Vertical diffusion of vertical velocity variable in ALADIN-NH

LACE stay report

Prague - Czech Hydrometeorological Institute,

11. Nov. 2013 – 6. Dec. 2013

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Contents:

1) Introduction

The object of this work was to make a proposal for the solution of calculating of the vertical diffusion of the vertical velocity variable, modificate the source code of the ALADIN-NH model and show the differences between the results of the model with and without this modification.

The basic guideline for this work was taken form Luc Gerards internal report about the vertical diffusion of pseudo vertical divergence (*Luc Gerard: Diffusion verticale de la quantité de mouvement veritcale (1996)*).

The equation for the pseudo vertical divergence is

$$d=-g\frac{p}{mR_dT}\frac{\partial w}{\partial\eta} \quad ,$$

where g is the gravity acceleration constant, p is the pressure, R_d is dry air gas constant , T is the temperature, w is the vertical velocity, η is the vertical hybrid coordinate and $m = \partial\pi/\partial\eta$, where π is the hydrostatic pressure (*Pierre Bénard, Ján Mašek: Scientific Documentation for ALADIN-NH Dynamical Kernel, VERSION 3.0 (2011), 17, eq. 2.33*). From that can be seen the tendency of the d caused by the vertical diffusion:

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

where F_w is the turbulent diffusion flux of w ($F_w=-\rho\overline{w'w'}$, where ρ is the density of the air and w' is the turbulent part of vertical velocity). This flux can be estimated from the values which appears during the computation of the turbulent kinetic energy (TKE) in the part of the code called TOUCANS (Third Order moments Unified Condensation Accounting and N-developement Solvar for turbulence and diffusion). There the second order moment of turbulent vertical velocity is

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

where e is the TKE, 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*). The term with the λ constants was substituted by the value 0.2, so the way of the computation of the turbulent diffusion flux of w was

$$F_w=-\rho e\frac{2}{3}\left[1-\frac{0.2}{1-Ri_f}\right] \quad .$$

It is optional to use w or d as the vertical velocity variable. According to this, we compute from F_w the tendency of w or d and use it in our modificated ALADIN-NH model.

After we made this modification, we plotted some fields, to show the effect of it.

2) Modifications

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

&NAMWTEND_EXTRA
LRWTEND=.TRUE.
/

The F_w values get on the level of the routine APLPAR from the routine ACPTKE. These fluxes are on the full levels. Then the routine CPTEND_NEW calculates from F_w the tendencies of *w*. These tendencies are on the half levels, and on the top and bottom levels are set to be zero. In case LGWADV = FALSE (which means, the vertical velocity variable is *d*) from the tendencies of *w* the routine GNHGW2SVDAROME makes tendencies of *d*, which are on the full levels.

These tendencies are then postponed to the routine CPUTQY. There they are multiplied by the time step and added to the main buffer, where the variables are stored.

There is only one place in the buffer for the vertical velocity variable either it is *w* or *d*. This place is for a full level variable, which has one less number of levels as a half level variable, so, if LGWADV = TRUE, then the zeroth level of the tendency of *w* (which is near the top) is omitted.

The structure of CPG routine:

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

For the case we want to use the Predictor-corrector, we made the needed modifications in the routine CPG_PT. We also had to declare (type_gmvs.F90) and add the right value (gmv_subs_mod.F90) to a new pointer called MCDPT.

