VALIDATION OF E801 CONFIGURATION (ADJOINT SENSITIVITY) IN ALADIN

Hopefully the last step to pass before running full Aladin 4DVAR configuration

Filip Váňa
CHMI/ONPP

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1 Introduction

Having all the components needed for 4DVAR assimilation system in Aladin, there is indeed an interest to run this variational assimilation technique with the LAM geometry. Instead of blindly launching the complete 4DVAR configuration and wondering what it computes, it was decided to test the temporal evolution of model with its the geometry-related settings (like LBC coupling) by so called adjoint sensitivity test (Rabier et al. 1996, Gustafsson et al. 1998) [1]. Such configuration known as e801 is available in the code for LAM geometry since long time ago, though being not really efficient from the computational point of view. It was used just occasionally and exclusively for research purposes (Soci 2000, Simon and Vana 2003, Soci 2004 and Soci et al. 2006).

The aim of this study should be then to:

1. To restore the e801 configuration after long time of not being in use. The last model cycle for which this configuration was used is CY26T1, the actual cycle is CY32T3.
2. To optimize the old e801 configuration by replacing the Eulerian advection by recently developed semi-Lagrangian one.
3. It is desirable to select the best simplified physics package suitable for relatively high resolution of the targeted simulations (equal to typical resolution of operational Aladin models).

The last point should ideally further imply the guidelines for the eventual further development of the simplified physics package targeted to high resolution.

2 Sensitivity experiments

One of the possible utilization of adjoint methods is to study the sensitivity of forecast error with respect to the initial conditions. Various papers deal with this problematics: Errico and Vukićević 1992, Rabier et al. 1996, Gustafsson et al. 1998, Soci et al. 2004 and Soci et al. 2006 among the others. Interested reader is then advised to refer them for detailed explanation of the basic principles of such experiments. Here just a brief recapitulation is given of the basic design of e801 in Aladin, the configuration for sensitivity experiments. A typical e801 consist from following sequence of processes:

1. A non-linear forecast (with full physics) is carried out from the initial time t_0. This step called reference or control run is also important for creation and storing of the model trajectories for adjoint. (Optionally the trajectories to store can be computed from TL model.)
2. At the verification time t, which is the end of the non-linear control integration, the difference between the forecast $\mathbf{x}(t)$ and verifying analysis $\mathbf{x}^a(t)$ is used to compute the cost function (based on square norm of total energy) and its gradient $\nabla J_t = \mathbf{x}(t) - \mathbf{x}^a(t)$. The both cost function and its gradient can be either computed for the whole domain or just for sub-area of interest.

[1] The remaining part completing 4DVAR is supposed to be well proven by various existing 3DVAR configurations.

3. Backward integration of the adjoint model is carried out projecting the gradient ∇J_t to the initial time t_0 to obtain ∇J_{t_0} . The adjoint model can be adiabatic only or there are two sets of simplified physics packages. The first one following Buizza (1994) offers very convenient simple parameterization of dry processes like gravity wave drag and vertical diffusion. It has been developed for the EPS system at IFS. Presently it is used for the computation of extra-tropic singular vectors of low resolution (T42) IFS only. The advantage of this physical package is among its relative computational efficiency the fact that it doesn't require any additional (diabatic) trajectory storage. The other more sophisticated physical package for adjoint model was developed by Janisková (1998). It was derived from the all major physical parameterization schemes. This package is logically more related to the physics of the non-linear model from which it requires some additional trajectory storage. Of course both physical packages are subjected to further customization.

4. Alternatively the so-called sensitivity forecast can be launched. This is another full non-linear forecast started from the initial state $\mathbf{x}_{t_0}$ corrected by the projected gradient of the cost function ∇J_{t_0} in the way: $\mathbf{x}_{t_0} - \alpha \nabla J_{t_0}$ where α is tunable scalar (typically being around 0.1).

It can be shown that this simple algorithm defining the sensitivity configuration has some similarity to a configuration of 4DVAR assimilation. Let us assume that the $\mathbf{x}_{t_i}$ and $\mathbf{x}^a_{t_i}$ respectively represents the model state as predicted by the observation operator[2] and the observation vector as a full model state vector[3] at the times t_i. In this case the the 4DVAR observation cost function J_o over the whole time interval $t \in < t_0, t_n >$ becomes:

$$J = J_o = \frac{1}{2}\sum_{i=0}^{n}(\mathbf{x}(t_i) - \mathbf{x}^a(t_i))^T \mathbf{R}_i^{-1}(\mathbf{x}(t_i) - \mathbf{x}^a(t_i)),$$

