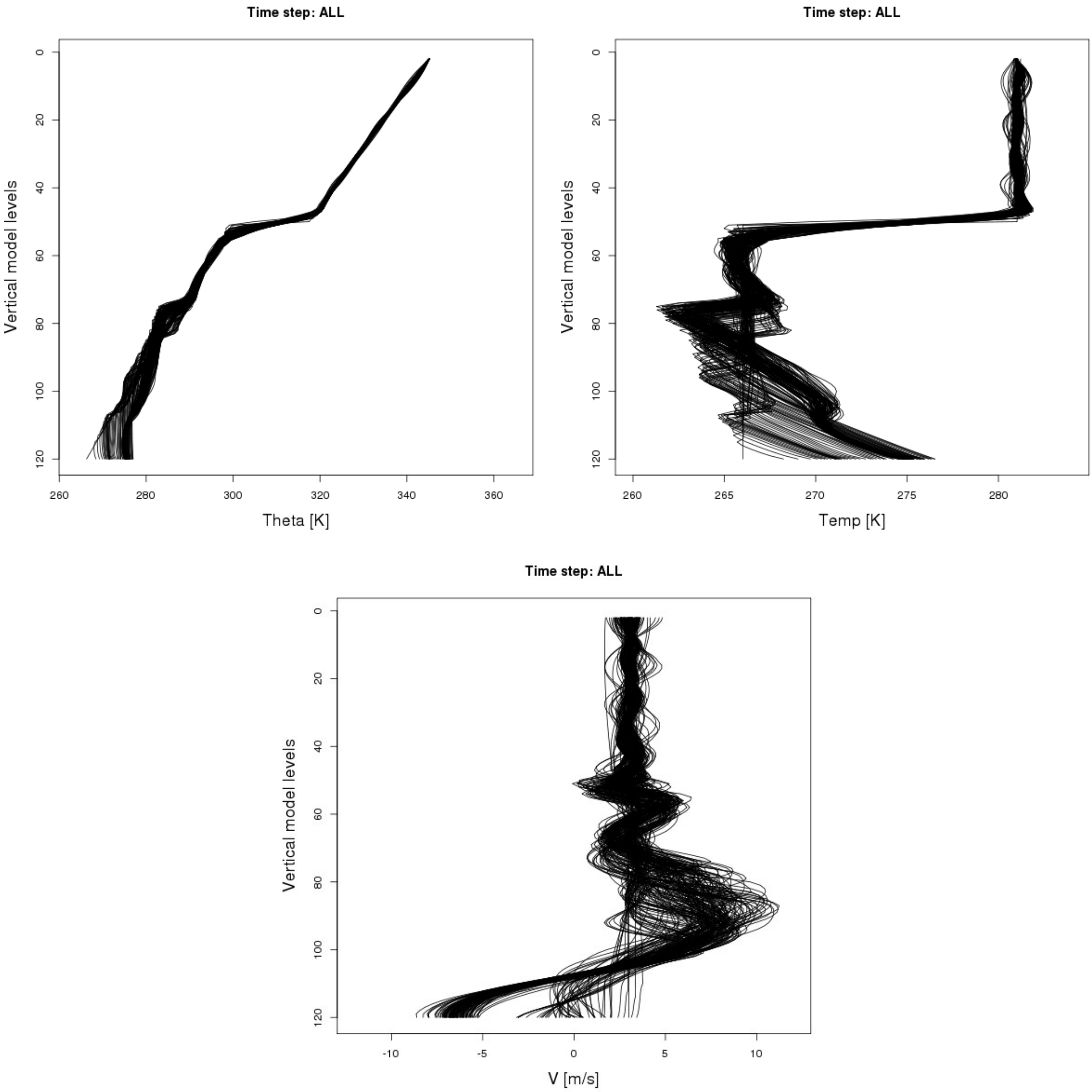
The observed maximum in the differences of the potential temperature vertical profiles was around 3 K and in the vertical profiles of standard deviation of w the maximum was close to 0.5 m/s.



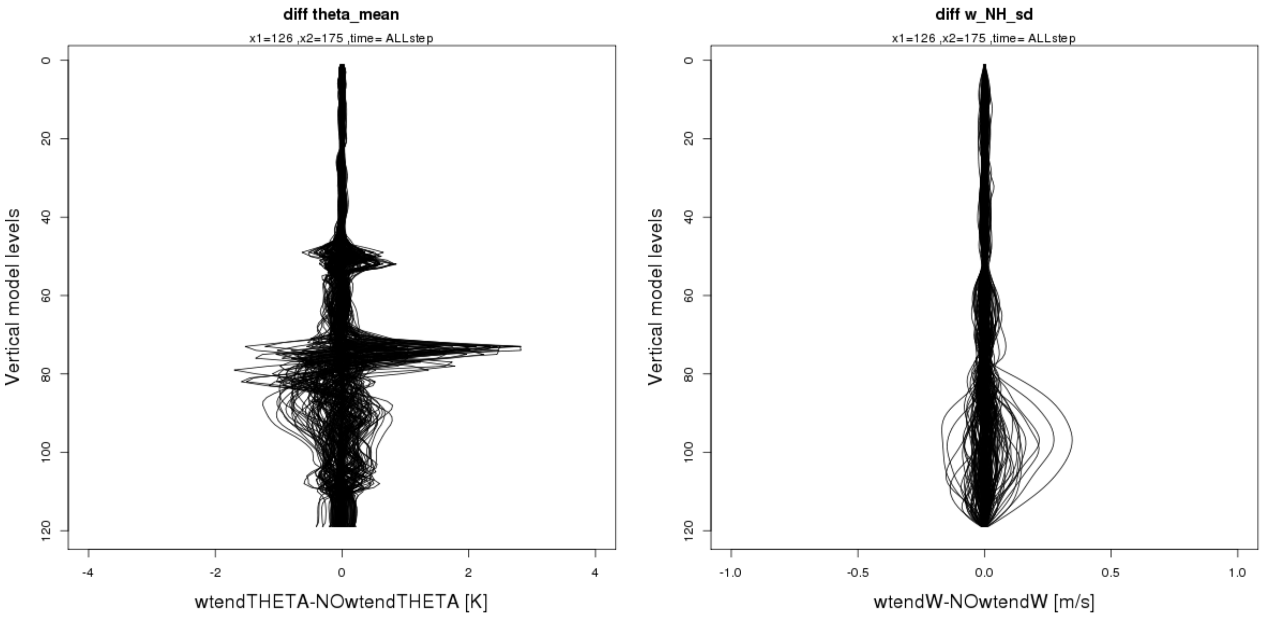
1) The arrangement of 2D experiments - the temperature [K] (top) and vertical velocity [m/s] (bottom) fields with the wind arrows at the end of the simulation.



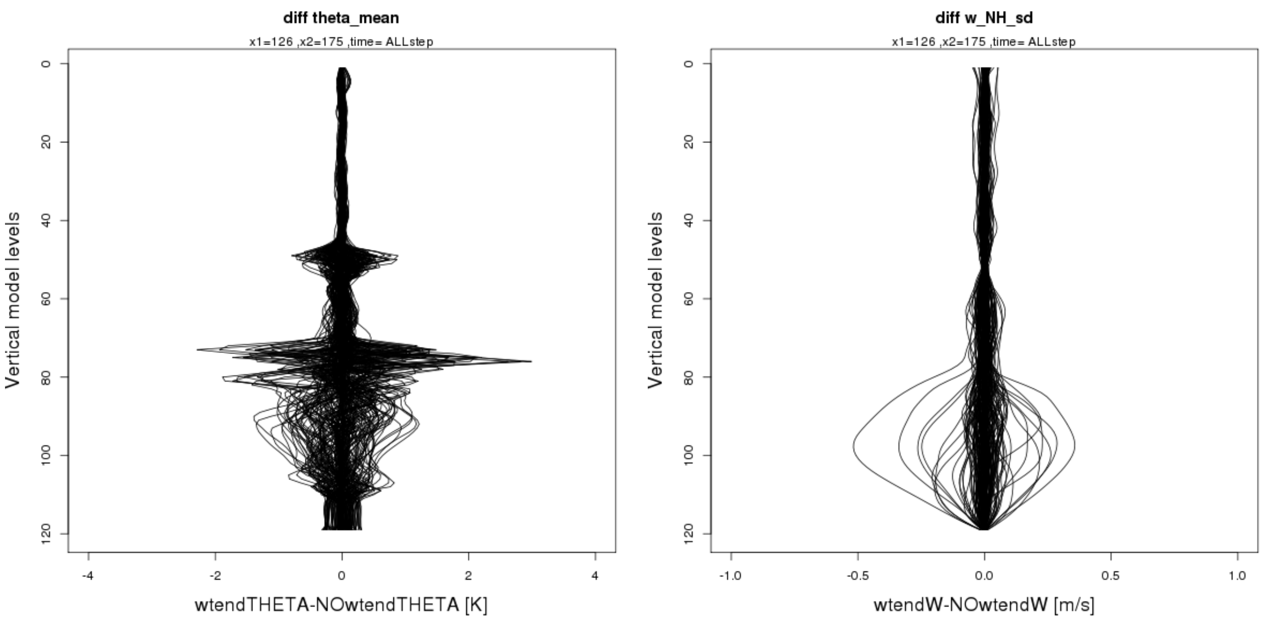
2) The initial profiles of the potential temperature (left) and the temperature (right) in 2D experiments.