3) Results

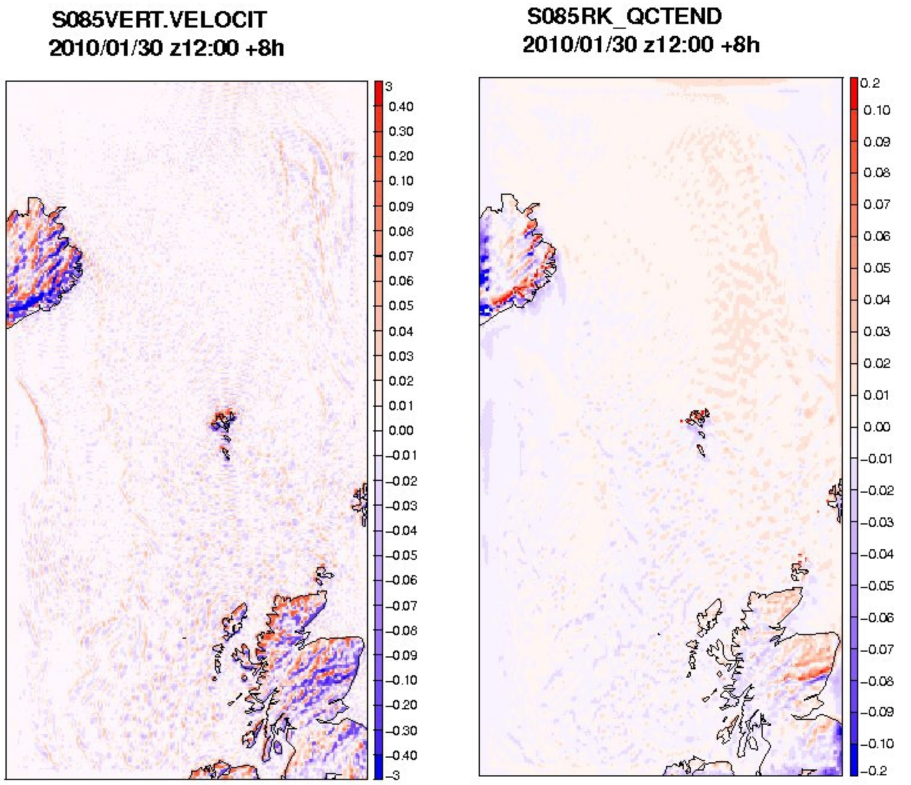
To compare the results of the model with and without our modification, we made runs for a case in the region north from the British Islands for the date 30. Jan. 2010 with time step = 150 s, grid size = 9 km (in both directions) and using the Predictor-corrector. In the following pictures are outputs and differences of outputs from the ALADIN-NH model with turned on/off modification and setting LGWADV = TRUE/FALSE.

Note n. 1: the switch LRDBBC (which is usually TRUE, when LGWADV = FALSE and doesn't let the *d* to be too large at the surface) was in all case FALSE.

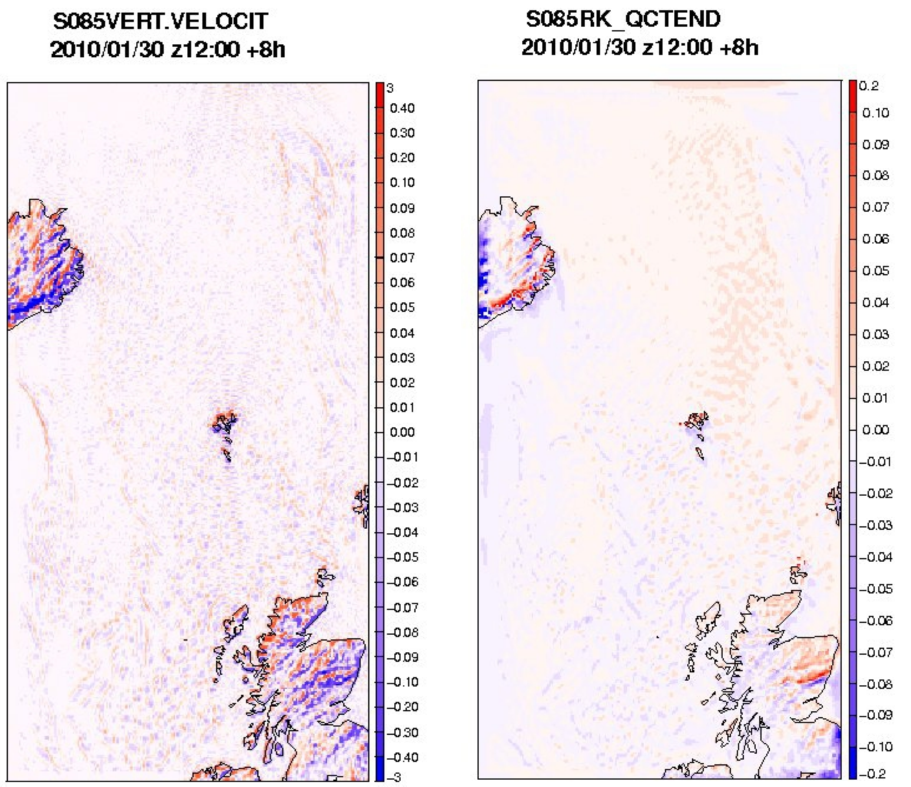
Note n. 2: the RK_QCTEND is a variable, substituted with the tendency of *w*.