with $\mathbf{R}$ being the error covariance matrix for the observations. When this matrix is defined as the total energy in the way used for the sensitivity cost function, the previous equation for the J_o cost function becomes identical to the sensitivity cost function J. Further on, the gradient of the 4DVAR cost function $J = J_o$ (setting for simplicity the other cost functions J_b for background field eventually J_c for filtered model state equal to zero) with respect to the initial model state is computed as an adjoint model solution over the time period $[t_n, t_0]$, similarly as the sensitivity cost function gradient is projected to the time t_0. This also explain why the configuration e801 can be regarded as idealized variational problem with only J_o term, one time-slot, without the obs operators and alternatively also without minimization (depending to the value of the model switch `LMINIM`). Like that this configuration becomes an ideal simple testing tool for the adjoint model component of the desired Aladin 4DVAR system.

3 Experimental setup

For all the subsequent runs the Aladin/France domain with the physics and dynamics setting is used running for the most recent available cycle CY32T3. All the simulations were performed for one specific case when the Aladin/France forecast was outperformed by the one from global model Arpége (Tardy et al. 2007). More precisely this is the case from 00 UTC November 25th 2005. After 12 hours of simulation Aladin (with 3DVAR assimilation) missed completely the small and very active meso-cyclone entering from north west the Aquitania region (south east of France), as illustrated by Figure 1. Even this was not the main aim of the study, it was found interesting to see whether this particular case can be improved by the backwards projected difference from the verifying analysis of 12 UTC.

All the presented e801 simulations started at 00 UTC of this day from the 00 UTC 3DVAR assimilation of Aladin/France. The coupling frequency was the standard Aladin/France 3 hours interval. The verifying analysis at the end of simulation was either 12 UTC 3DVAR assimilation of Aladin/France in case of 12 hours simulation or the initial file (00 UTC 3DVAR assimilation) for all the other cases.

[2] typically represented by $\mathbf{y}_{t_i}$ in variational formalism

[3] usually represented by $\mathbf{H}(\mathbf{x})_{t_i}$

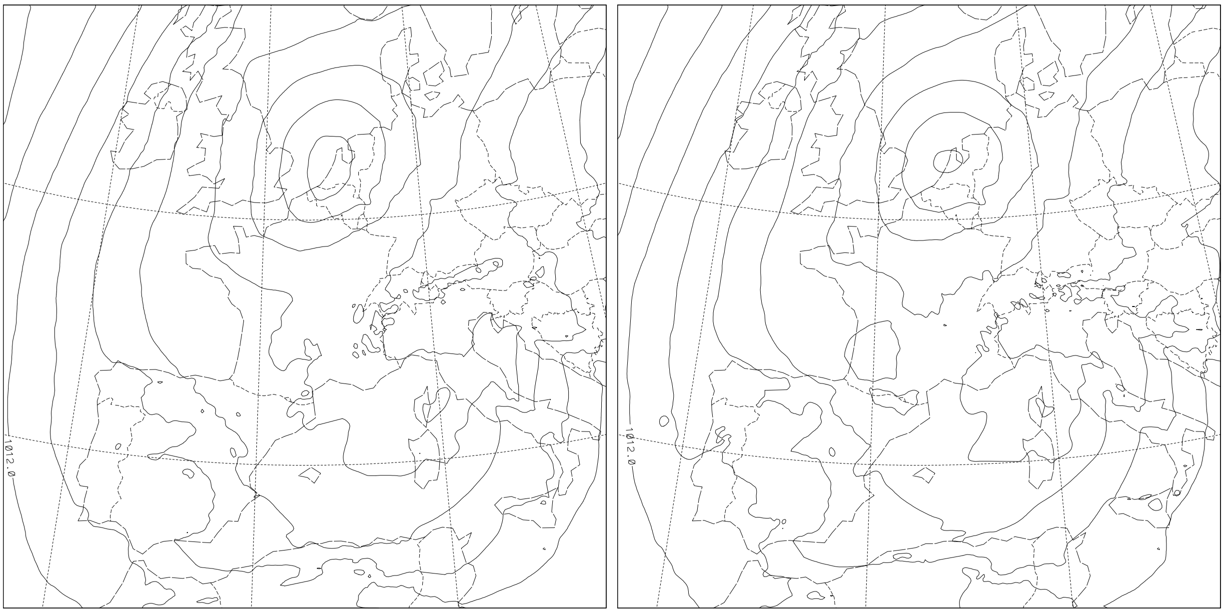

Figure 1: *The MSL pressure field at 12 UTC November 25th 2005 obtained by 12 hours simulation of ALADIN/France starting from 00 UTC 3DVAR assimilation (left) and by 12 UTC 3DVAR assimilation (right).*

4 e801 resuscitation

As mentioned the configuration e801 allowing sensitivity studies was not in use since CY26T1 for Aladin. During that time it was sort of validated by the Mitraille system but no results were ever checked from those runs. Moreover with the migration of Météo-France environment to the new supercomputer platform even the norms produced by those validation jobs possibly got changed. Logically a more precise validation of e801 configuration in terms of results was desirable.

