1.4 THE OPERATIONAL 4D-VAR DATA ASSIMILATION SYSTEM OF METEO-FRANCE: SPECIFIC CHARACTERISTICS AND BEHAVIOUR IN THE SPECIAL CASE OF THE 99 XMAS STORMS OVER FRANCE

Jean-François Geleyn *, D. Banciu [1], M Bellus [2], R. El Khatib, P. Moll, P. Saez and J.-N. Thépaut [3]
Météo-France, CNRM/GMAP, Toulouse, France
1 INMH, Bucharest, Romania
2 SHMU, Bratislava, Slovakia
3 CNRM/GMAP - Present affiliation: ECMWF, Reading, UK

1. INTRODUCTION

The operational data assimilation part of the ARPEGE/IFS global spectral variable resolution system of Météo-France went from the 3D-Var to the 4D-Var status (at equal resolution for the deterministic model, at similar resolution for the control variable and for a roughly trebled computing cost) on 20/06/00. The plans leading to this second NWP operational implementation of 4D-Var (after ECMWF's one in November 1997) are detailed in Thépaut et al. (1997).

2. CHARACTERISTICS OF ARPEGE 4D-VAR

While similar to its ECMWF IFS/ARPEGE counterpart, the 4D-Var of Météo-France relies for cost-efficiency reasons on two novel features:

- The introduction of digital filter initialisation as a weak constraint imposed during the minimisation (Gauthier and Thépaut, 2001) in order to replace the so-called Jc-NMI normal mode based penalty term of the classical formulation of 4D-Var (the technique is named Jc-DFI by mimicking, even if the two techniques are radically different, in particular in terms of complexity and costs). The advantages of this technique are its generality (like for any DFI application), its efficiency (neither additional integrations nor change of computational space are necessary) and its implicit incremental character (following the one of the 4D-Var algorithm). Despite all these advantages, it was found necessary to keep in our ARPEGE system a small degree of explicit filtering for the final result of the whole 4D-Var procedure. This is achieved at little extra cost via so-called "incremental semi-external DFI", i.e. by applying a classical but weakened DFI procedure on the high-resolution integrations that "bracket" the forward-backward steps towards-from the three minimisation steps. It was shown that this extra filtering procedure was necessary because of the strong incremental character (a factor seven at worse) of our procedure over some data void area, such as Sahara.
- A multi-incremental approach (Veersé and Thépaut, 1998): the inner loops are successively solved at T42, T63 and T95 uniform resolution while the outer loop is at T199 with a stretching factor of 3.5 (i.e. variable resolution from T56 to T699). In this sense the system can be said to be "decremental" in the area of minimum resolution, especially for the third update loop. The latter is also the only one where the "regularised" ARPEGE physical package (Janiskova et al., 1999) is activated. There are no changes in the vertical resolution, 31 levels each time. Each of the three updates involves 25 minimisation steps. The change of geometry, truncation, orography, etc are performed using a rather sophisticated set of interpolating procedures, named Full-Pos.

3. GENERAL RESULTS

All aspects of the 4D-Var implementation (the ECMWF-like ones as well as the novel ones) were extensively tested over summer and winter periods. In the latter case this was done using the January-February 1997 FASTEX period, with particularly interesting and well-documented IOPs, which could be studied with benefit when using a 4D-Var reanalysis.

When everything seemed ready a test suite was started (May 2000) in which the use of ATOVS pre-processed radiances was added to the 4D-Var implementation for convenience. Figure 1 describes the improvements to the scores during the lifetime of this final test suite; those could be attributed half/half to the two ingredients, with more emphasis on ATOVS in the Southern Hemisphere and in the stratosphere and more emphasis on 4D-Var in the Northern Hemisphere and in the troposphere.

The introduction of the semi-external DFI procedure was posterior to the operational implementation of this test suite on 20/06/00.

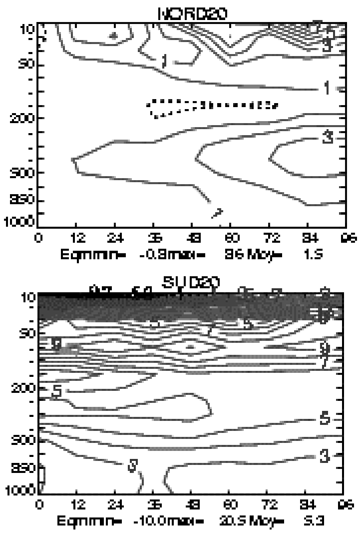
4. ARPEGE 4D-VAR AND THE 99 XMAS STORMS

When France was hit by the two extreme storms of 26/12/99 and 27/12/99, the operational NWP system brought excellent results for the first so-called "T1" storm (consistently good forecasts at 30-hour and 18-hour ranges as well as precise "last minute" analysis) while the situation was more contrasted for the second so-called "T2" storm (mixed success for the forecasts and data rejection problems for the "last minute" analysis).

