The trajectory search in the SL advection scheme

RC LACE stay report
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1 Introduction

The time scheme used in the model employs an iterative technique for computation of the semi-Lagrangian trajectory. Assuming that the particle is at moment t in the origin point and arrives at the final point (a known gridpoint) at moment $t + \Delta t$, the position of the departure point is unknown. In order to determine the semi-Lagrangian trajectory, the position of the origin point is computed using an iterative scheme. The most common number of iterations used is 2 or 3, depending on the extrapolation methods.

Recent results in global model IFS of ECMWF [1] show that an increase in the number of iterations may prove beneficial for some of the gridpoints, especially for severe weather cases when high values of wind speed occurred. On the other hand, a higher number of iterations may cause lower accuracy of the forecast, in case of divergence in the iterative procedure. The solution proposed there is a dynamic approach of choosing different number of iterations for each gridpoint, depending on the convergence rate of the trajectory search for that specific point. Following this outcome, the subject of this stay was to assess the convergence rate of the departure point iterative scheme for LAM model configuration ALARO in high horizontal resolutions (2.5km/1.25km).

The first step in order to implement this idea was to verify the distances between two points representing estimations of the origin point from two successive iterations. This algorithm was applied separately for horizontal and vertical components. The number of iterations was increased to 5. The differences between distances (arrival - departure) were checked for consecutive iterations: 2 - 1, 3 - 2, 4 - 3, 5 - 4. They were defined as follows:

$$\delta x_{D,ik}^{(l)} = \frac{|x_{D,ik}^{(l)} - x_{D,ik}^{(l-1)}|}{d_k}, \; l = 2, 3, ... \tag{1}$$

where ik refers to the i_{th} gridpoint of the k_{th} level. In vertical, $x_D = \eta_D$, the vertical coordinate of the departure point and d_k represents the distance between two vertical levels of the model $k-1, k$. In horizontal, $x_{D,ik}$ is the distance of the departure point from the arrival point, for a given grid point and d_k is the horizontal resolution. After evaluating these values, referred as norms, the next step was to define a convergence rate for each gridpoint, representing the ratio between two succesive norms :

$$cr_{ik}(l) = \frac{|x_{D,ik}^{(l)} - x_{D,ik}^{(l-1)}|}{|x_{D,ik}^{(l-1)} - x_{D,ik}^{(l-2)}|}, \; l = 3, 4, ... \tag{2}$$

2 Implementation in the cycle 40t1

The necessary changes for the evaluation of the amounts described above were implemented in routine *elarmes*. Hence, routines *lapinea* and *call_sl* were modified accordingly. For easier representation, the values which we want to test were assigned to some fields that were already present in the code, but currently were unused. When checking some values of these fields, it was noticed that the expected quantities had slightly shifted values. It was then found by Ján Mašek and Petra Smolíková that the packing of fields before writing them into the historical files was inserting this very small error (equivalent to $err = (max - min)/2^b$, where max, min are the maximum and minimum values of the field to be written and b is the number of used bits). Taking into account that the fields that we wanted to check may have varying values, this small error had to be taken into consideration. The solution in order to have correct results was to remove the packing of the fields (by setting NVGRIB to 0 in namelist NAMFA), this leading to huge historical files and larger integration time, but exact results obtained.

Two cases were chosen with different sizes of the integration domain and different resolutions: a severe weather case from 31 March 2015 when a storm occured over several areas in western and central Europe ($\Delta x = 2.5km$). The second case is from 17 June 2016 and is integrated on a smaller domain ($\Delta x = 1.25km$).