Fortunately it turned out that the original configuration (with adiabatic adjoint) works properly even for the recent cycle. One has to be however extra cautious with the namelist setting. It is essential for proper 801 performance to set up the last step of forward integration (or the zeroth step of the adjoint) as the only step dealing with simulated observation. More precisely the parameter `NREFTS` of the `NAMVAR` namelist must be set in the following way:
`NREFTS(0)=1, NREFTS(1)=NSTOP/NFRREF` .
In the previous the `NSTOP` stands for the last timestep of the model and `NFRREF` is the frequency of observation events.

Once the namelist is set properly the reference e801 on CY25T1 performs similarly to the one on CY32T3. The norms are not exactly the same (which should not be that surprising aiming the numerous code changes between the two compared cycles) the results are very comparable. This can be illustrated by Figure 2. There the initial cost function computed for the defined sub-area of model domain and its backward projection is visualized for surface pressure field. This short test was computed with both CY25T1 and CY32T3 model cycles. (Here the adjoint is adiabatic using no simplified physics package.)

The conclusion from this part of the work is that the original configuration of e801 works also for the recent model cycle.

5 SL advection

The popularity of the semi-Lagrangian transport scheme for NWP is given namely through its ability to deliver long timestep, typically several times longer compared to other alternatives. This quality becomes extremely useful for adjoint applications where trajectories from the every model time step need to be stored. Longer timestep then allows not only reduction of a model computational time but implies also savings in memory requirements.

The adjoint of the semi-Lagrangian scheme becomes the model feature at around 2000 for the global geometry. It has been promoted to LAM domains during 2006 entering the common source at the level of CY32T2 and being further optimized on CY32T3. Logically there has been an interest to compare the old Eulerian advection scheme (used in previous sensitivity studies) with the performance of the new SL scheme.

To switch Eulerian advection to SL in e801 is the same as for any other configuration: one needs just to modify the namelist keys `LTWOTL` (key activating two-time-level scheme) and `LSLAG` (key activating semi-Lagrangian advection) from $.false.$ to $.true.$. The latter can be set also through the command line as the argument of the executable. In this case the argument *"eul"* is replaced by *"sli"*. Optionally some specific SL keys can be also setup in order to further customize the SL advection. In this work the `NITMP` key was set to 2 specifying the number of iterations used for SL trajectory research. The default more costly and more memory consuming value 3 is better suited for low resolution global model configurations.

The chosen particular situation was special by presence of strong wind. Like that the CFL criterion was fulfilled with timestep $\Delta t < 47$s. For safety the Δt_{eul} was set equal to 30s. Logically the first test to compare the two advection was done with the same timestep for both. Similarly to the case presented on Figure 2 also this comparison used just 5 timesteps. The left panel of Figure 3 shows the two advection schemes difference of the cost function gradients computed after forward integration. The right panel of the same Figure shows the final difference of the gradients projected into the initial time t_0= 00 UTC. It is evident that left panel basically shows the forward model difference between the two advection schemes. The right panel than illustrates how such difference is further amplified (or diminished) by the appropriate adjoint counterpart. It is quite evident, that although there are some differences, the both results are very comparable.

The next step than was to define the optimal length of timestep to be used with the semi-Lagrangian advection. Indeed the aim is to use as long timestep as possible for maximal computational efficiency. Here the Δt= 150s was considered as a sort of reference time step being around 3 CFL so in the typical range for the SL advection. The lower panels of Figure 3 shows the difference in e801 performance with this timestep with respect to the Eulerian advection. The timestep Δt= 150s was further extended to 200s and 300s to see the eventual drop of the e801 performance. As it it illustrated by Figures 4 and 5 the results were not very different even with respect to the Eulerian advection[4]. The following table then summarize the technical characteristics of 1 hours e801 as obtained with 1 CPU on NEC SX-8R during standard computing regime (not under benchmark conditions so the presented results have just illustrative character). The `NSTOP` represents the number of timesteps, V. Op. Ratio characterizes the vectorization of whole job, VLEN stands for length of vectors (can be further optimized by namelist parameter `NPROMA` which was kept constant for all the subsequent experiments).