3) The potential temperature (top left), the temperature (top right) and the horizontal wind (bottom) mean profiles during the simulation.



4) Differences of the mean profiles of the potential temperature (left) and the standard deviation of the vertical velocity (right) between the experiments with and without the modification (modified - reference) during the simulation. The VDW is the vertical velocity.



5) Differences of the mean profiles of the potential temperature (left) and the standard deviation of the vertical velocity (right) between the experiments with and without the modification (modified - reference) during the simulation. The VDW is the vertical divergence.

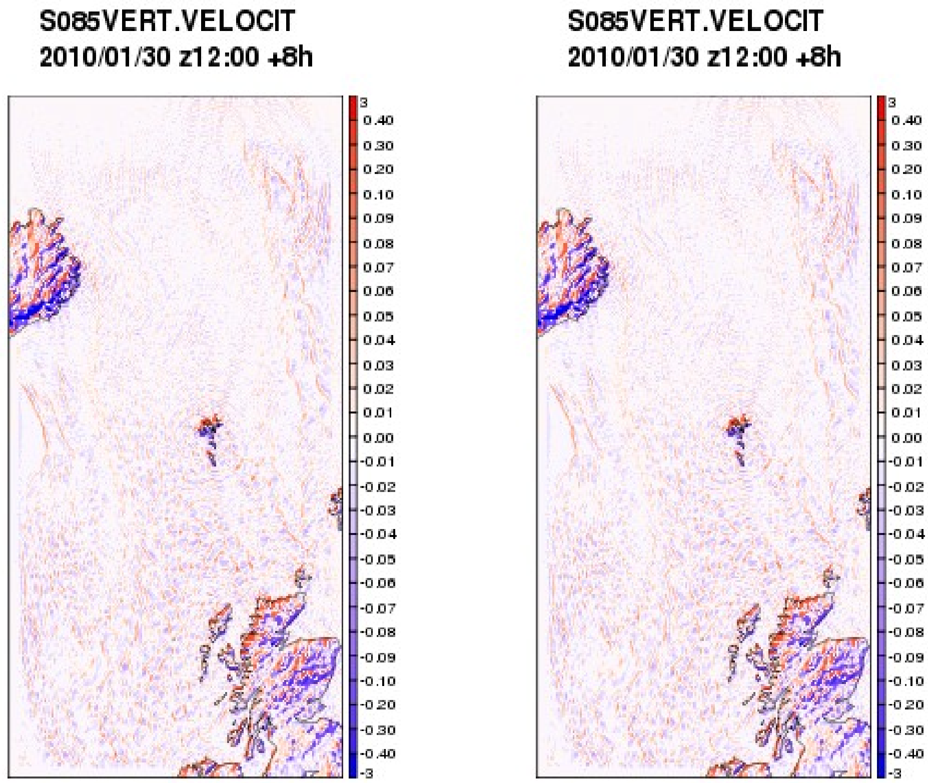
4) Real simulations

We tested the modification on three different real cases.
First case
The first one is the same we used on the first stay to test the modification. It was in the region north from the British Islands on 30. of January 2010. The horizontal resolution of the domain was 4000 m and the time-step was 150 s. The length of the simulation was 8 hours. We tried this case with both settings of the VDW (*d* and *w*).
Second case
The second was situated in the Alps on 31. of March 2015. The horizontal resolution was 1250 m and the time-step was 20 s. The length of the simulation was 9 hours and VDW was set to *w*. With *d* and the turned on modification the simulation ended with the “wind too strong” error message.
In the first and the second case the using of the equation (3) instead of (1) was tried (figure 21). There the tendencies become weaker with equation (3).
Third case
The third simulation's domain was over the Czech Republic on 27. of January 2008. The horizontal resolution was 1000 m and the time-step was 20 s. The length of the simulation was 12 hours. The VDW was set to w.

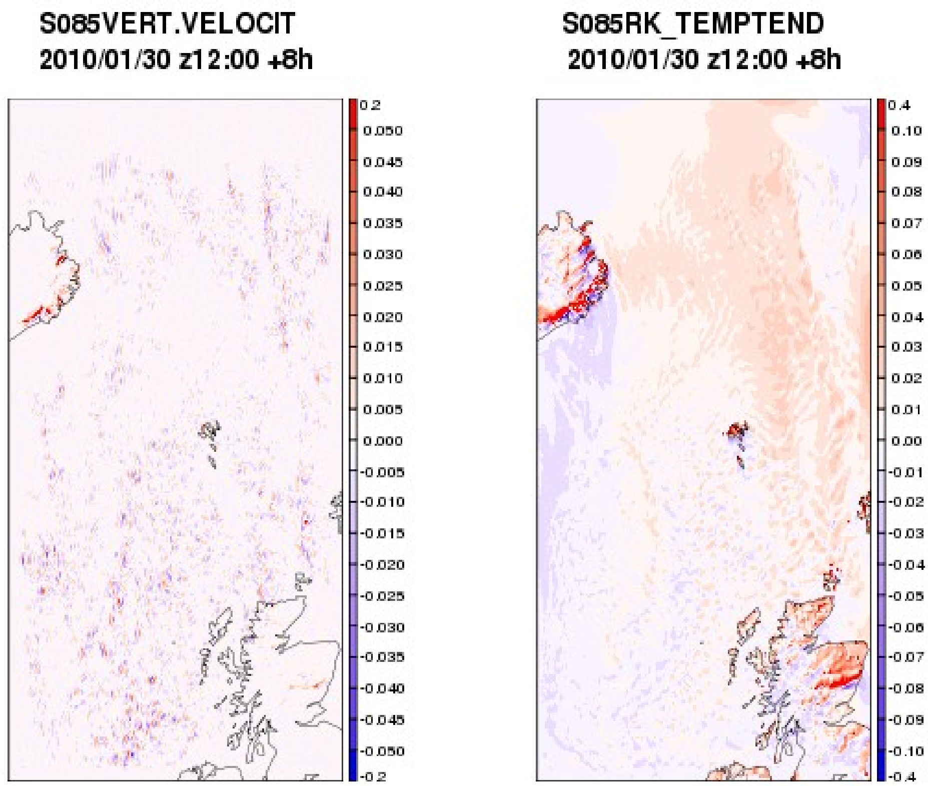
In the following pictures are the results of the real case experiments. They all show the situations at the end of the simulation. The vertical velocity and *w* tendency horizontal fields are on the 85. model level (there are 87 levels in every case and the 1. level is the top, 87. level is the bottom). In the pictures the vertical velocity tendency is multiplied by *g* (the gravity acceleration) and its name in historical file is RK_TEMPTEND.

Note, that some of the scales have very high maximum and very low minimum values relative to the linear middle values. This is because the average *w* and *w* differences have low amplitudes, while much higher values appear in certain grid-points.

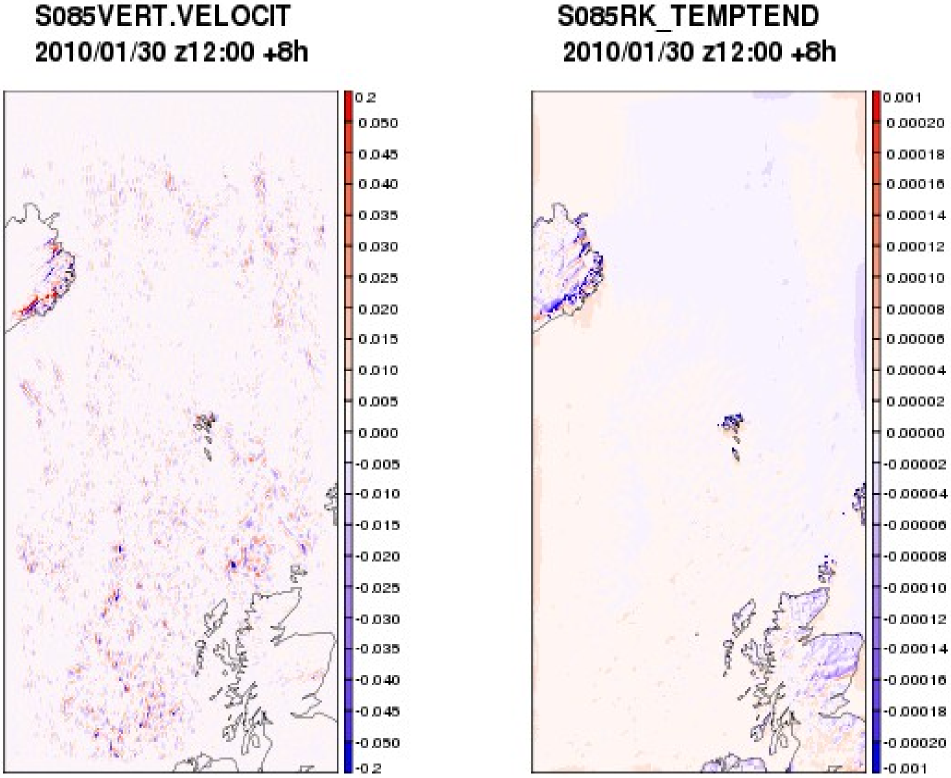
FIRST CASE



6) The vertical velocity field [m/s] in the first case without (left) and with (right) the modification at the end of the simulation. The VDW is the vertical velocity.

