Extending the functionality of “convection diagnostics” in the ALADIN/ALARO/AROME FullPos software

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Part 2 (JC):
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1. Storm motion vector and vertical wind shear

a. Methodology

Storm motion vector is a prerequisite for storm relative helicity computation (see point 2), but it can itself be considered a quantity of interest for the forecasters.

It is most commonly defined as an average wind in the lowest 6 km above ground level:

$$\overrightarrow{STRMM} = \frac{1}{p_{6km\ AGL} - p_{ground}} \int_{ground}^{6km\ AGL} \vec{v}\, dp \qquad (1)$$

Some literature also mentions slightly modified versions of the formula (1), for instance 30 degrees to the right of the vector computed under (1). Nevertheless, expression under (1) is needed for most of other storm motion vector estimates.

Vertical wind shear is a typical quantity for assessing potential for severe storms. It can easily be computed also offline, but through developments during this stay it was also available in fullpos. Two typical wind shear values are coded:

deep layer shear = $\left\| \vec{v}_{6km\ AGL} - \vec{v}_{ground} \right\|$

and

low level shear = $\left\| \vec{v}_{1m\ AGL} - \vec{v}_{ground} \right\|$.

Deep layer sheer is needed for organized convection to form, while low level shear is mostly an indicator of possible tornado threat.

b. Examples

The case for testing was August 19, 2013, when a cold front coupled to an upper level trough was moving eastward along and north of the Alps. Marginally severe storms developed ahead of it with few reports of severe weather. Figure 1 shows storm motion vector over a zoomed area and figure 2 shows both shear values: deep layer wind shear on the left, and low level wind shear to the right, again over the same zoomed area.