Note n. 3: the *w* (the tendency of *w)* is everywhere in m/s (m^2/s^4) and after 8 h running

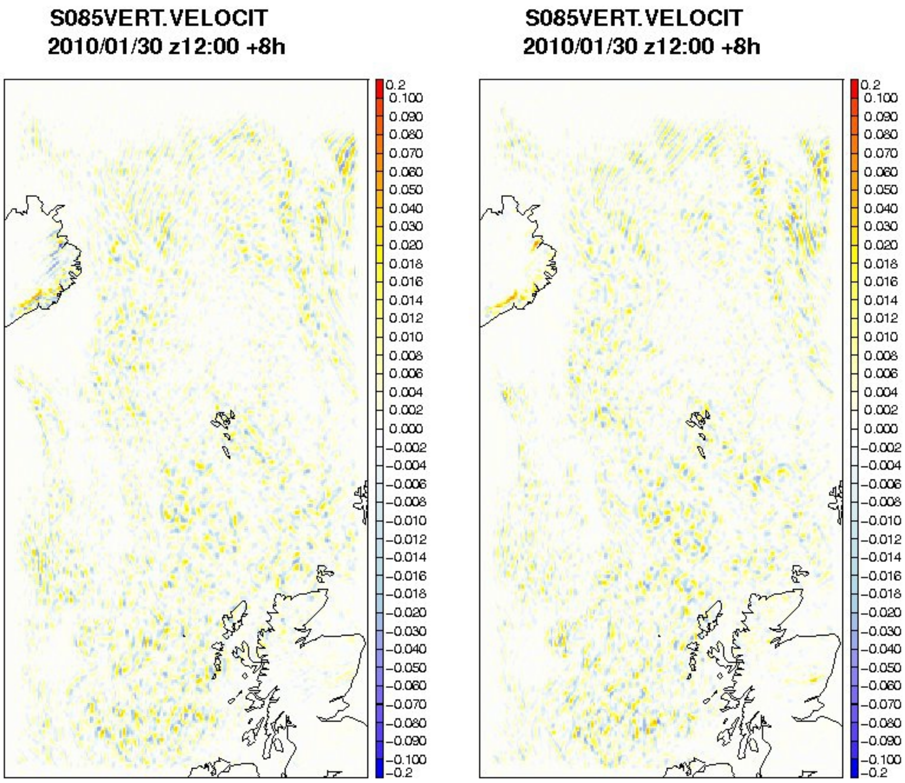
Note n. 4: the tendency of *w* is everywhere multiplied by *g* (the gravity acceleration)



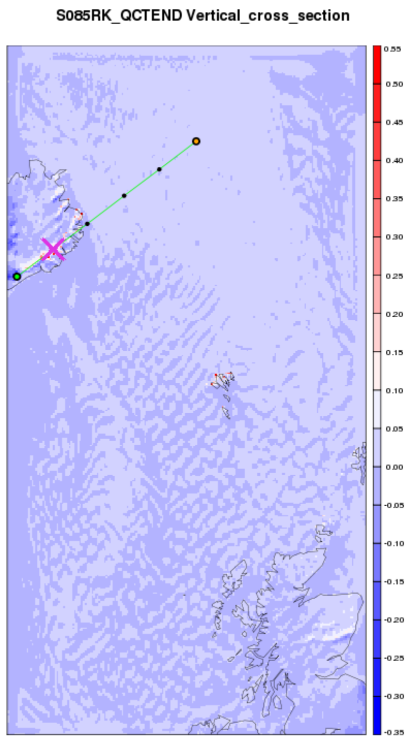
1) The vertical velocity and tendency of w on the 85. model level with LGWADV = FALSE when the modification is turned on