* *Corresponding author address:* Jean-François Geleyn, CNRM/GMAP, Météo-France, 42 Avenue G. Coriolis, F-31057 TOULOUSE Cedex 1, FRANCE; e-mail: jean-francois.geleyn@meteo.fr

FIGURE1

Amélioration des scores 4D-Var+ATOVS (N20/S20)



Differences in RMS geopotential scores between the pre-operational suite "4DVar+ATOVS" and the operational version of ARPEGE for the period from 25/05/00 to 18/06/00. The x-axis corresponds to the forecast range, the y-axis to the pressure standard levels. Verification is done against the ECMWF analysis. Positive impact of the test is marked continuous, negative impact dashed, zero dotted. Plotting interval 1m. Top = North of 20N. Bottom = South of 20S.

4.1 *Basic results*

Given this overall satisfying performance of the 3D-Var ARPEGE system operational at the time, it was of paramount importance to assess the performances of the forthcoming system on the same cases. While the results oscillated around the same quality (with varying results depending on the range of prediction) for the "T1" storm, the forecast of the "T2" event was dramatically improved when introducing 4D-Var. This was not so surprising since part of the (partial) failure of the operational system at the time had been traced-back to a syndrome of exaggerated «first-guess-check» rejection of crucial data once the assimilated trajectory of the deepening low had started to diverge within the order of magnitude of its (small) active radius. Figure 2 perfectly illustrates this point at its more spectacular time, i.e. before continental SYNOP data will take back the 3D-Var assimilation on the right track.

Since, despite satisfying EPS results, the ECMWF deterministic forecast was by far not as successful as either the ARPEGE operational forecast or our 4D-Var rerun and given the strong similarity of the two systems (physics and resolution are the sole structural differences), a specific study was undertaken to better understand the reasons of the rather good ARPEGE results.

4.2 *IFS vs. ARPEGE and 3D-Var vs. 4D-Var comparison*

A first series of 10 forecasts with the same model (ARPEGE operational at the time T199/C=3.5/L31) but three different initial states (ARPEGE 3D-Var (a), ARPEGE 4D-Var (b) and IFS 4D-Var (c)) was run for different ranges verifying on both 26/12/99 06 UTC (T1) and 27/12/99 18 UTC (T2). The results can be synthesised as follow:

- for "T1", (b) and (a) are of equal (good) quality and beat (c);
- for "T2", (b) beats (a) and (c) of equal (poor) quality.

Since the 3 systems have roughly the same dynamics and since their variational "backbone characteristics" are similar, success seems to depend here on a subtle interaction between data assimilation and parameterisation of physical processes.

A second series of 5 forecasts with the same initial state (IFS operational at the time T319/C=1/L60) but three different models (IFS (d), ARPEGE in the IFS geometry (e) and ARPEGE in its own geometry (f)) was then run under similar conditions. This time there was no firm conclusion except that the IFS model behaves (relatively to ARPEGE) better on "T1" than on "T2".

This neutrality confirms the relative independence of the results on model's characteristics (especially horizontal resolution), outside the data assimilation cycle's problematic.

5. THE MORE GENERAL PROBLEM OF THE "T1" AND "T2" STORMS

A more conclusive result was finally obtained from a study aiming (also with the help of reruns of the preceding year Xmas storm of 20/12/98) to understand the reasons for the high rate of successful forecasts of the ARPEGE system when other operational and research systems had forecasting problems for "T1" (and sometimes "T2"). Showing the lack of influence of model characteristics in pure forecasting mode was easy (see above) and brought us back to the data assimilation problem. There it appeared that the crucial ingredient lying not in the assimilation technique itself but in the tuning of the parameterisation set of the model was to be mainly found in the computation of turbulent fluxes of heat and moisture in deep stable PBL situations.

Lessons drawn from the ARPEGE systematic failure to forecast the 20/12/98 storm at ranges beyond 36 hours in operational conditions from that time led to the operational implementation of a set of 12 physical parameterisation changes on 19/10/99. When rerunning the "T1" case with a switchback to the previous situation, the importance of the change's impact was striking (see Figure 3). Several tests were run to sort out the most important ingredients of the package responsible for this surprising result. Three of them came out, in increasing order of importance, the last one outplaying the others two:

- the parameterisation of the pressure differences between convective clouds and their environment;
- the way to partition convective from stratiform precipitation;
- the formulation of turbulent vertical exchange in the stable case.