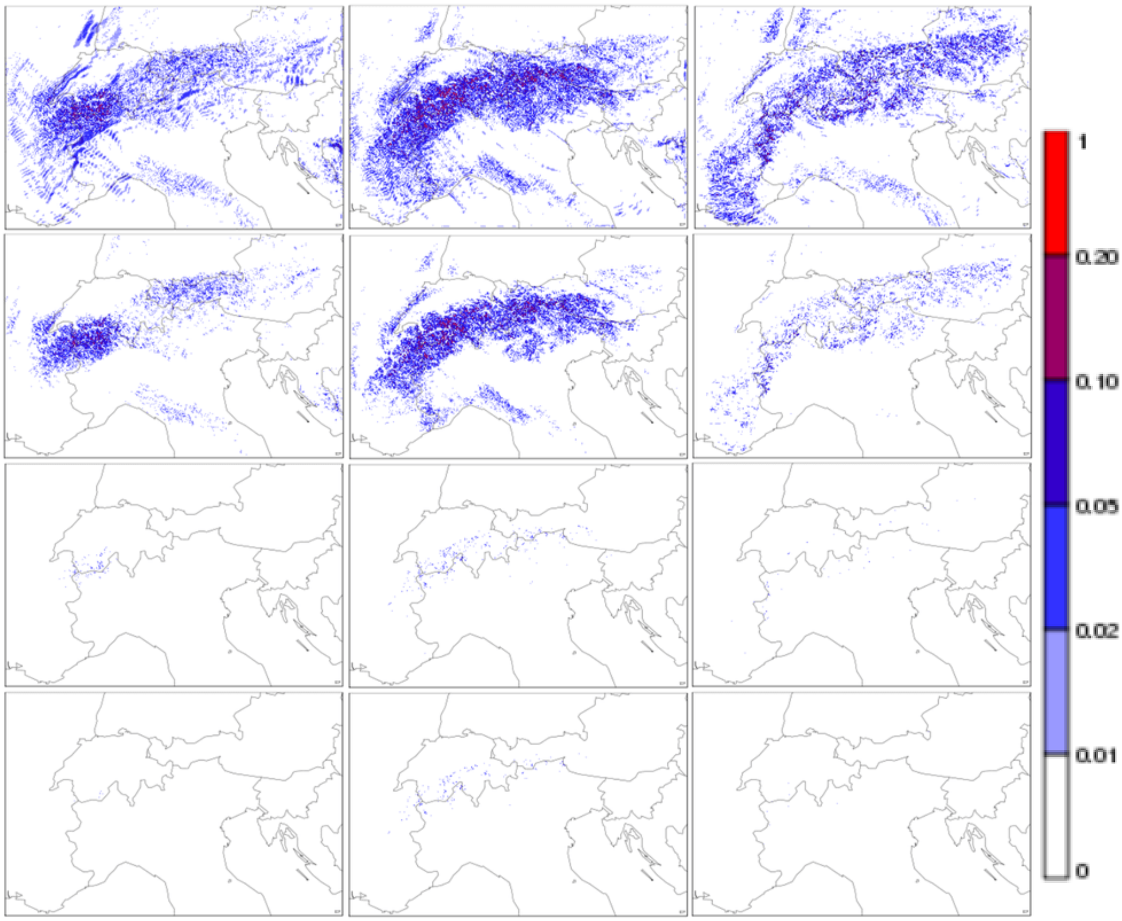

Figure 1: *Differences between distances for consecutive iterations: l=2 - first row, l=3 - second row, l=4 - third row, l=5 - fourth row, for different layers: first column - level 30, second column - level 50, third column - level 80, forecast from 31 March 2015 00 UTC for 24 hours*

As expected, the norms (computed for horizontal) show some gradual decrease after each iteration, for both cases. Most of the values are between 0 and 0.1 for the case shown in figure 1. Some of the points have larger values for the norms after only 2 or 3 iterations. Most of these values decrease after 4 iterations.