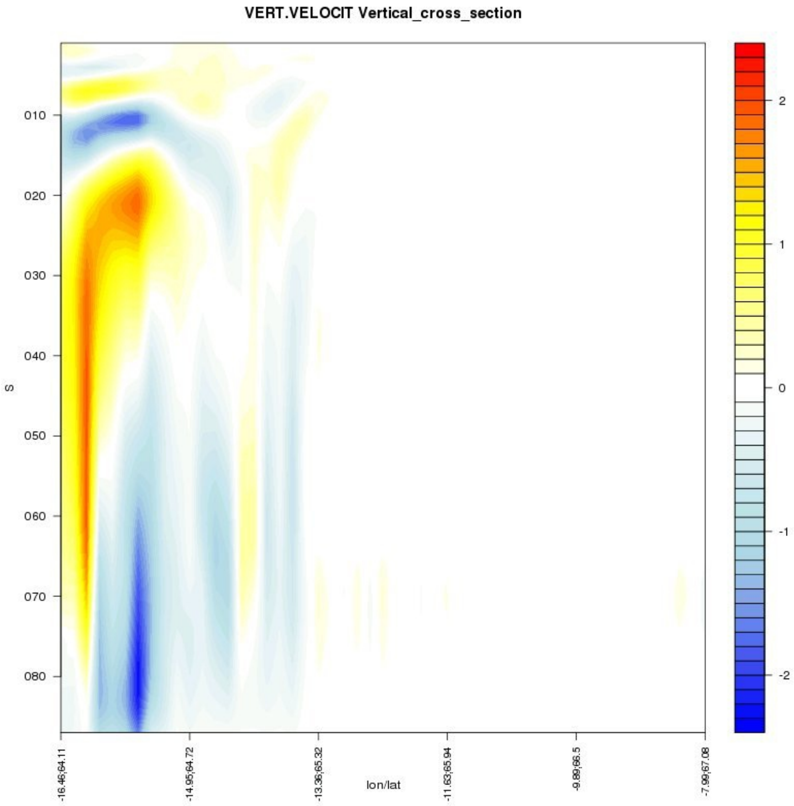
2) The vertical velocity and tendency of w on the 85. model level with LGWADV = TRUE when the modification is turned on



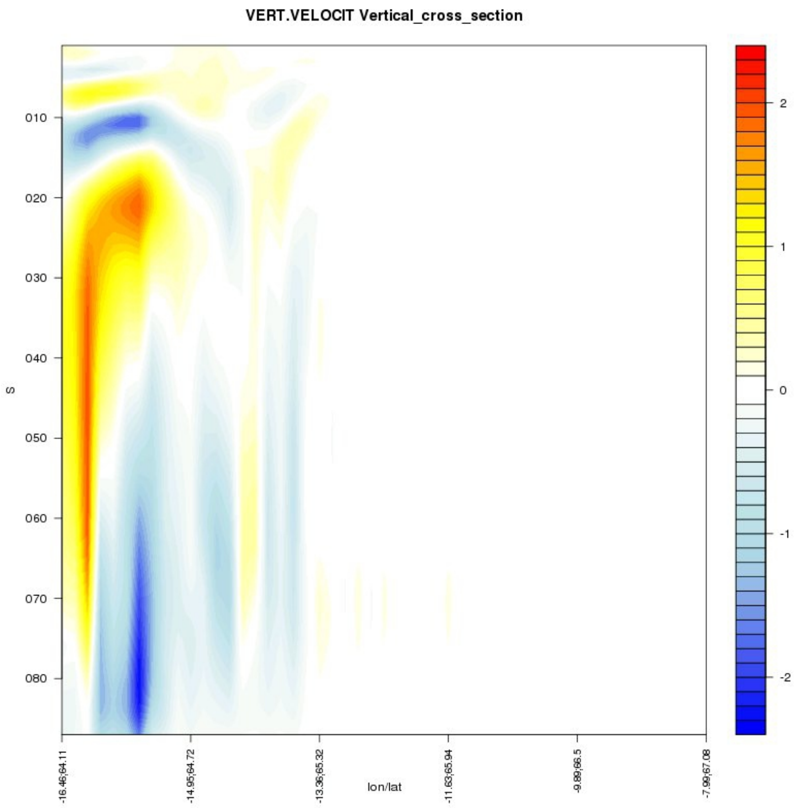
3) The differences ($w_{mod.}$ - $w_{not\ mod.}$) of the vertical velocities of the runs with and without the modification on the 85. model level with LGWADV = FALSE (left) and LGWADV = TRUE (right)