Advection	Δt	NSTOP	Memory size (MB)	V. Op. Ratio (%)	VLEN	User Time (sec)
Eulerian	30	120	14806.131775	98.840484	204.331821	323.960791
SL	30	120	44468.366150	99.417129	233.196152	934.128532
SL	150	24	14298.522400	99.254995	230.269544	278.535606
SL	200	18	12412.928650	99.189286	229.304795	151.954404
SL	300	12	10527.334900	99.060637	225.627098	115.596896

It is evident that the more complicated semi-Lagrangian advection consumes significantly (around three times) more memory and CPU time per one timestep. For the whole job however this disadvantage is more than

[4]This should not be really surprising knowing that the standard operational timestep for Aladin/France is longer than 300 s.

compensated by the possibility of allowing fairly longer timestep with respect to Eulerian scheme. What is also important especially for the vector computers, that the semi-Lagrangian advection possesses at worst the same vectorization as the Eulerian one (the length of vector registers VLEN can be further tuned, while the V. Op. Ratio is already given by the way of coding). Moreover to have around 99% of the job containing adjoint code vectorized is really good result. (Here it shows that the IFS support to the vectorized SL adjoint has been successfully promoted into the LAM geometry.)

As the conclusion of this section it has been demonstrated that SL advection gives comparable results with the Eulerian one. Although the SL advection is more costly per timestep than the Eulerian advection, the advantage to use fairly longer timestep (here 10 times longer with respect to the Eulerian one) makes the whole configuration significantly more efficient. It is than logical to rely on SL advection only for the further runs. As this was further proved the advantage of longer timestep becomes even more evident for longer simulations (like 12 hours).

6 Simplified physics package for adjoint

The adjoint (AD) model is derived as the exact counterpart (transpose) of the tangent-linear (TL) model. The tangent-linear approximation of the full non-linear model can be only used for period for which the NWP integration remains within a linear regime. It is known that with increased model resolution where the physics starts to increasingly participate to the simulated processes, the linear approximation of the TL approximation looses it validity in shorter period. Hohenegger and Schär (2007) for example show that while the T255 (80km) IFS model keeps the TL validity for between 42 and 144 hours, the 2.2-km LM model preserves the same assumption only for periods between 1-5 hours. By interpolation of previous one can hope to keep linear assumption to at least 5 hours for the scales like 10 km (ideally the targeted resolution for Aladin 4DVAR). Indeed it is desirable, that the TL model reflects maximum processes of the full non-linear model. As the physical processes plays important role on such scales, it is evident that they should not be ignored by an adjoint model. Only like that the linear model tendencies would correspond to the non-linear model evolution. However an extra care must be paid to this as it is known, that linearization of diabatic processes is not straightforward due to its high non-linearity and the on/off nature.

The ideal strategy for inclusion of simplified physics remains still unknown (or at least matter of debate). Aiming also the use of the adjoint model at the same resolution as the non-linear model, one should not rely on a common assumption, that the linear physics doesn't need to be the exact tangent-linear version of the full physics. Here this simplifying assumption can't be anymore justified by the fact that low resolution adjoint model is not anyway able to reproduce all the higher resolution non-linear model features. Although the simplified physics can't in principle exactly reproduce the results from the full one, it should at least behave in the very similar way in the terms of tendencies with respect to the adiabatic model. It is evident that to derive such package is not a simple task, especially when simplified physics should further remain simple, regular, enough realistic and computationally affordable (the typical requirements for simplified physics package as specified in Janisková (2004)). The positive sign of being at high resolution is the expectation that model is sufficiently close to the real state. Assuming this, the increments than should be small and one can hope to have less difficulties with linearized physical processes, namely regarding the trade between the regularization and physical realism of the simplified physics.

It is evident, that any high resolution adjoint model must contain parameterization of the diabatic processes. As already mentioned, there are two packages of simplified physics available in the Aladin model. The first one is the very simplified package after Buizza (1994) used primarily for the singular vectors derivation at ECWMF. The other one is the more complex physical package developed by M. Janisková (Janisková 1998) from the operational (around that time) physical package of Météo-France.