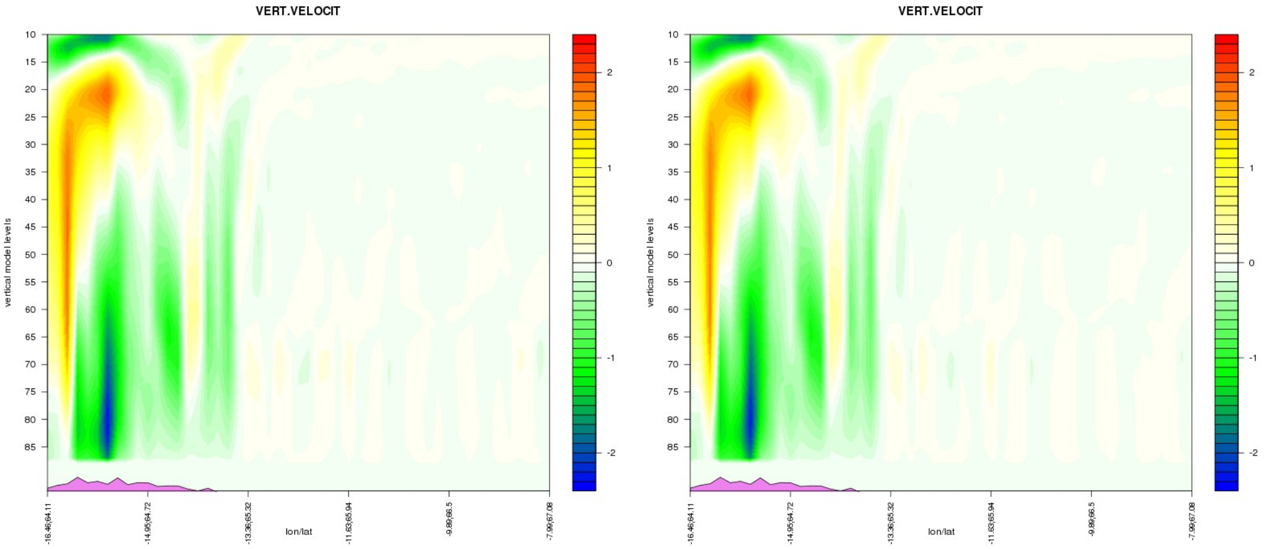


7) Differences (modified - reference) in the vertical velocity fields [m/s] (left) and the tendency of gw [m^2/s^4] (right) in the first case. The VDW is the vertical velocity.

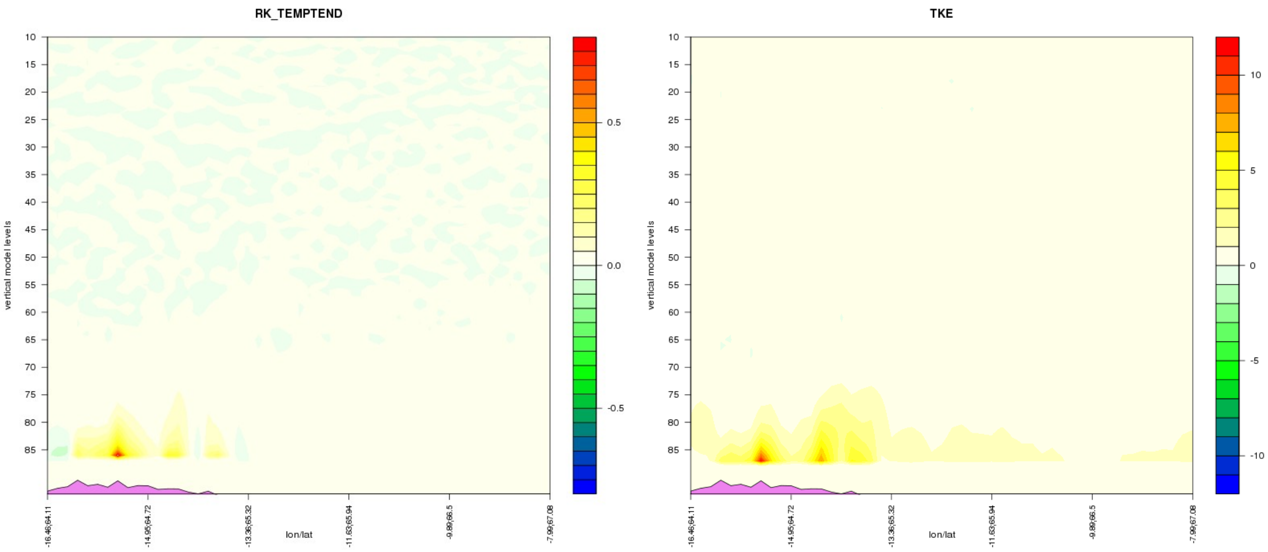


8) Differences (modified - reference) in the vertical velocity fields [m/s] (left) and the tendency of d [1/s²] (right) in the first case. The VDW is the vertical divergence.

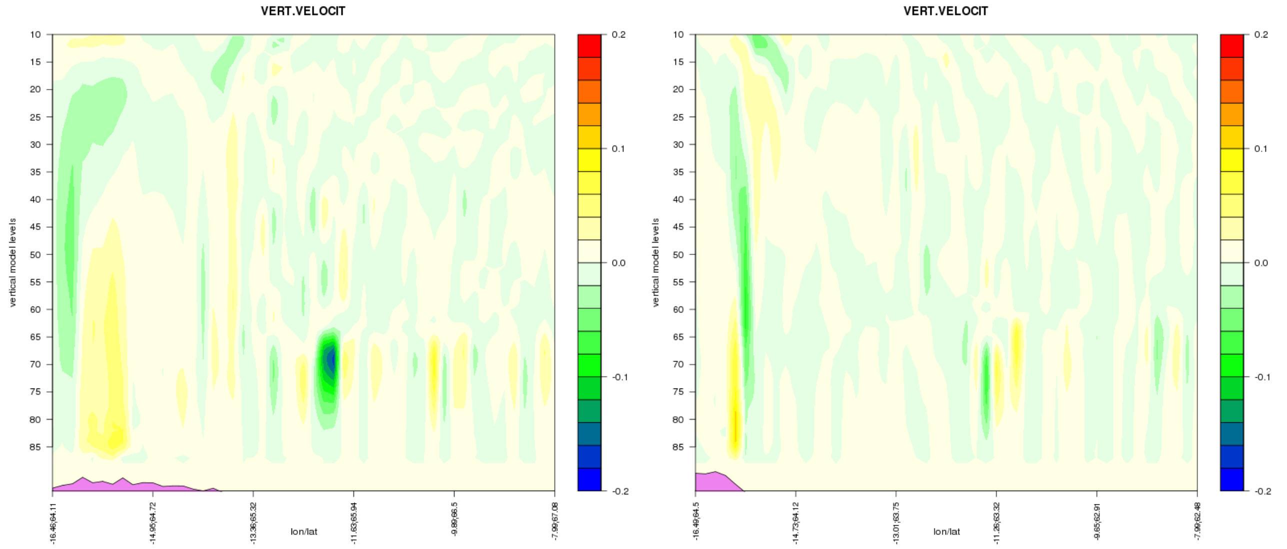
9) The locations of vertical cross sections in the first case - V1 (left) and V2 (right)