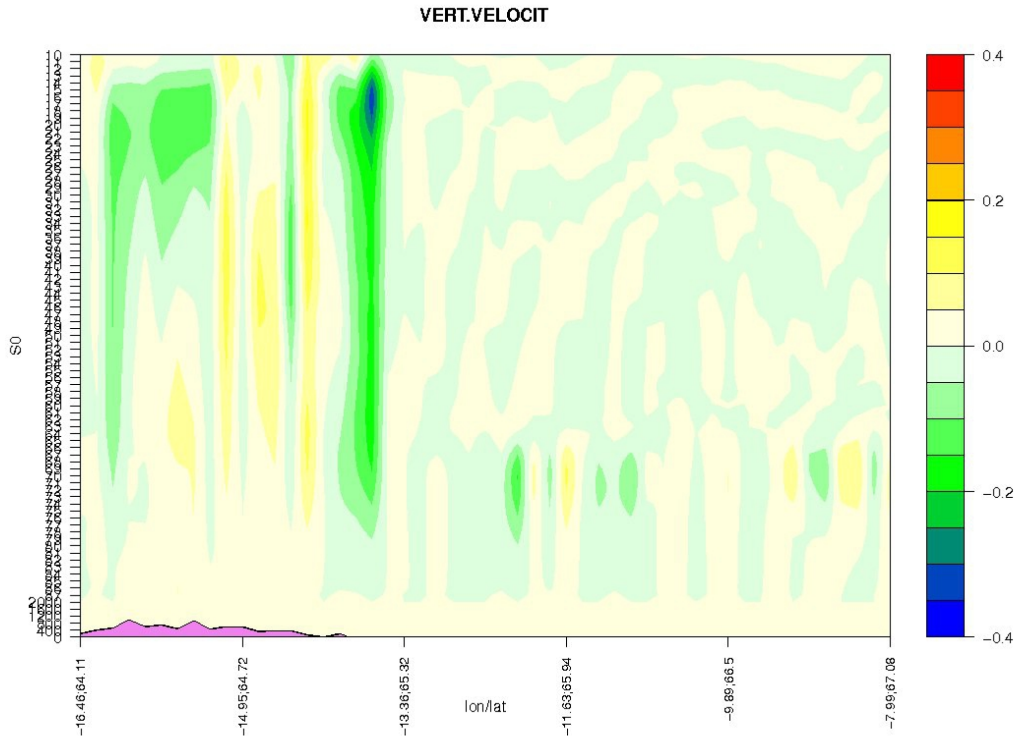
4) The line of the vertical cross-sections (green), the point of examining the tendency of w (pink)



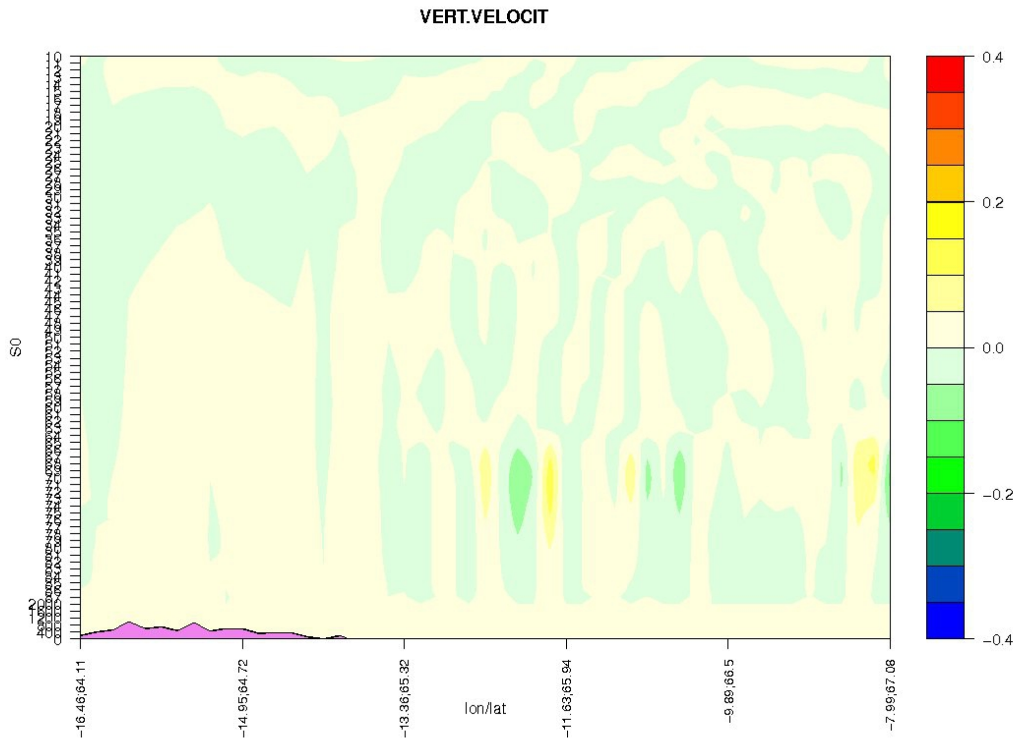
5) Vertical cross-section of w when the modification is turned on (on the y axis are model levels)