One of the aim of this work was to check the availability of those packages and eventually demonstrate their skills for the assumed targeted resolution. Unfortunately none of the physical packages works for configuration 801 based on CY32T3. It turned out that to activate Buizza's physics for this configuration was relatively simple (fix of two control level routines). So far the Janisková's package doesn't work for LAM. There the situation is further complicated by additional trajectory computation (and storage) which works (with the mentioned fix) well for global model, but leading to unrealistic results for the LAM geometry. As the last running LAM configuration was performed before the introduction of the GFL, GMV structures, it seems that the problem might be related to this modification in model dataflow. Figure 6 documents the positive impact of the Buizza's physics for the adjoint model. It can be seen, that the adjoint model already with the very simple diabatic processes parameterization creates less noisy gradients fields looking more realistic. It should be said that although the sensitivity forecast from the corrected 00 analysis by sensitivity gradients was slightly better when the Buizza's physics was used in adjoint model, the both forecast were quite successful (not shown). Most probably the biggest impact to the missed cyclone was coming from the area above Brittany. As it can be seen from Figures 6 the gradient field looks very similar there from both settings. Referring this further to the Figure 1 of Tardy et al. 2007, the analyzed MSL pressure field is really different for this ares from the Aladin/France 3DVAR and Arpége 4DVAR assimilation systems. This case might be worth to be further explored by specific study explaining what exactly happen above Brittany in Aladin 3DVAR making the analyzed atmosphere different from the one of Arpége 4DVAR.

7 Conclusion

The aim of this work was to check the adjoint dynamics and physics of Aladin. For this the e801 configuration was chosen through its close relationship to the 4DVAR. It turns out that the adjoint dynamics including coupling works as expected (for details about coupling see Soci 2000). When replaced Eulerian advection by semi-Lagrangian one, an increase of the computing efficiency was obtained (both in memory and CPU consumption) without negative impact to the results. Some problems were experienced when running the Météo-France (Janisková's package) simplified physics with LAM geometry. In this case the results are not correct, most probably affected by a bug in the code. The other problem detected was linked to the configuration e801 itself. The evolving setup of the Météo-France physics hadn't been updated for this rather research configuration. So to have physics in e801 adjoint, simple fix of two control routines of this configuration was needed. The relevant code for CY32T3 is available under ClearCase branch `mrpe706_CY32T3_801fix` in Toulouse. Once the problem with the Météo-France simplified physics is solved it seems the Aladin model is ready for the full 4DVAR configuration.

8 Acknowledgments

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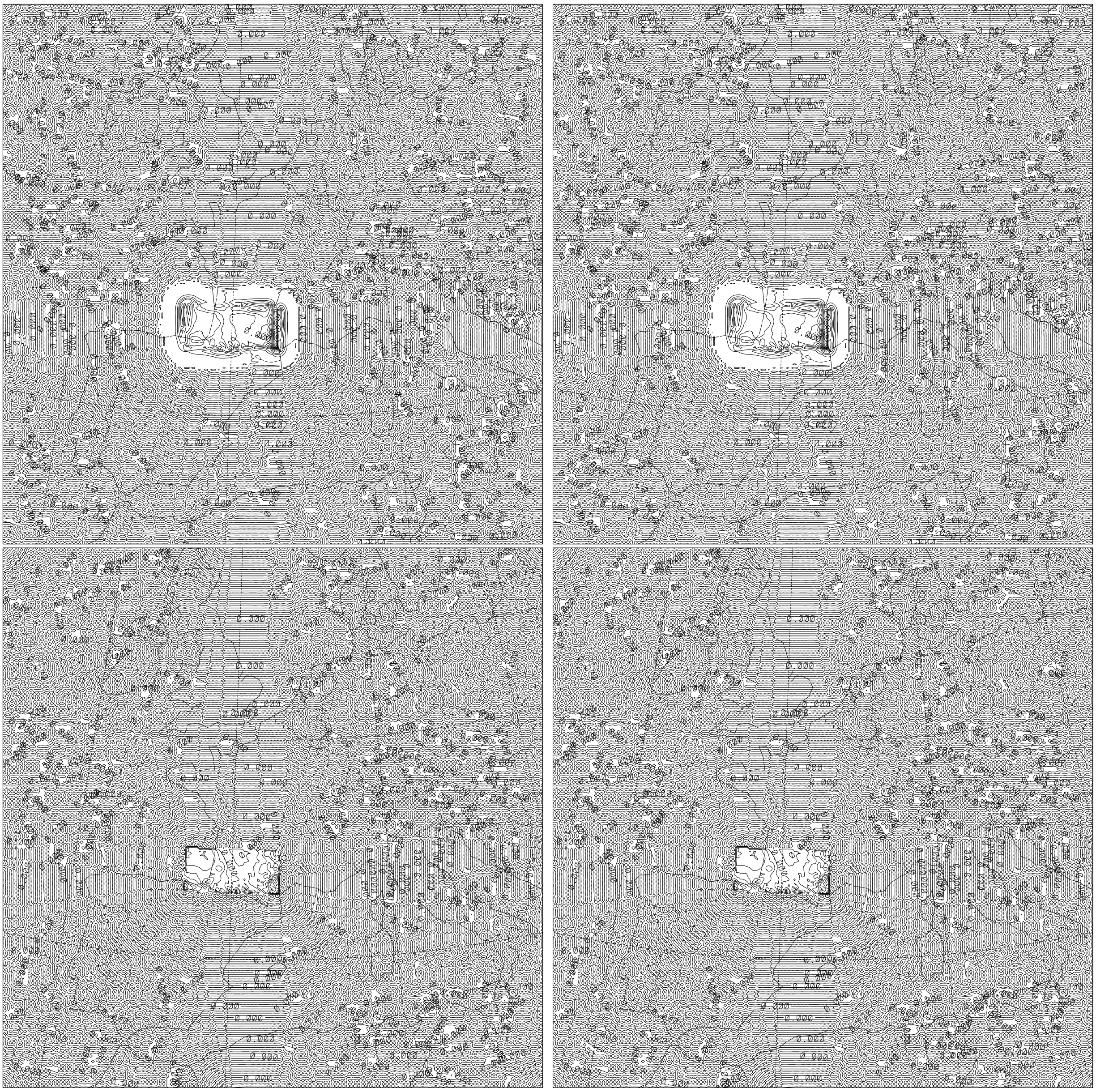