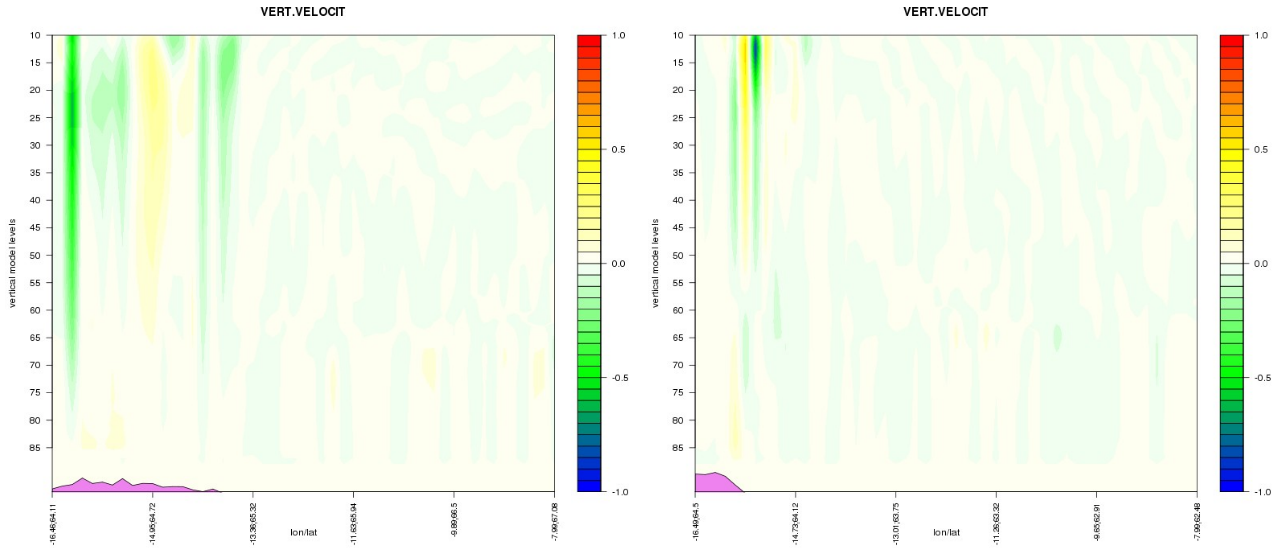
10) Vertical cross section of the vertical velocity [m/s] in the first case without (left) and with (right) the modification at the location V1. The VDW is the vertical velocity.



11) Vertical cross section of the gw tendency [m^2/s^4] (left) and turbulent kinetic energy [m^2/s^2] (right) in the first case at the location V1. The VDW is the vertical velocity.

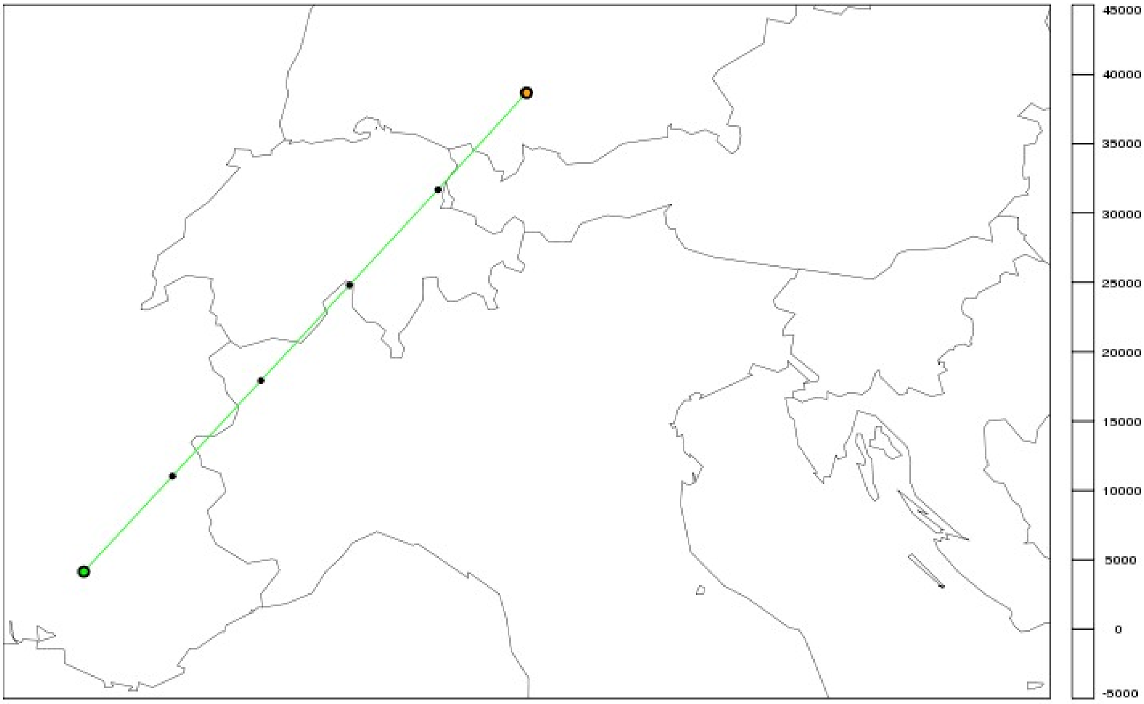


12) Vertical cross section of the vertical velocity differences [m/s] (modified - reference) in the first case at the location V1 (left) and V2 (right). The VDW is the vertical velocity.

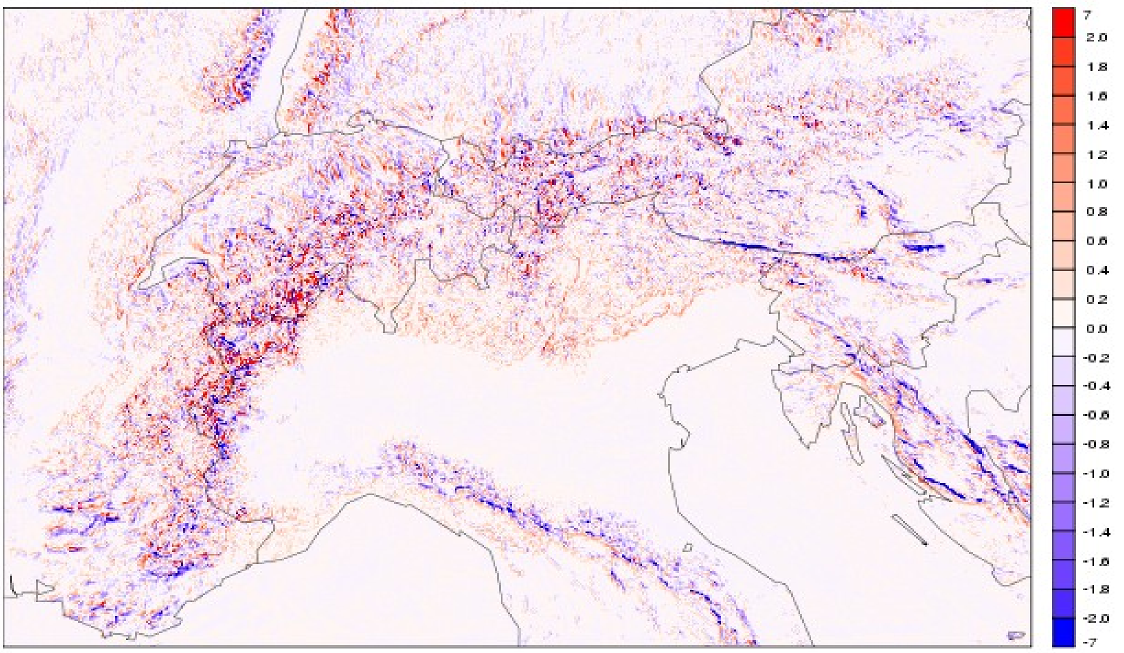


13) Vertical cross section of the vertical velocity differences [m/s] (modified - reference) in the first case at the location V1 (left) and V2 (right). The VDW is the vertical divergence.