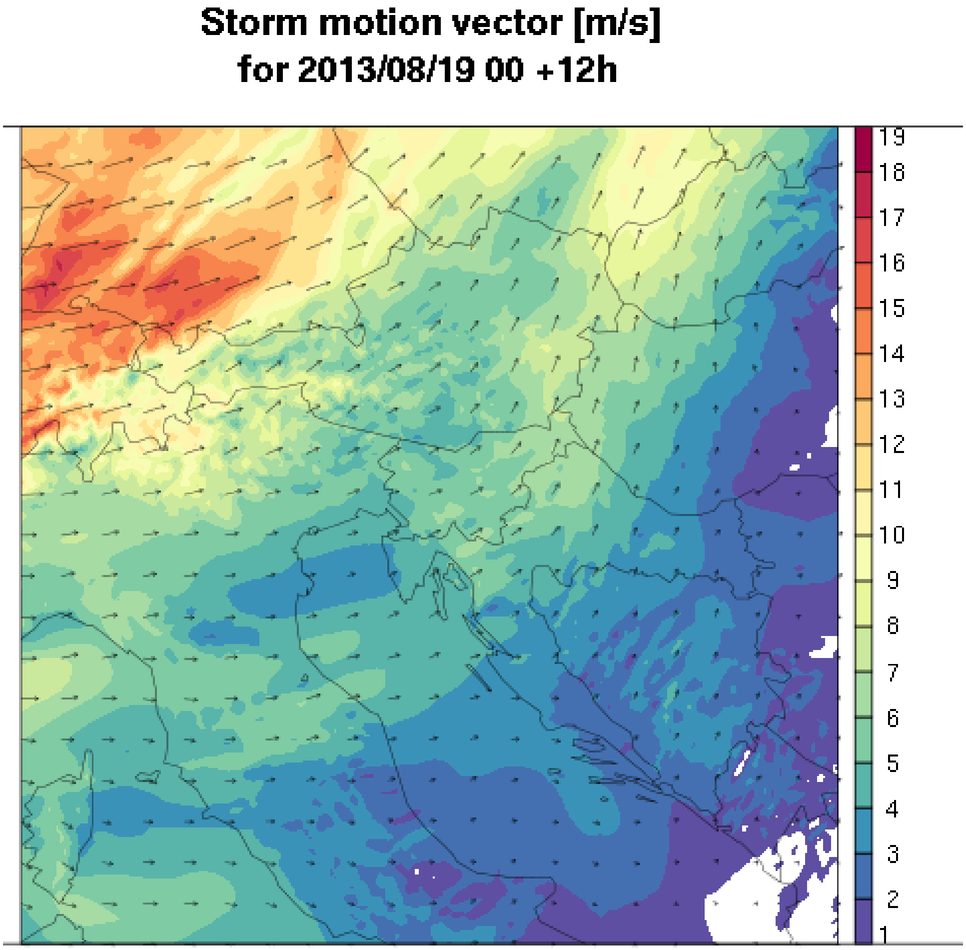

Figure 1: Storm motion vector, direction and magnitude (contours).

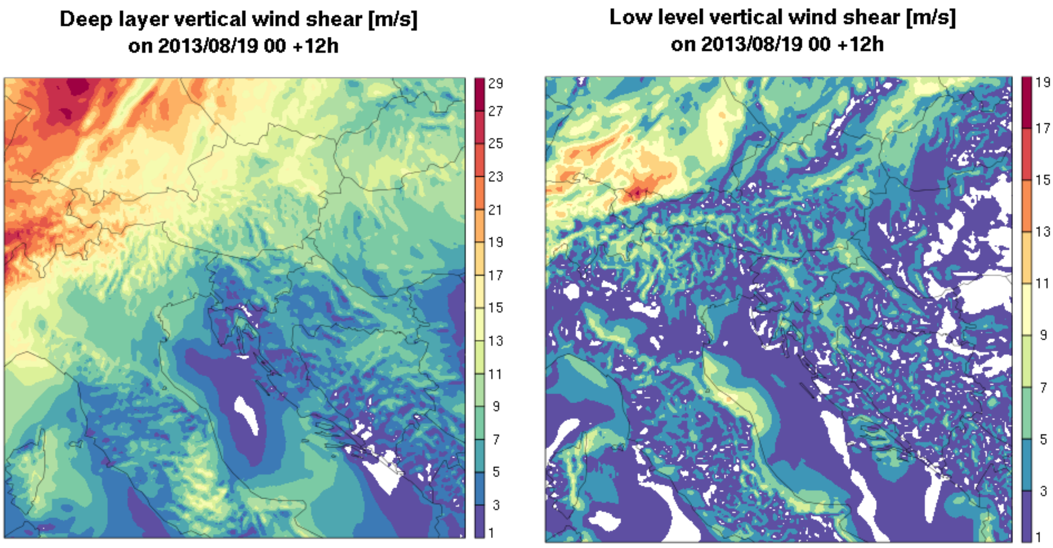

Figure 2: Vertical wind shear: deep layer (left) and low level shear (right). Note that the colouring of contours is different.

2. Storm relative helicity

a. Methodology

Storm relative helicity is a vertical integral from ground to 3 km above ground level of a dot product between storm relative motion and 3D vorticity:

$$SRHEL = \int_{ground}^{1km\ AGL} (\vec{v} - \vec{c}) \cdot (\nabla \times \vec{v}) dp, \qquad (2)$$

where c is storm motion vector, computed under 1. Writing the integrand in components yields:

$$(\vec{v} - \vec{c}) \cdot (\nabla \times \vec{v}) = (u - c_x)\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right) + (v - c_y)\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right). \qquad (3)$$

Obtaining 3D vorticity or horizontal derivatives of w is not a very easy task and would require a lot of additional dataflow. The vertical integral that computes vertical velocity would need to be derived and this would produce 5 terms that could then had to be translated to quantities of which horizontal derivatives are obtainable from dynamics. However, in case of hydrostatic case, finding horizontal derivatives of w would be even more complicates. This is due to the fact that in hydrostatic case vertical velocity is entirely diagnostic field, which would make translation to variables of which horizontal derivatives are available even more difficult.

Therefore, the effort was put in estimating the order of magnitude of horizontal derivatives of vertical velocity compared to vertical derivatives of horizontal wind speed.