Figure 2: *The 5 time steps (Δt= 30s) backward projected surface pressure gradients at initial time (upper panels) and the gradient of cost function obtained from the difference between 5 time steps forecast and verifying analysis (lower panels) as obtained with CY25T1 (left) and CY32T3 (right).*

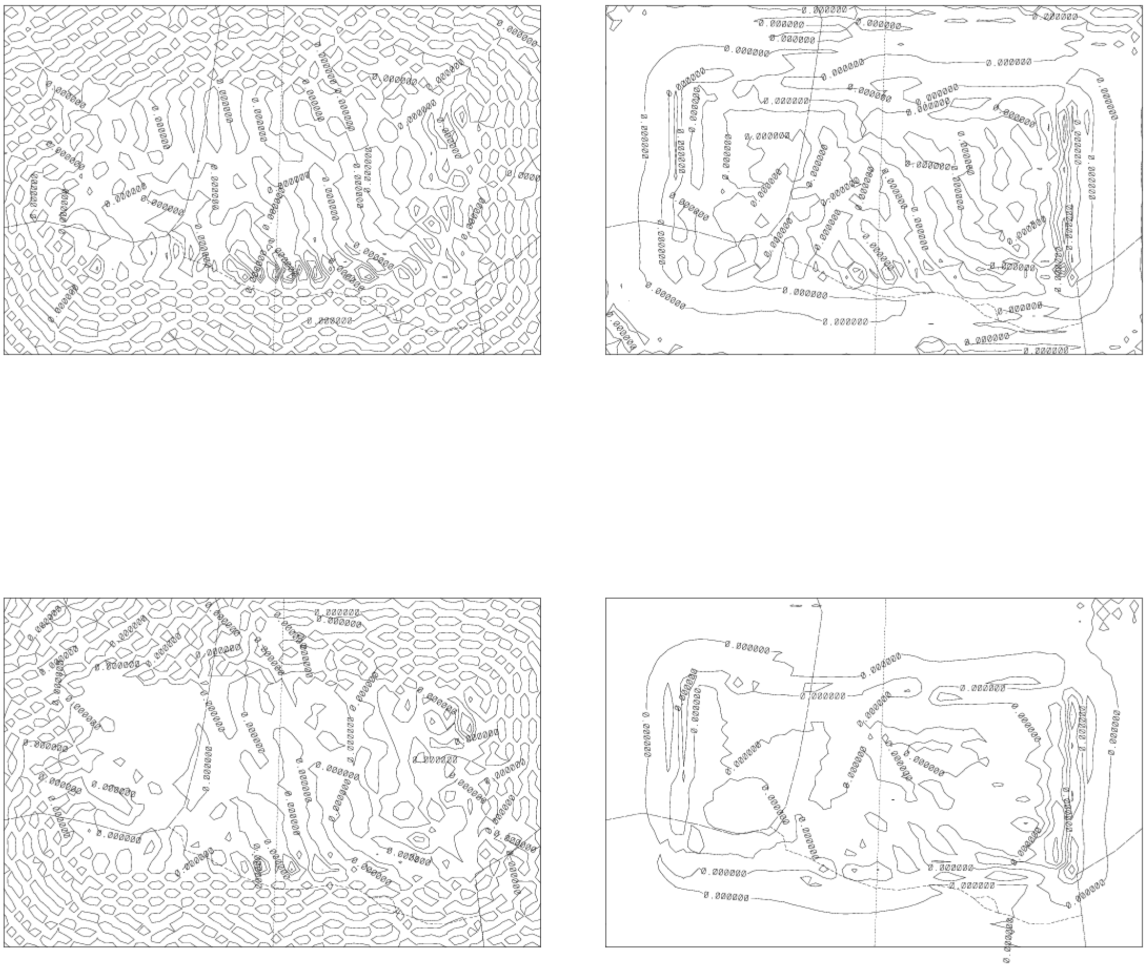

Figure 3: *The differences of 5 time steps $\Delta t = 30s$ (upper row) and 1 time step $\Delta t = 150s$ (lower row) e801 configurations with SL and Eulerian advection (both cases $\Delta t = 30s$). The model configuration is the same as in Figure 2. The left panels