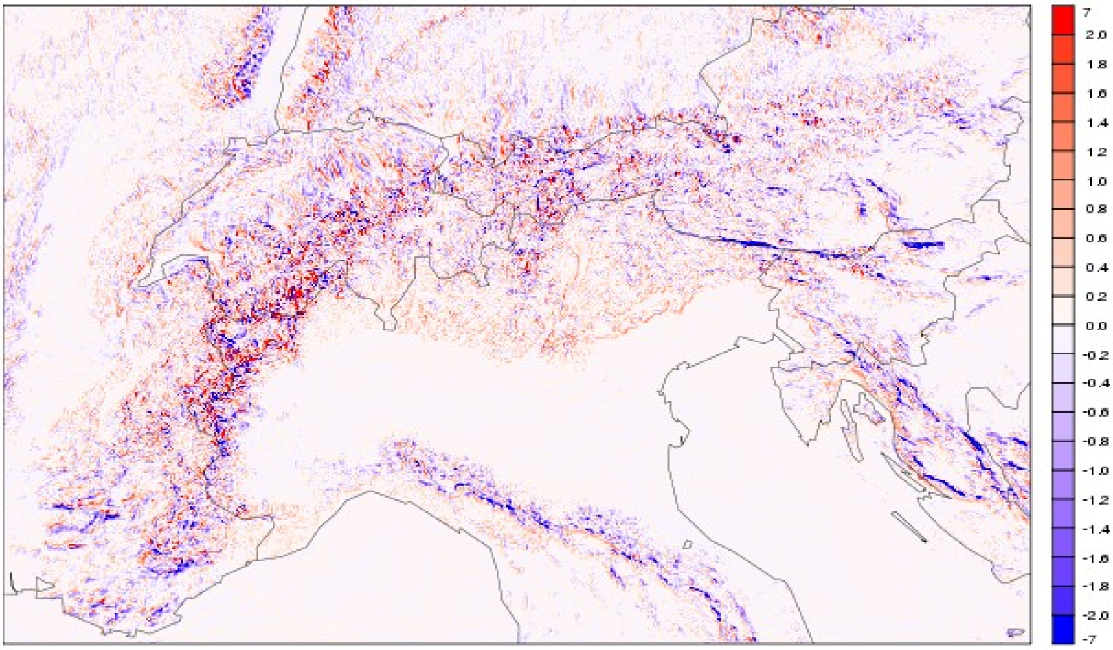
SECOND CASE



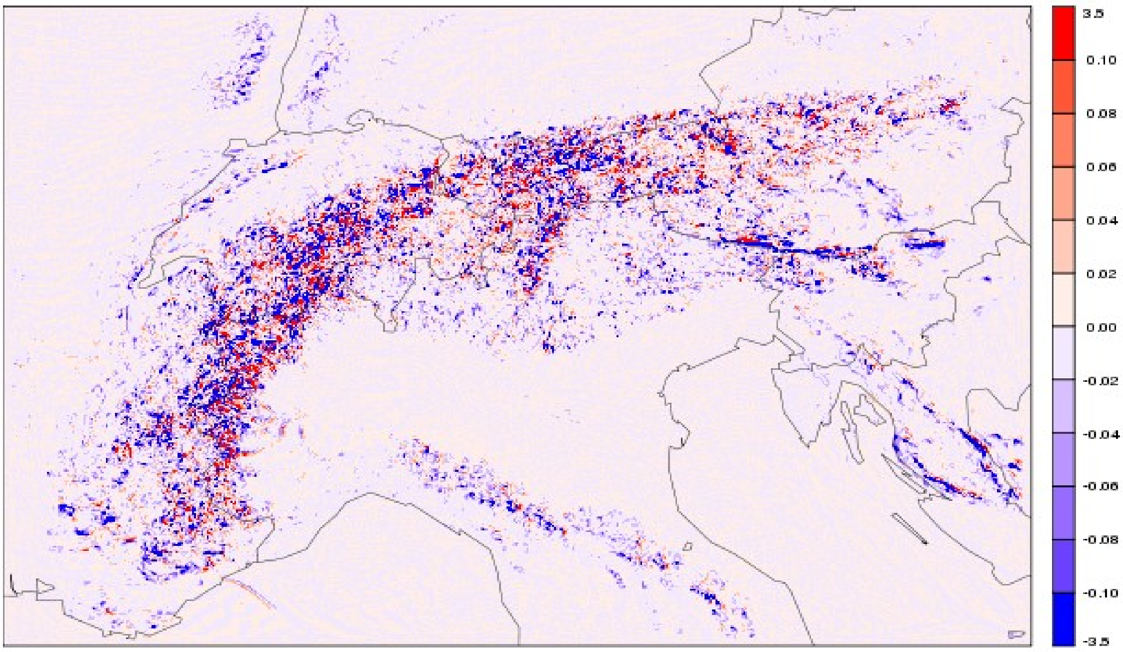
14) The location of vertical cross section in the second case.



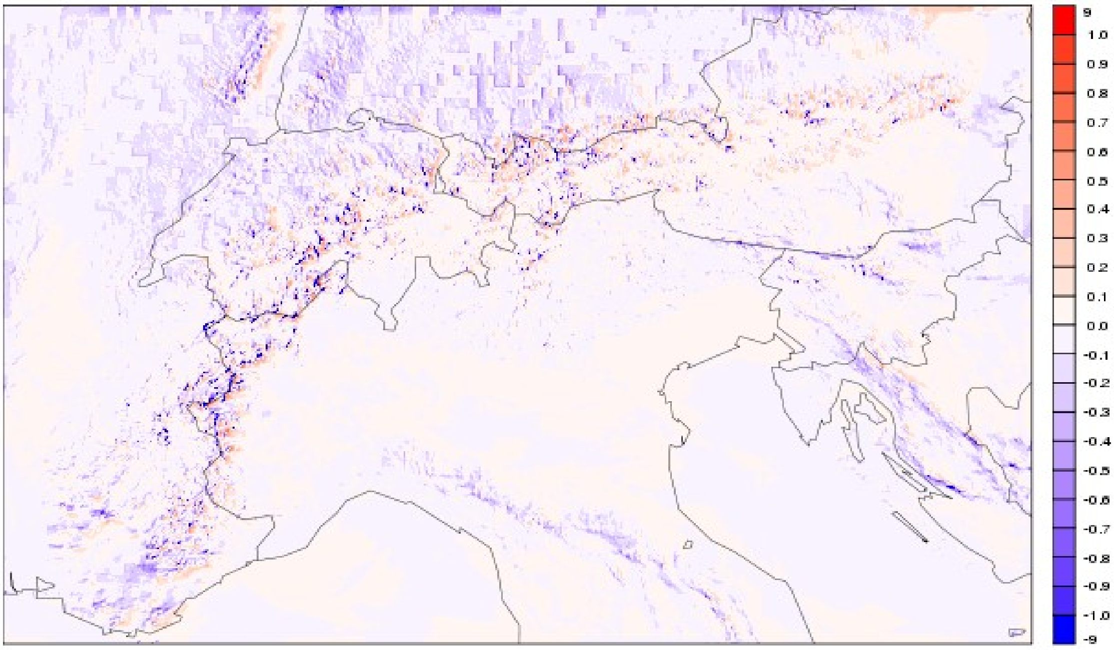
15) The vertical velocity field [m/s] in the second case without the modification.



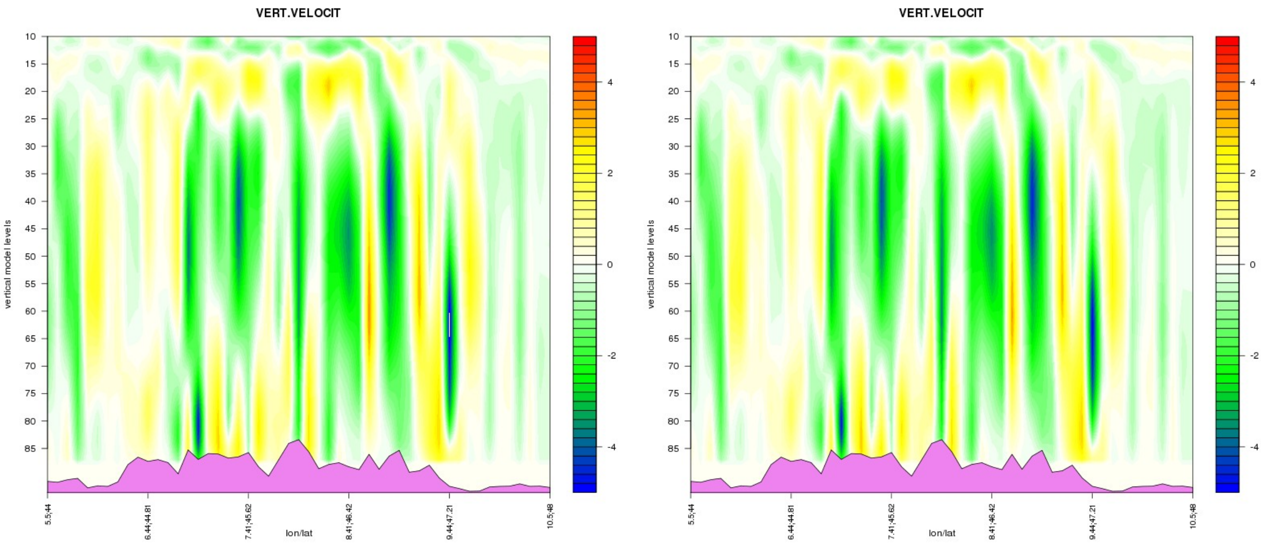
16) The vertical velocity field [m/s] in the second case with the modification.