Coming back to the 20/12/98 case, it was found (not shown here) that the influence of this computation of PBL fluxes in stable conditions might be critical only when the PBL is stable over all its depth and that the downstream propagation of the impact may take a few days.

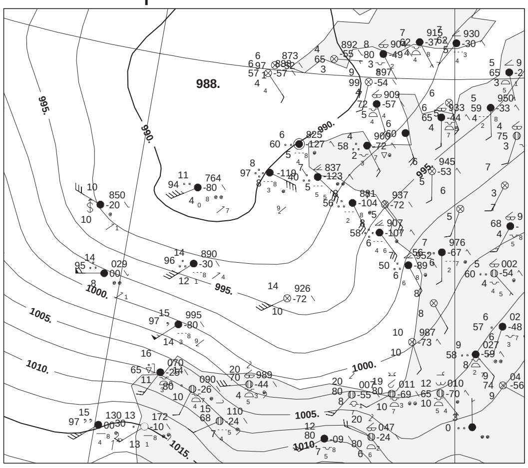
Work is now underway to try and link this empirical finding with a more in-depth explanation of the influence of such «physical» choices on the use of observed data around the model trajectory, inside the variational data assimilation procedure, since such is the surprising result of this part of the work on the French Xmas storms.

FIGURE 2

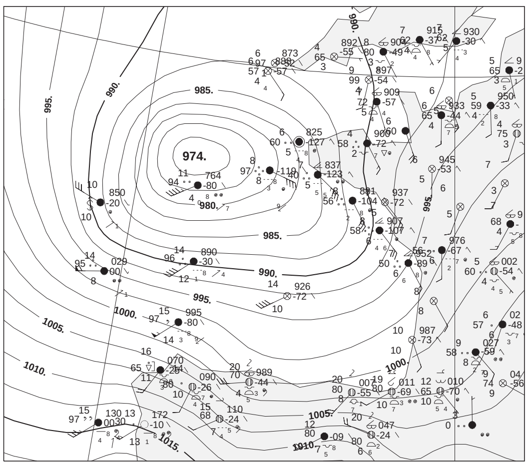
COMPARAISON ANALYSE / OBSERVATIONS

le 27 Décembre 1999 à 12h

ARPEGE opérationnel



4D-Var



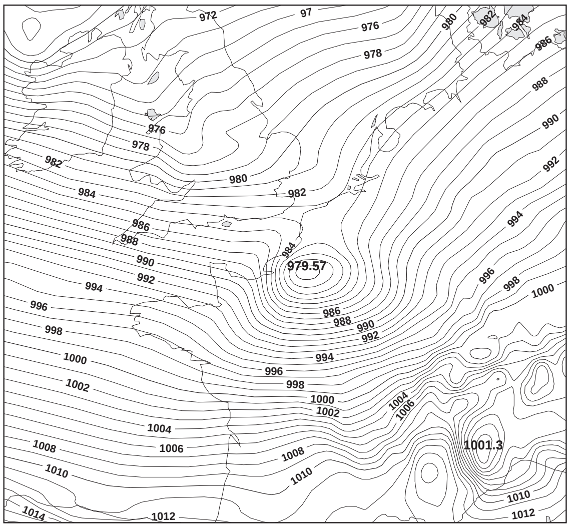
Comparison between the mean sea level pressure analyses of the ARPEGE operational (3D-Var) system at the time and a pre-operational 4D-Var test (all other things equal) for 27/12/99 12 UTC. The syndrome of a dedoubling of the structure between the guess and the observations (leading to the rejection of crucial information and hence to a weakening and ill-positioning of the analysed low) disappears when the full sequence of observations can be taken into account continuously.

FIGURE 3

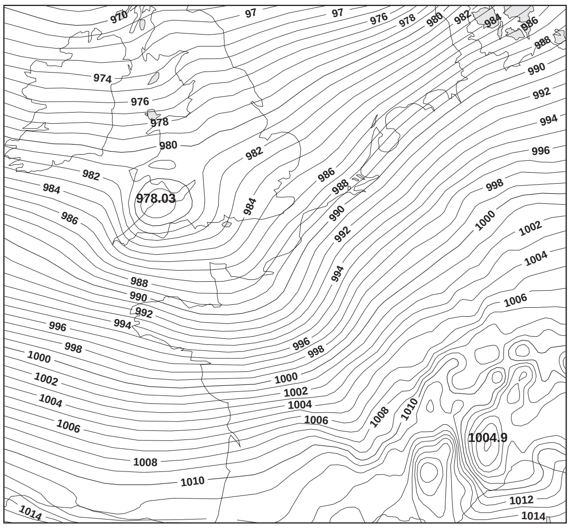
IMPACT DES MODIFICATIONS "CYCORA"