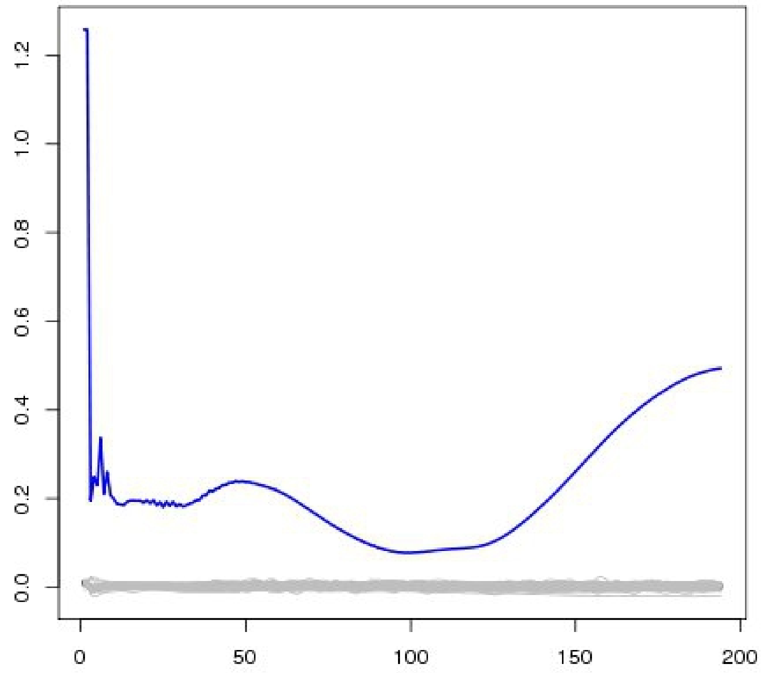
6) Vertical cross-section of w when the modification is turned off (on the y axis are model levels)



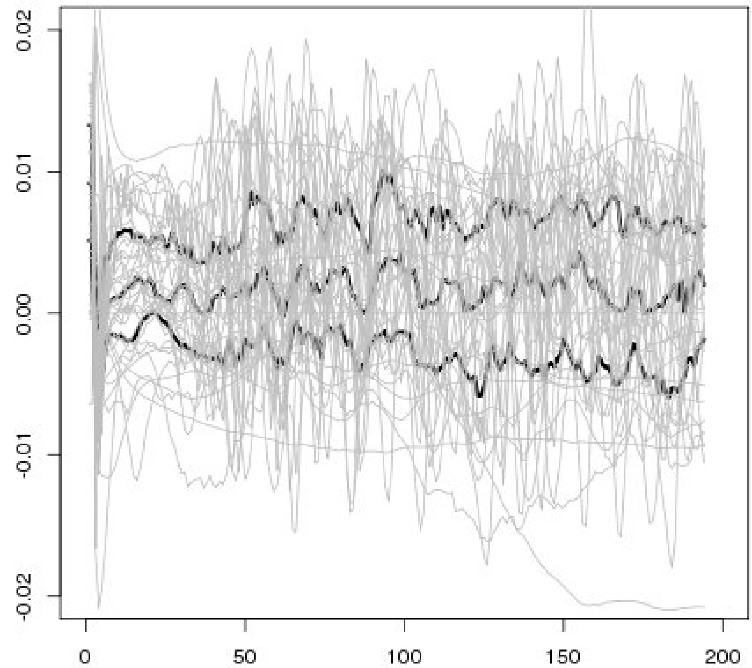
7) Vertical cross-section of the differences ($w_{mod.}$ - $w_{not\ mod.}$) of the vertical velocities of the runs with and without the modification, with LGWADV = FALSE (on the y axis are model levels)