As it concerns the convergence rate of a specific gridpoint, some results are shown in figure 2, for the case of 31 March 2015. When this parameter is bigger than 0.5, it is considered that the departure point has diverged. For the 50^{th} model layer, the results in figure 2 indicate that there are many points that seem to diverge. We may say that this may happen because of the definition itself: having very small value in the denominator in equation 2 (we may see in figure 1 that the differences between departure and arrival point do not change much after each iteration) leads to high convergence rate for some points. We do not have explanation for different behavior of odd and even iterations. There is much smaller difference coming from an even iteration compared to the previous iteration result then for an odd iteration. The "diverging points" are distributed quite homogeneously over the domain, not being connected to some particular phenomenon in flow, nor orography.

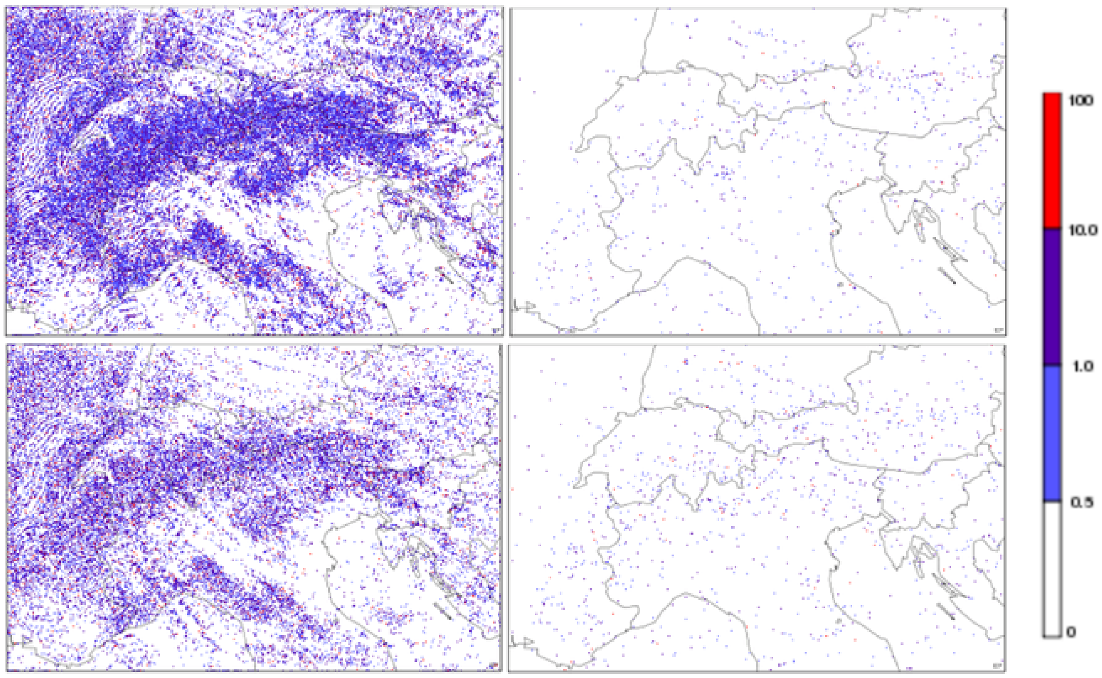

Figure 2: *Convergence rates after consecutive iterations: l=3 - top left, l=4 - top right, l=5 - bottom left and l=6 - bottom right, level 50, forecast from 31 March 2015 00 UTC for 24 hours*

3 Conclusion

We propose to design other convergence rate evaluation taking into account the distance between origin point estimations. If this value is very small, there is no need to improve the origin point estimation any further and the origin point calculation may not be considered as diverging. Also, we do not know what is the reason for the differences in the convergence rates for odd and even iterations (figure 2). We can not conclude that the iteration procedure is diverging in all the red points. Hence, the criterion for convergence has to be changed. Further tests are needed, especially for severe weather cases with high values of wind speed, for longer timesteps and longer period.

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References

[1] M. Diamantakis and L. Magnusson, *Numerical sensitivity of the ECMWF model to Semi-Lagrangian departure point iterations*, Technical Memorandum 768, 2015