A test case was run with AROME NH at 2,5 km resolution. The output was then analysed to find the magnitudes of four terms of (3). Namely:

$$\overset{1}{(u - c_x)\frac{\partial w}{\partial y}} - \overset{2}{(u - c_x)\frac{\partial v}{\partial z}} + \overset{3}{(v - c_y)\frac{\partial u}{\partial z}} - \overset{4}{(v - c_y)\frac{\partial w}{\partial x}}.$$

Figure 3 shows a histogram in which, for one particular date, scale of terms 1 to 4 (as labelled above) is analysed by taking a ratio of sum of absolute values of terms related to horizontal derivatives of w (abs(1)+abs(2)) against the difference of remaining two terms (3-2). This histrogram shows that the horizontal vorticity terms´ contribution to storm relative helicity is on the average less than one order of magnitude (but in general even much less) compared to the other two terms. It was therefore concluded that for the time being, the endeavour to code the storm relative helicity without neglection of vertical velocity terms would be pursued only some time in the future providing that a simplified formulation would show some problems.

However, at the moment, as a first guess it seems that such a formulation of storm relative helicity yields satisfying results.

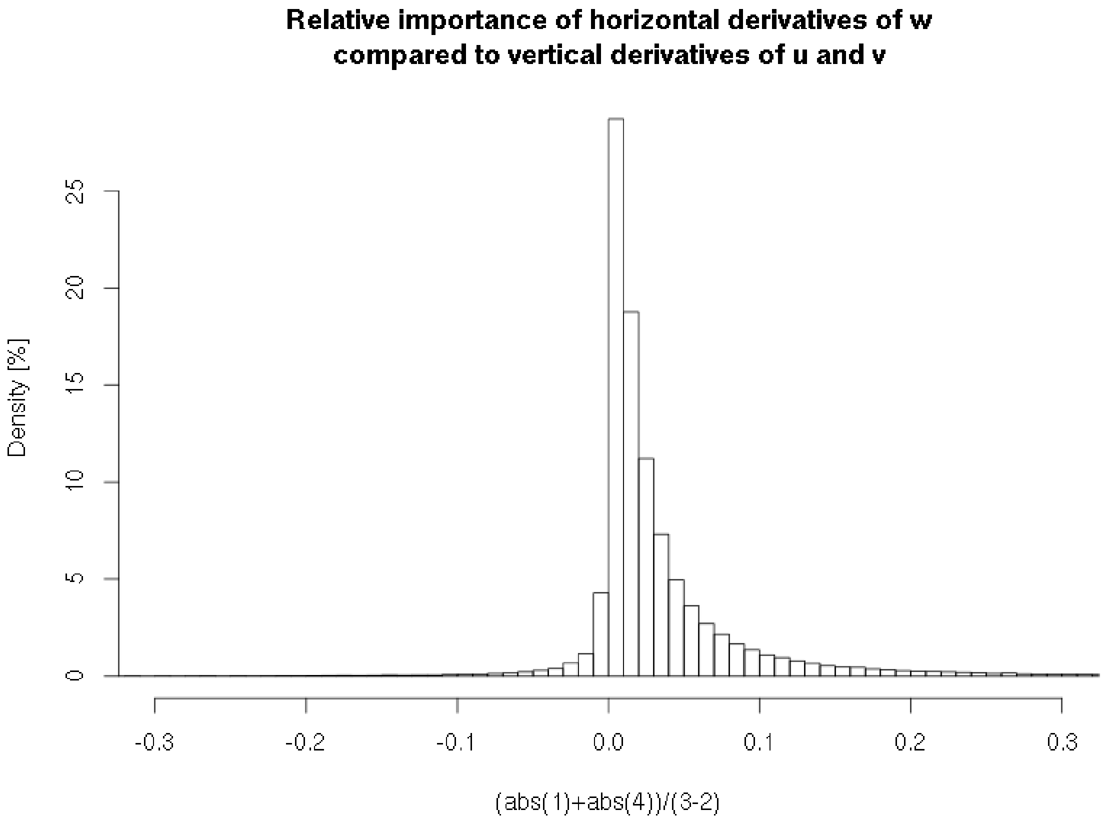

Figure 3: Scale analysis for relative importance of horizontal derivatives of w: histogram of absolute values of terms 1 and 4 divided by difference of terms 3 and 2.