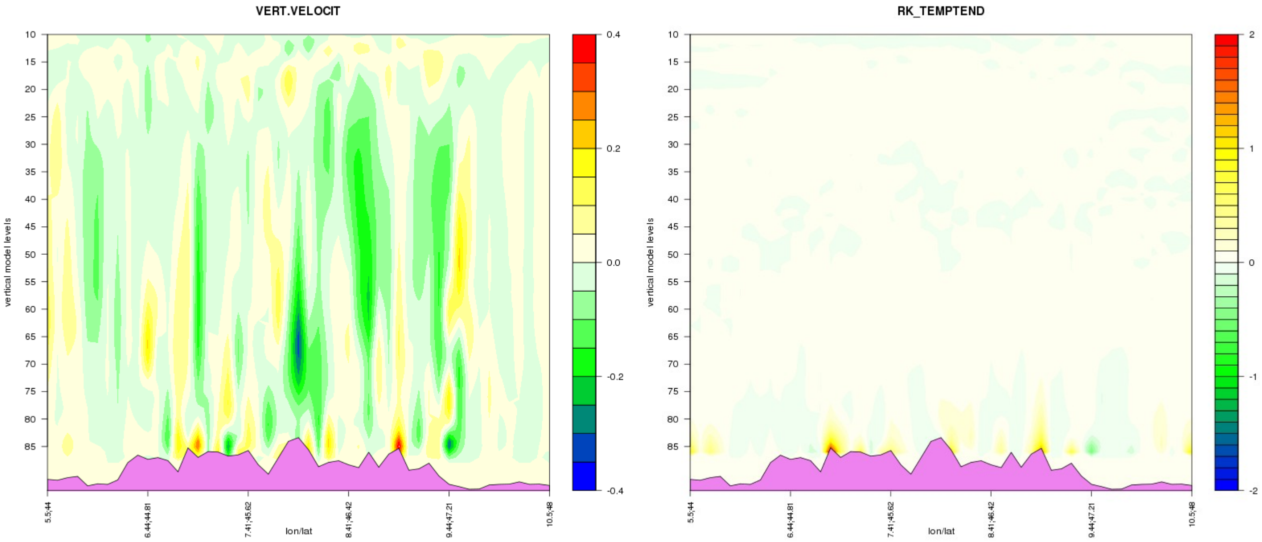
17) Differences (modified - reference) in the vertical velocity fields [m/s] in the second case.



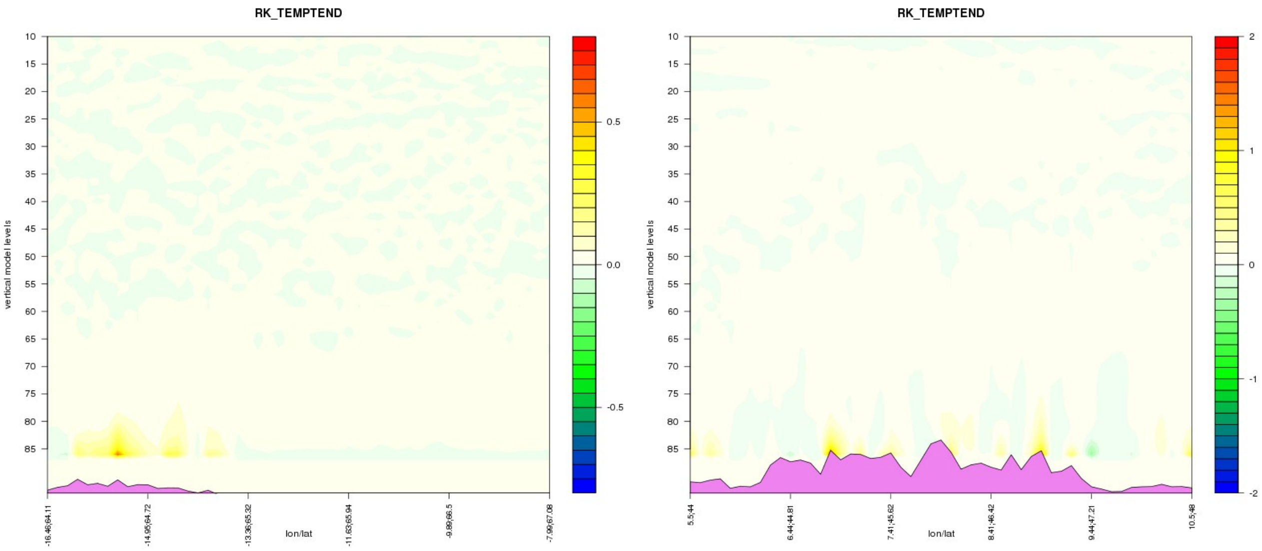
18) The tendency of gw [m²/s⁴] in the second case.



19) Vertical cross section of the vertical velocity [m/s] in the second case without (left) and with (right) the modification.

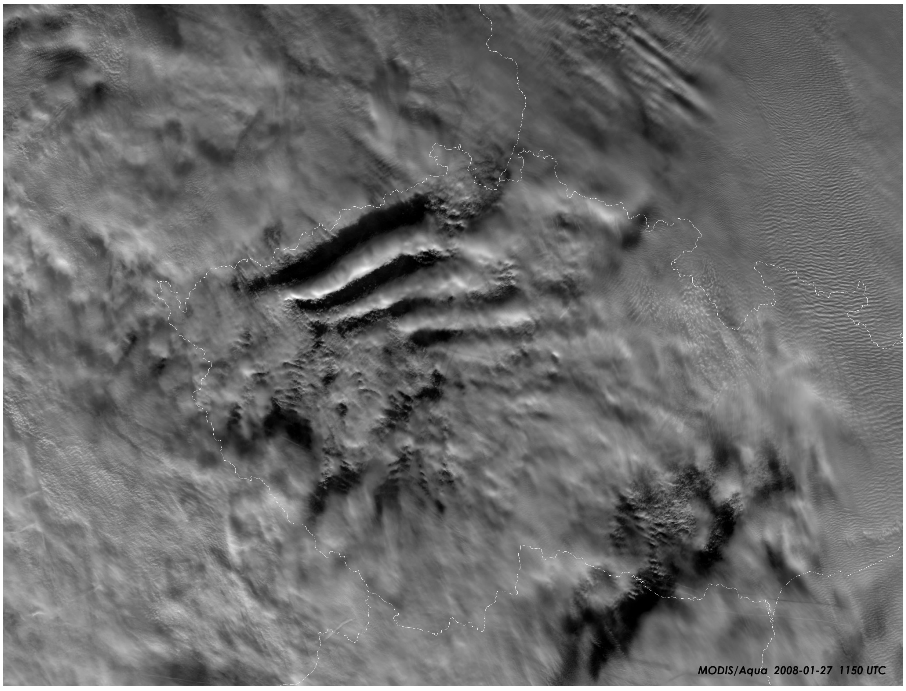


20) Vertical cross section of the vertical velocity differences [m/s] (modified - reference) (left) and of the gw tendency [m^2/s^4] (right) in the second case.

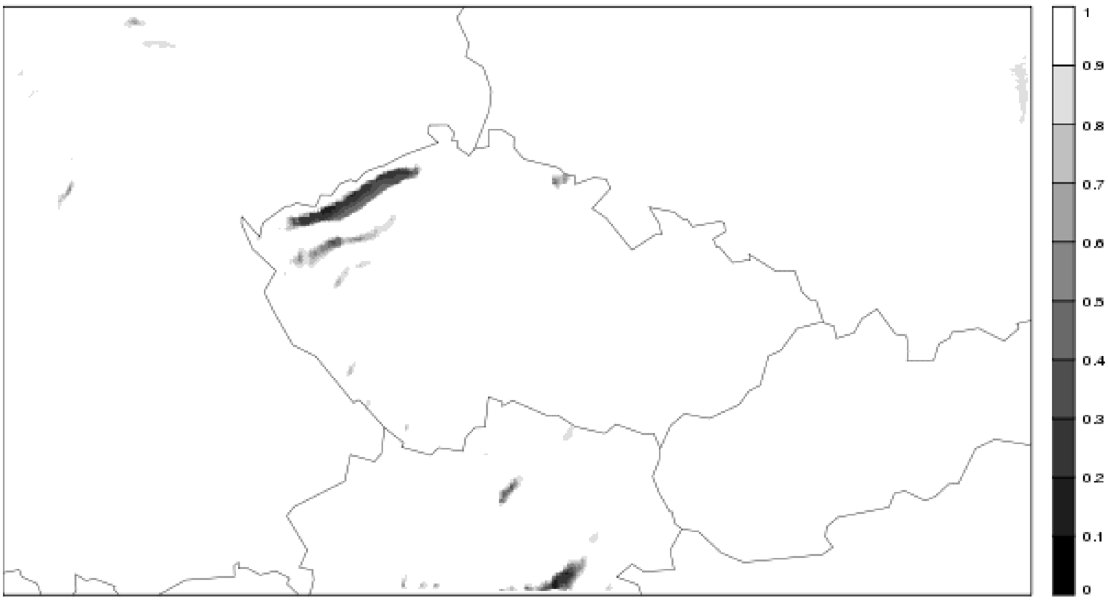


21) Vertical cross section of the gw tendency [m^2/s^4] in the first-V1 (left) and second (right) case when the turbulent flux of the vertical velocity is computed from the second order momentum of the turbulent vertical velocity in the TOUCANS.