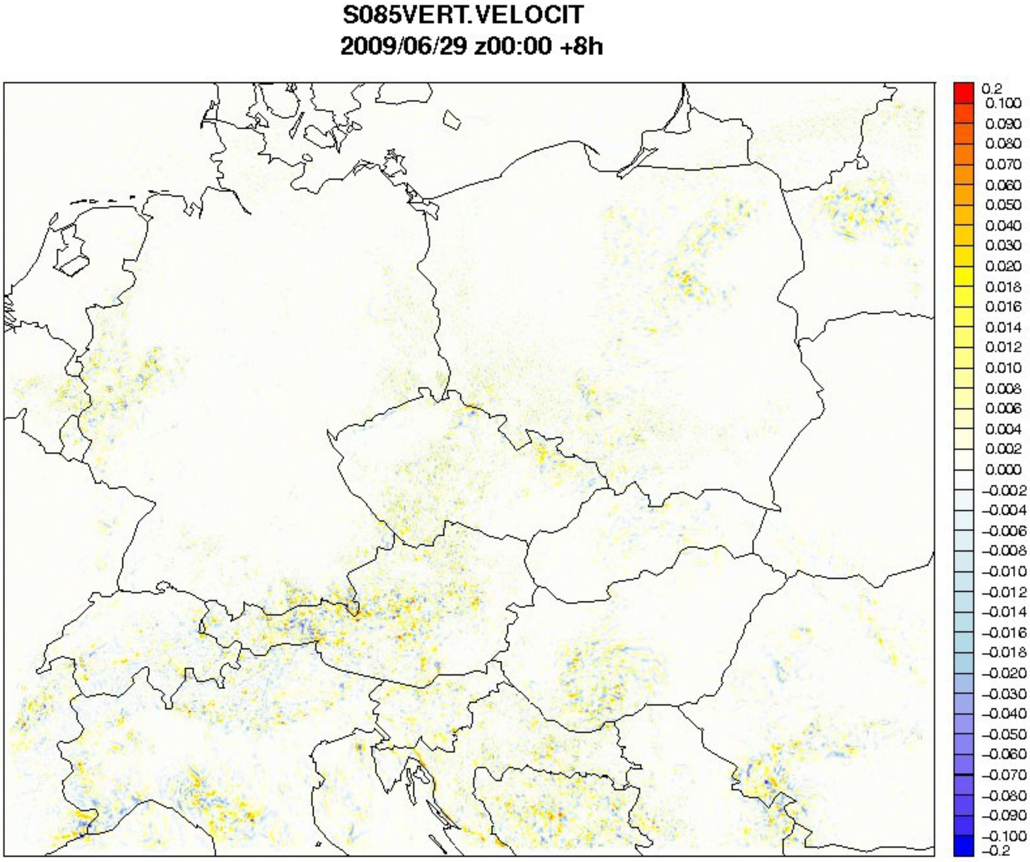
8) Vertical cross-section of the differences ($w_{mod.}$ - $w_{not\ mod.}$) of the vertical velocities of the runs with and without the modification, with LGWADV = TRUE (on the y axis are model levels)



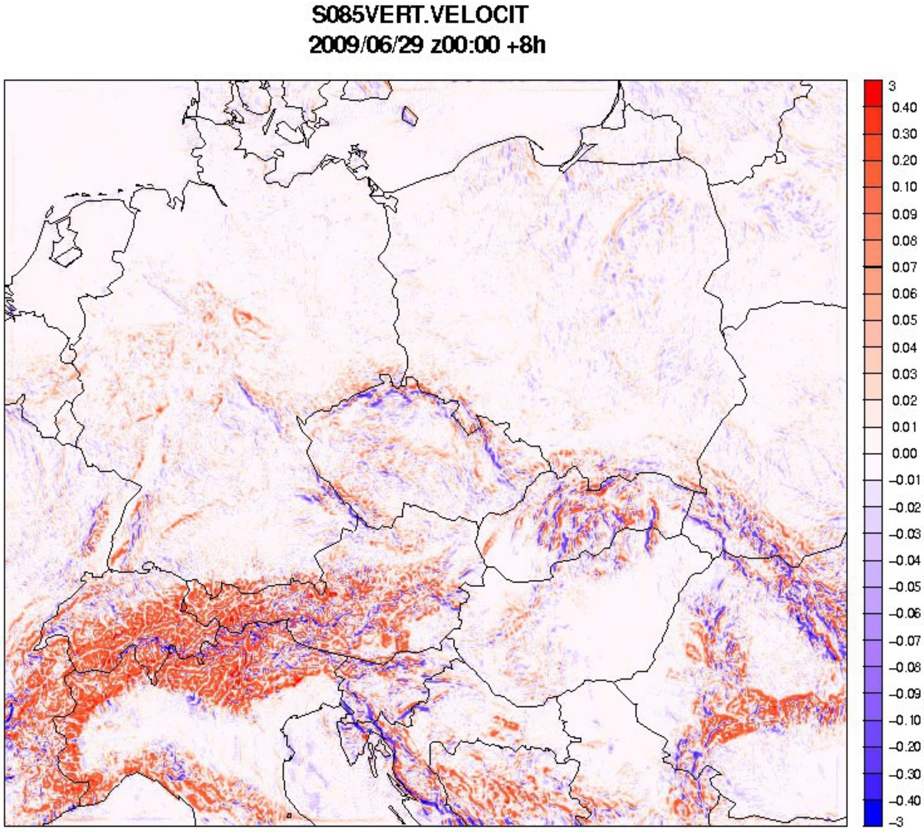
9) The development of the tendency (blue) in the pink point (in the figure 4)), and in some other points (on the x axis are the time steps) - ***after the spin-up no numerical instabilities are detected***