b) Results

Storm relative helicity was computed for the same case as in 1, see Figure 4. Notice the most intense signal in front of the advancing upper level through (from Switzerland, through Germany towards NW part of Poland). Three patches of relatively intense reddish colour can be found in the central European area. This areas with helicity values 100 m2/s2 and above are areas in which formation of super-cellular convection is likely.

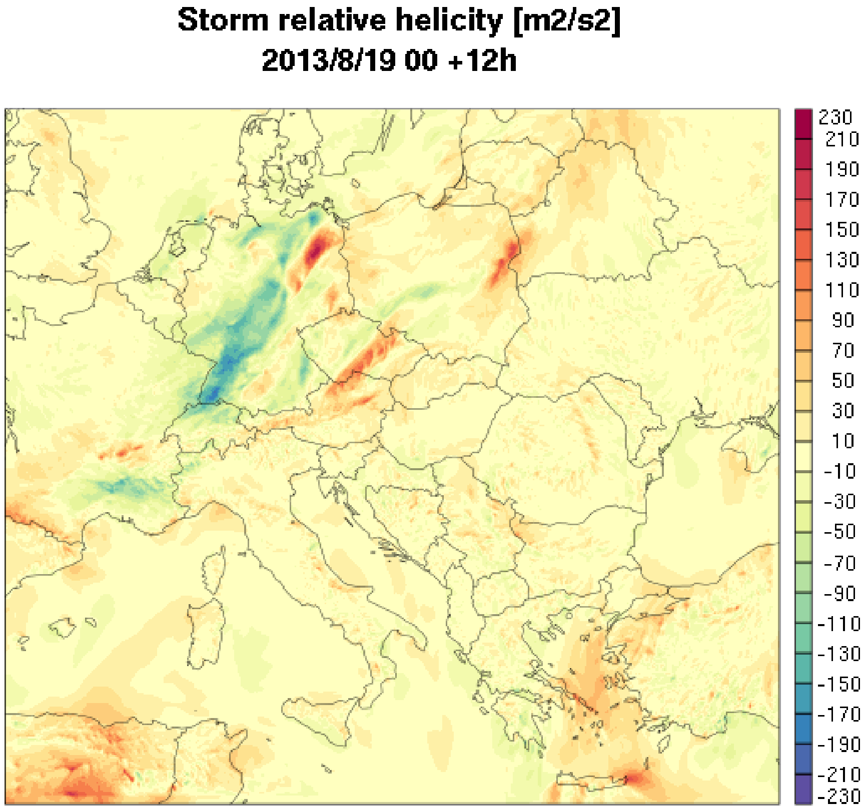

Figure 4: Storm relative helicity computed for a case on August 19, 2013, using ALARO at 5 km resolution, ZAMG domain.

3. Lightning diagnostics

Further work was carried out on the code and validation of lighting diagnostic routine. After some debugging and minor code redesign, all configurations of lightning diagnostic worked and a some test cases have been run. It has been established that the coefficients used in the study on north American cases (McCaul et al 2009 and Price and Rind, 2001) seem pretty far from what we observed. This is also true for vertically integrated total cloud ice – the values in ALARO and AROME are much smaller (for summer 2013 cases) to what was used in the American literature.

In order to best match observation of instantaneous lightning frequency, we estimate that the three calculations need to be multiplied by 300 for value of namelist parameter NMT=0, 10000 for NMT=1 and 25 for NMT=2.

An example for one particular case is shown in Figure 5. Comparison to observations seems quite good. However, this is mostly due to the fact that the squall line movement was very well captured by the model anyway. The results shown in Figure 5 are already multiplied by the factors mentioned above.