show the differences of gradient cost functions after forward integration (corresponding to the lower panels of Figure 2), right panels then the differences after additional gradients projection to initial time by adjoint (corresponding to upper panels of Figure 2). All panels show zoomed area of interest.*

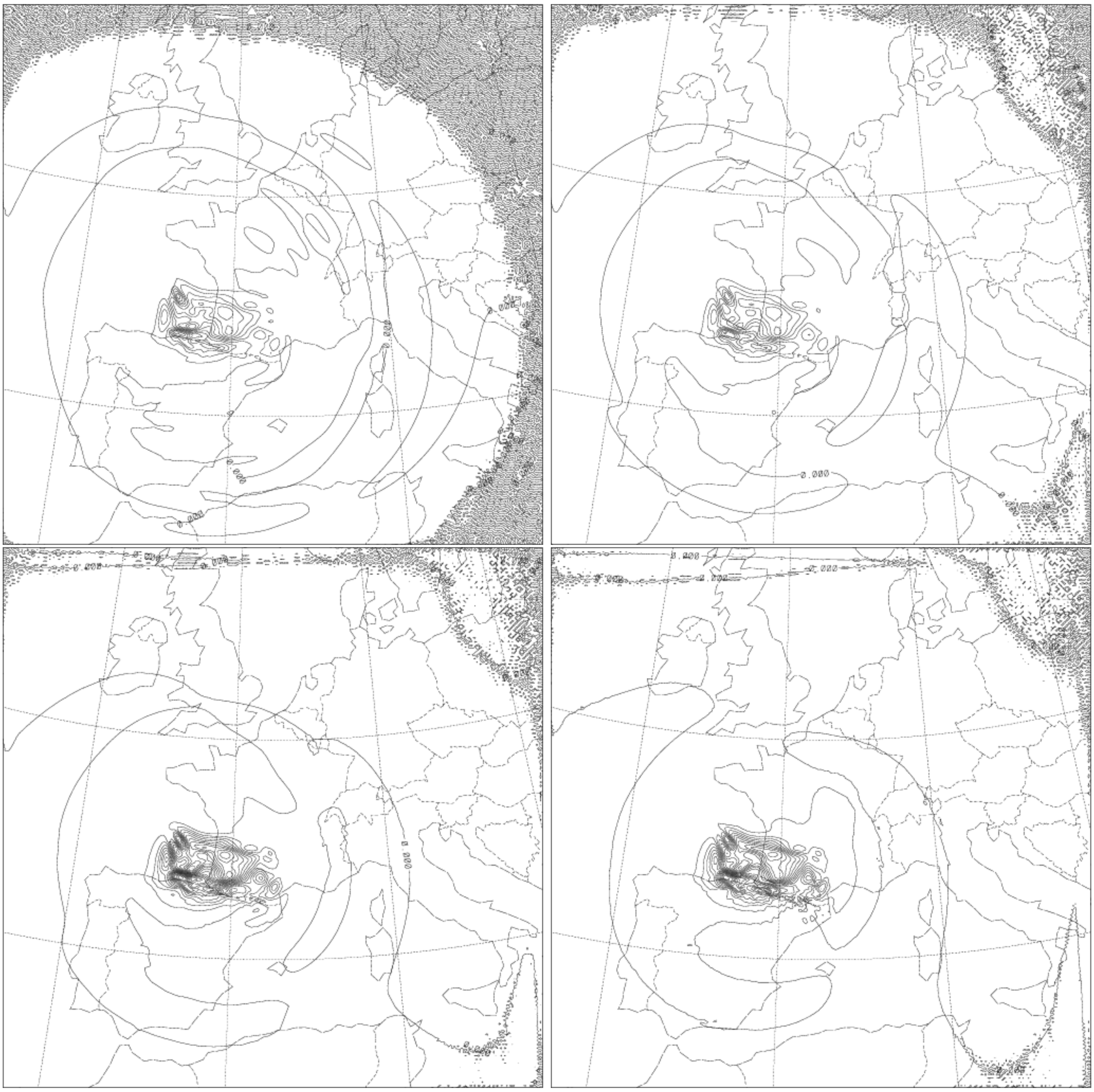

Figure 4: *The projected cost function gradient to* t_0 *as resulted from 1 hour e801 (with adiabatic adjoint model). Upper row: left: Eulerian advection* Δt*=30s, right: SL advection* Δt*=150 s; bottom row: left: SL advection* Δt*=200 s, right* Δt*=300s.*