CYclogénèse COnvection RAyonnement (19/10/1999)

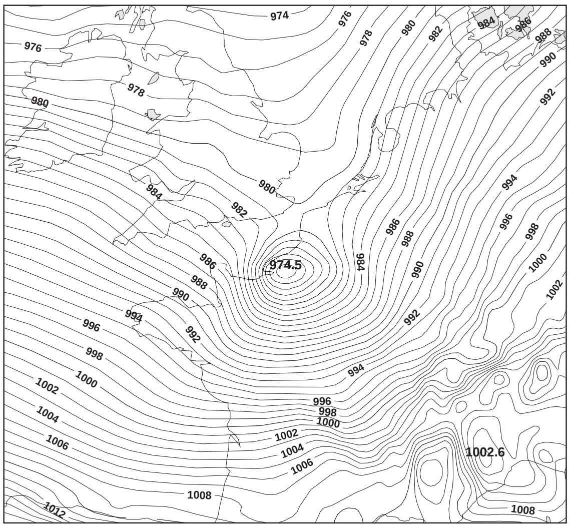
ARPEGE CYCORA 25/12 00h +30h



ARPEGE SANS CYCORA 25/12 00h +30h



Analyse vérifiante ARPEGE 26/12 à 06h



Impact of the physics of ARPEGE on its capacity to forecast the first French 99 Xmas storm. Two mean sea level pressure 30-hour forecast are compared to the verifying analysis (bottom) for 26/12/99 06 UTC. The "CYCORA" one (left) corresponds to the operational forecast. The "SANS CYCORA" one (right) to a return to the physics package in operational use before 19/10/99 (with data assimilation also rerun here from 20/12/99 to 25/12/99). It can be proved (not shown) that the spectacular impact comes from both final forecast and data assimilation but in majority from the latter and that the treatment of stable PBL fluxes is the key issue of this physics influence within the 6h forecasts cycling the assimilation (still 3D-Var at that time, but the results are very similar in 4d-Var).

6. CONCLUSIONS

6.1 *About 4D-Var*

As can be judged from our (short) experience with it, 4D-Var is worth the enormous scientific and logistic effort it requires because (i) it helps removing big cases of short range failure from the NWP landscape, (ii) it provides a welcome continuity to the assimilation procedure in case of rapidly propagating events such as "T2" and (iii) it is the necessary intermediate step for the intensive use of remote sensed data in everyday NWP routine.

The combination of the incremental method, of its multi-incremental variant and of the implicit methods for DFI-filtering can bring the intrinsic computing overhead of 4D-Var to a reasonable factor with respect to 3D-Var

6.2 *About the storms*

The conclusions below are slightly more general than what could follow from the above sections but it seems worth giving them as such:

- This is a global and complete NWP problem (especially for "T1") and the societal importance of the event should kills the too simplistic paradigm «extreme event = small scale = short lifetime = local forecasting problem = sophisticated LAM approach».
- Model resolution and the non-hydrostatic vs. hydrostatic issue (not developed here) are not at all of paramount importance, but nesting strategies are; in some sense the "T1" case was «made for ARPEGE» and its global variable resolution.
- The main problem for correctly predicting these storms is one of data assimilation with a strong diabatic flavour.
- The speed of displacement of the events in their building-up phase gives a clear advantage to continuous data assimilation methods on such a case.
- HIRLAM and ARPEGE were the two NWP systems that gave the best overall operational response to the challenge. But these are surely not the one having the best average 500 hPa RMS error scores for the 99/00 winter over Europe-Atlantic! Is this is purely a coincidence?

6.3 *About physics*

The only conclusion here is that the attention paid to PBL processes should not be systematically proportional to the magnitude of the observed or computed fluxes; stable cases may sometimes be far more important than unstable ones!

7. ACKNOWLEDGMENTS

The work reported here benefited from many collaborations, in the first place from the IFS/ARPEGE one between ECMWF and Météo-France, without which the operational goal of 4D-Var in Toulouse would still be ahead of us. Most of the work around the physics within the data assimilation procedure was supported by the ALADIN cooperation and its RC-LACE branch. The help of the CNRM/GMME/RECYF and DP/PREVI/COMPAS teams in Toulouse was crucial for running and interpreting all the necessary experiments. Several "visitors" to GMAP also took part in this effort and they should know that our thanks go equally to the permanent people of the NWP research team of CNRM and to them.

8. REFERENCES

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