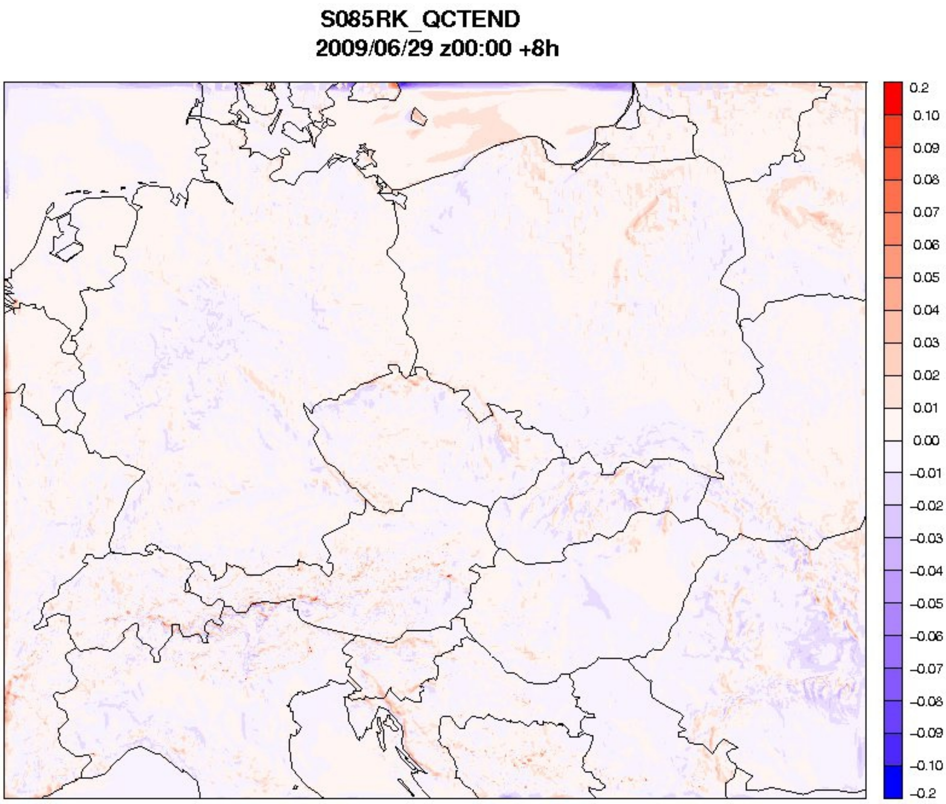


10) The same as in the figure 9), just zooming on the small values with the median and the 25% and 75% quartiles - ***after the spin-up no numerical instabilities are detected***



11) The differences ($w_{mod.}$ - $w_{not\ mod.}$) of the vertical velocities of the runs with and without the modification on the 85. model level with LGWADV = FALSE in an other case (2.) than in the former figures, this case is on 29. Jun. 2010, in central Europe





12) The vertical velocity (up) and tendency of w (down) on the 85. model level in the 2. case when the modification is turned on

4) Summary

We made the needed modifications on the ALADIN-NH model to count with the vertical diffusion of the vertical velocity variable. On the results seems, that the differences between the modificated and not modificated model outputs are small. In our case the maximal calculated differences of *w* were in order of magnitude of 10^{-1} m/s. It can be also noticed, that there are some phenomenons, which remained unexamined. For example near the lateral boundaries appears anomalies in the tendencies of *w* [*1), 2) ,12)*] and in the figures of vertical cross-section of differences of *w* [*7), 8)*] are different plumes above the hills only in the case of LGWADV = FALSE.

To determine the exact effects of the vertical diffusion of the vertical velocity variable, further examinations are needed.

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. They precious help was indispensable for this job.