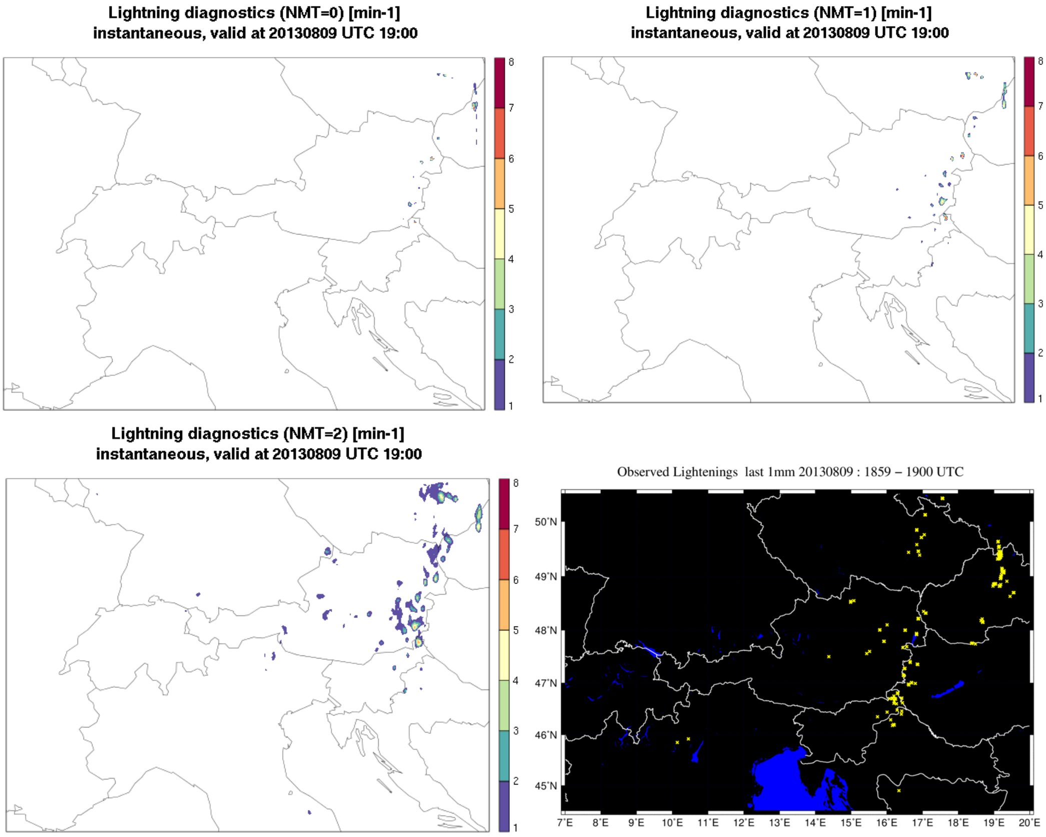

Figure 5: Lightning strikes on August 9, 2013: observations (bottom right), and as simulated by different methods: top left for Price and Rind method, top right for the first method described by McCaul et. al. (evaluating graupel flux in the mixed phase of the cloud) and bottom left for the second method of McCaul et. al. (vertical integral of all ice phases).

4. Conclusion, problems, further work

a) Helicity, storm motion vector, shear

The code has to be implemented also in the endpos part of fullpos – to make it available for other configuration apart from CFPFMT=´MODEL´.

b) Lightning diagnostics

Because lightning is an instantaneous flux, some additional redesign of the code will be necessary. As it is done now only flash rates for one time-step can be obtained, unless one minute output files are available and post-processesed.

One suggestion is to move the lightning diagnostics code to model physics and to make it available during integration run by storing it in historical array (as is done for precipitation, for example). In this case the output would be a cumulated value of flashes. Another option is to complement automatic satellite image movie creation by adding lightning flashes to it. For instance, by adding similar marks as with lightning observations and colouring those depending on their age.