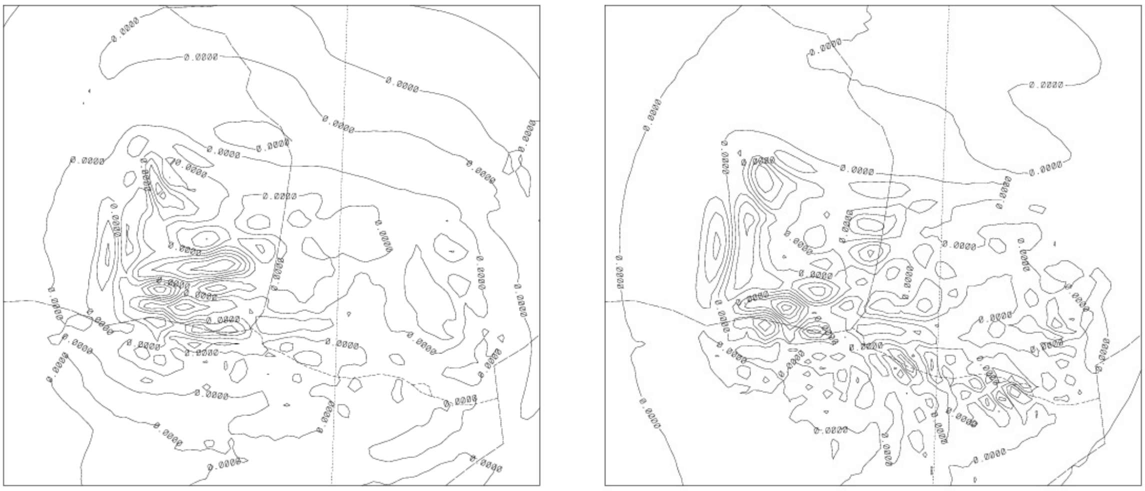

Figure 5: *Differences between sensitivity gradients projected to time t_0 obtained witch SL Δt=150s minus Eulerian advection Δt=30s (left) and SL Δt=300s minus SL Δt=150s (right).*

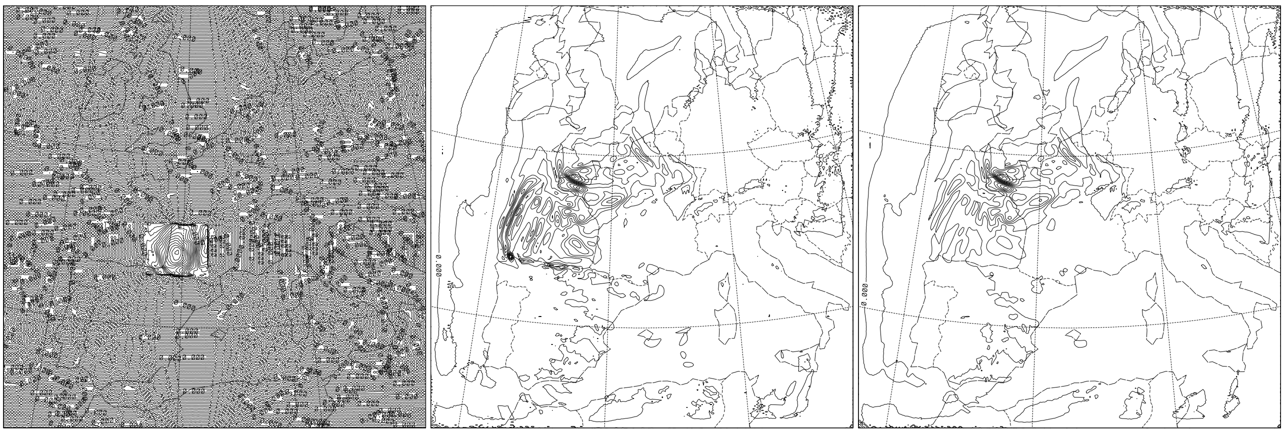

Figure 6: *Sensitivity gradients from 12 hours e801 configuration with Aladin/France. The left panel shows the cost function gradient computed for the selected area as the difference between the 12 hours forecast and 3DVAR analysis. The middle panel shows the backward projected gradient by adiabatic adjoint model. The right panel shows the same when the Buizza's physics is activated.*