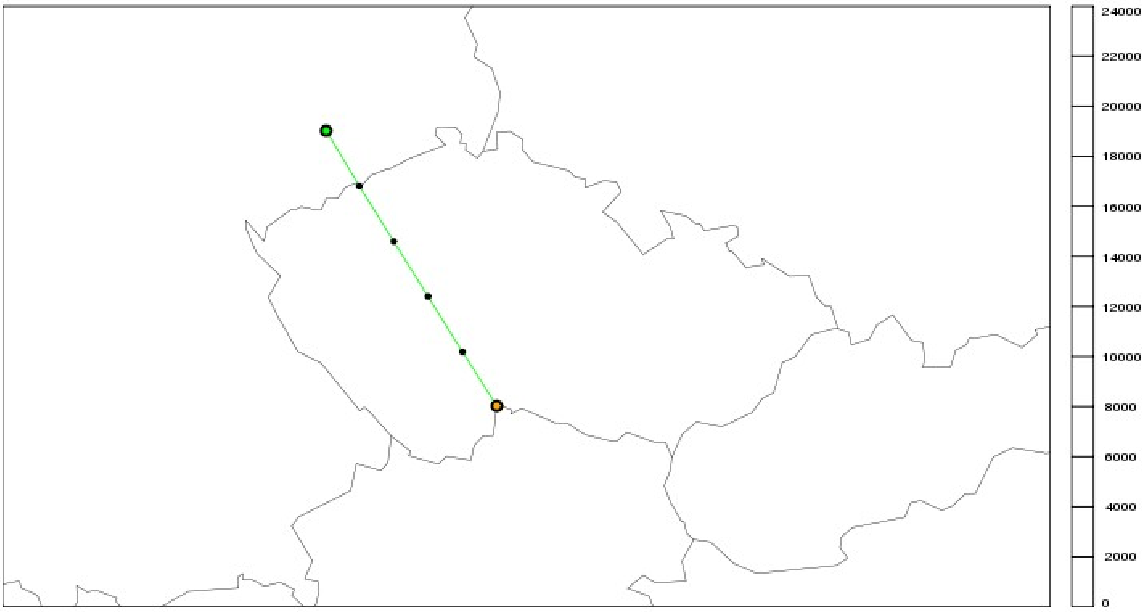
THIRD CASE



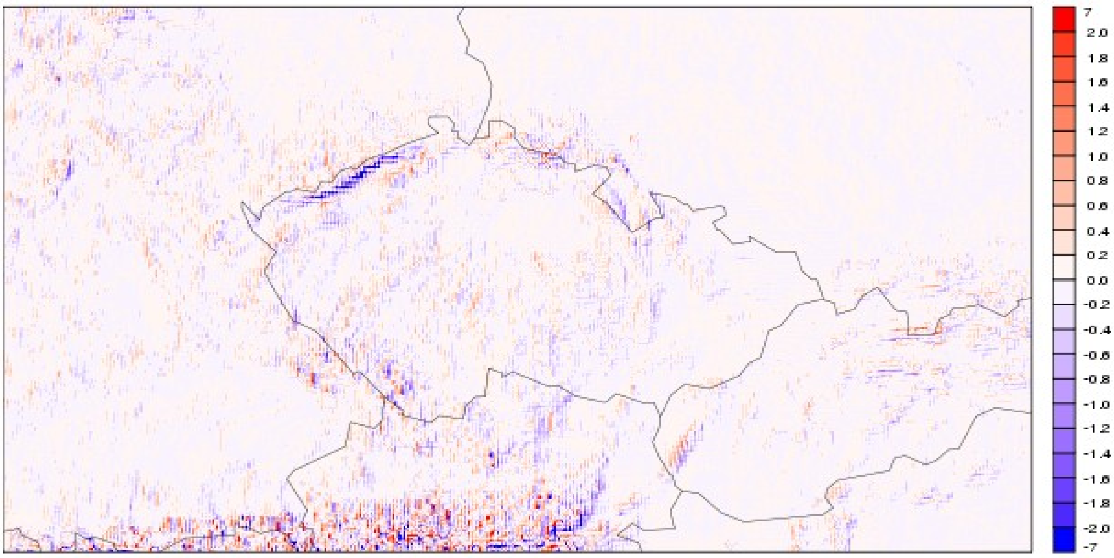
22) Satellite image of the third case at 11:50 UTC.



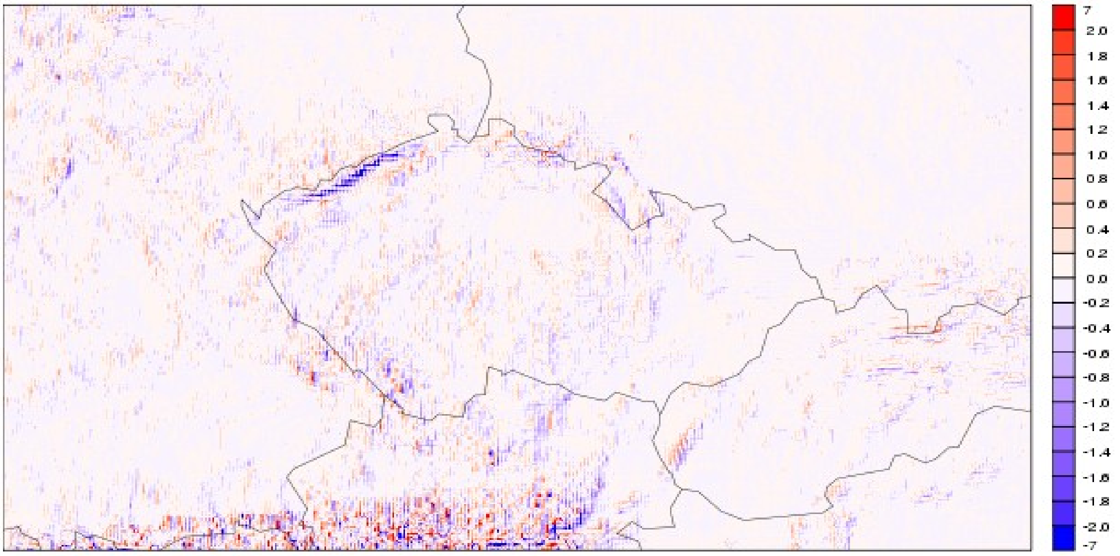
23) Total cloudiness from the simulation of the third case whit the modification.



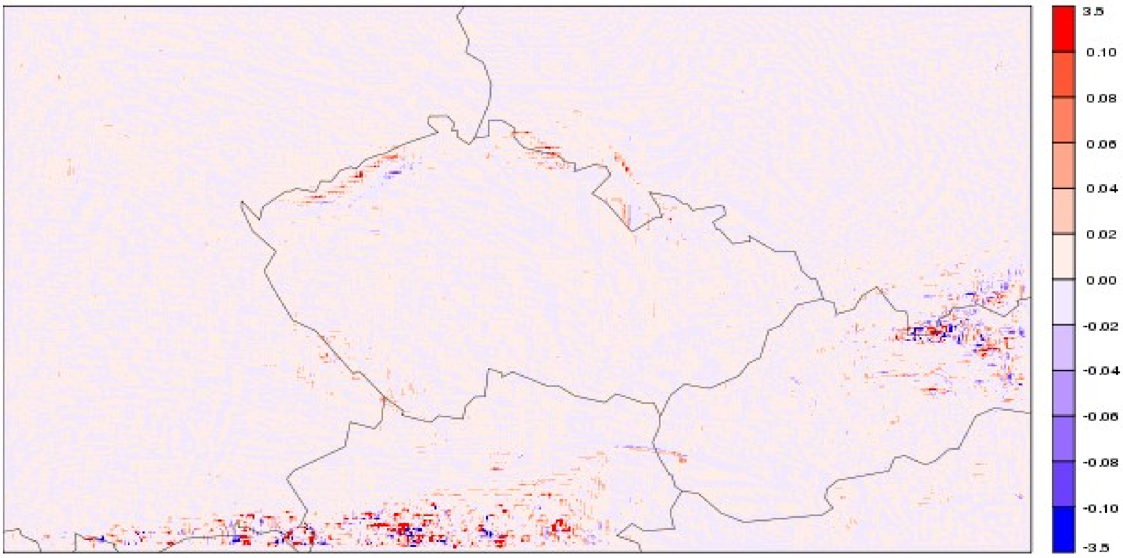
24) The location of vertical cross section in the third case.



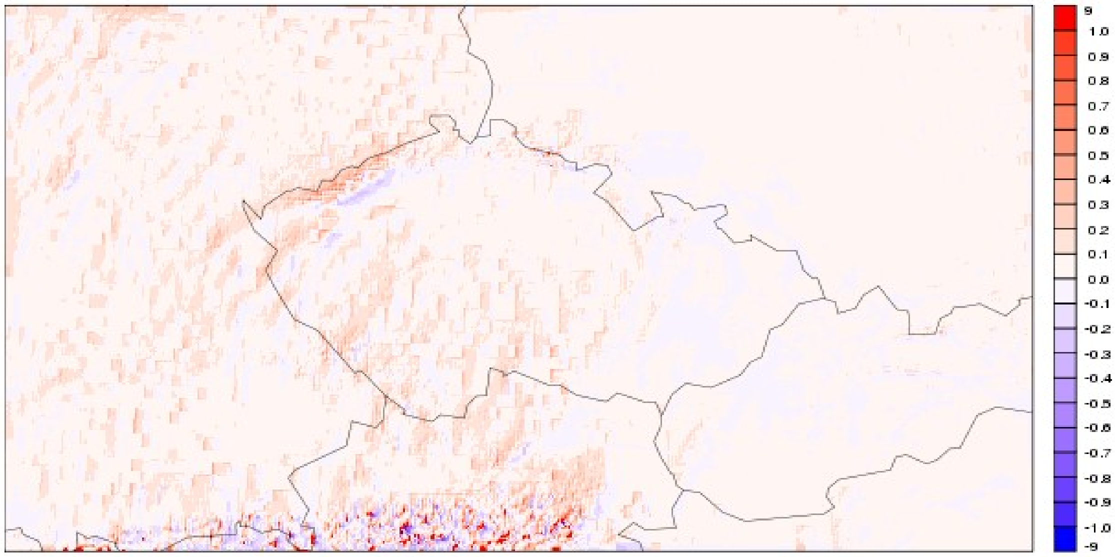
25) The vertical velocity field [m/s] in the third case without the modification.



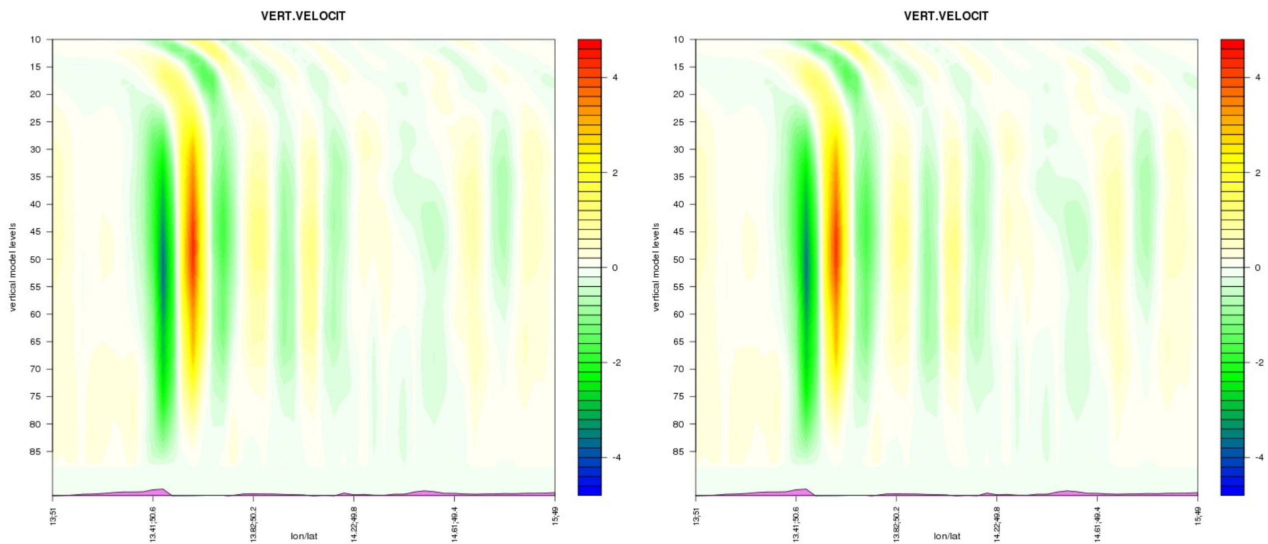
26) The vertical velocity field [m/s] in the third case with the modification.



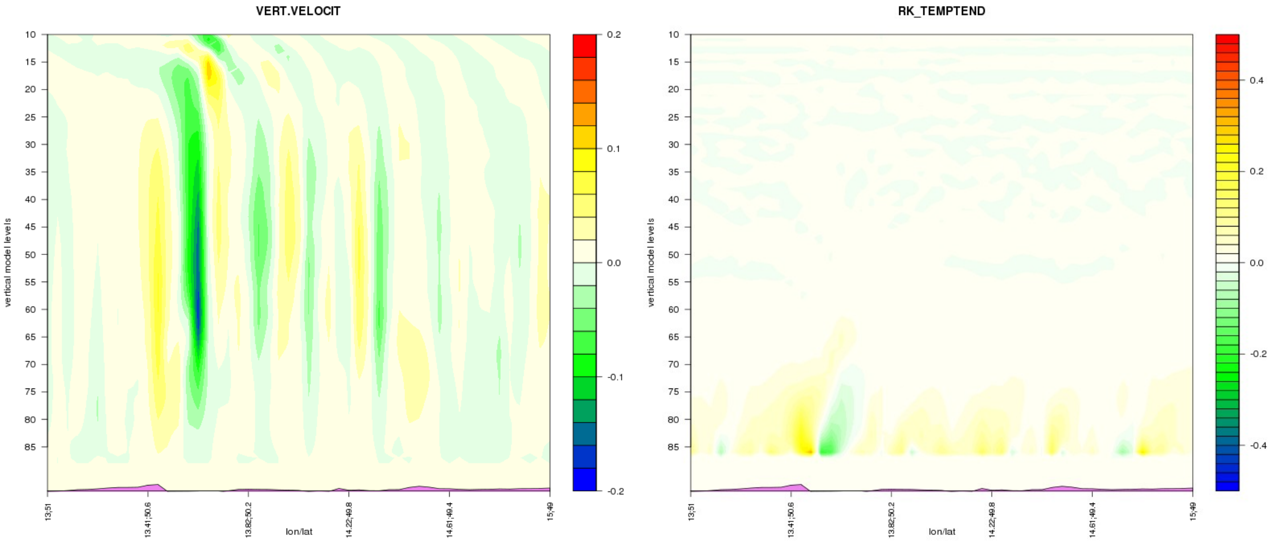
27) Differences (modified - reference) in the vertical velocity fields [m/s] in the third case.



28) The tendency of gw [m^2/s^4] in the third case.



29) Vertical cross section of the vertical velocity [m/s] in the third case without (left) and with (right) the modification.



30) Vertical cross section of the vertical velocity differences [m/s] (modified - reference) (left) and of the gw tendency [m^2/s^4] (right) in the third case.

5) Summary

The vertical diffusion of vertical velocity was implemented into the ALADIN-NH CY38 model in which values computed in the physical parametrization were passed to the dynamics. The effect of this modification was tested on vertical 2D and real case experiments. In the 2D simulations the maximal difference in the mean potential temperature we detected was around 3 K but the deviation was not clearly positive or negative, it was altering in the time.

We tested the modification on three different real cases and examined they vertical velocity fields. The differences are in average small and exceed 0.1 m/s only occasionally near the high topography (e.g. Alps), where *w* reaches high values (>2 m/s). The highest detected difference was around 3 m/s, but such big values occur only in few grid-pints and do not have strong influence on the final average. The maximum temperature differences in the real cases are ~1.4 K.

Note that these numbers are based on the values from the 85. model level, but the vertical cross section (figure 20) shows that this height is reasonable. If VDW is set to *d*, there are unexpectedly high differences in the upper atmosphere (figure 13), but the reason of this is not clear.

In the third case the damping effect of the vertical diffusion on VDW can be seen in figure 27 where the orographic wave over Krusne hory is located (NW boundary of the Czech Republic).

Generally we can say that the impact of the vertical diffusion on vertical velocity does not seem to be significant, but we have proposed an original solution for this process which could be further developed, used and tested.

6) Acknowledgments

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