FINE-MESH LIMITED AREA FORECASTING WITH THE FRENCH OPERATIONAL "PERIDOT" SYSTEM

M. Imbard, A. Craplet, Ph. Degardin, Y. Durand,
A. Joly, N. Marie and J-F. Geleyn

Direction de la Météorologie Nationale,
Paris, France

1. INTRODUCTION

This lecture will attempt to illustrate, with a few practical examples, both the successes and the remaining basic problems of operational fine-mesh limited area forecasting at the "Direction de la Météorologie Nationale" (DMN). We believe that this rather loose ensemble of numerical results may be of interest outside our institution owing to the pioneering character of the "Peridot" system and to the meso-scale features that will be briefly discussed in Section 2. Section 3 will be devoted to the forecasting potential of the system as evaluated after 2½ years of operational application and Section 4 to the main obstacles preventing further improvement. A summary of these facts will be the object of Section 5 leading to a temptative outlook towards the next operational system at DMN (Section 6).

It should first be mentioned that all results presented are the product of the efforts of many who contributed to the research and development and to the operational implementation and maintenance phases (and for some of them to both). We want to pay tribute to all of them in the knowledge they will recognize themselves when reading this text.

Another item deserves to be mentioned here: "Peridot" is an operational system. This implies that it is the result of several compromises between scientific ambition and reliability needs and, as such, it should not be judged as severely as one would do for a pure research system. Thus some of our problems might appear overstated at first glance; in such a case the reader should remember this warning before making up his mind.

2. OVERVIEW OF THE "PERIDOT" SYSTEM AS OPERATIONAL IN SEPTEMBER 1987

Peridot is the result of the adaptation of a large scale primitive equation concept to α-meso-scale forecasting, but with a very specific data assimilation procedure. It is at present the system with the finest mesh (at least to our knowledge) in full data assimilation mode (i.e. the background for the analysis provided by a model forecast).

We shall here simply state a few of its basic characteristics and the interested reader is referred to Imbard et al. (1987), Durand (1985) and Durand and Juvanon du Vachat (1986).

Analysis:

- Evaluated directly on the model grid (horizontally and vertically) except for humidity (clustering of adjacent model levels and increment technique on the way back);

- 3-D multivariate O/I technique;

- Background field directly taken from the latest forecast (12 hour cycle up to now);

- Maximum use of fine scale observed data especially HIRS and MSU radiances. Directly incorporated in the O/I procedure through the computation of synthetic "background" radiances;

- Extension of this "clear-sky" procedure to partially cloudy cases using AVHRR information to retrieve "clear" pseudo-increments for each radiance;

- Anisotropic horizontal structure functions for the humidity errors, the anisotropy being of the background field (for a better representation of frontal structures);

- Relaxation of the non-divergent constraint on the wind increments;

- Model initial state (before NLNMI, see below) produced as a progressive blend of large scale structures from the large scale analysis (produced

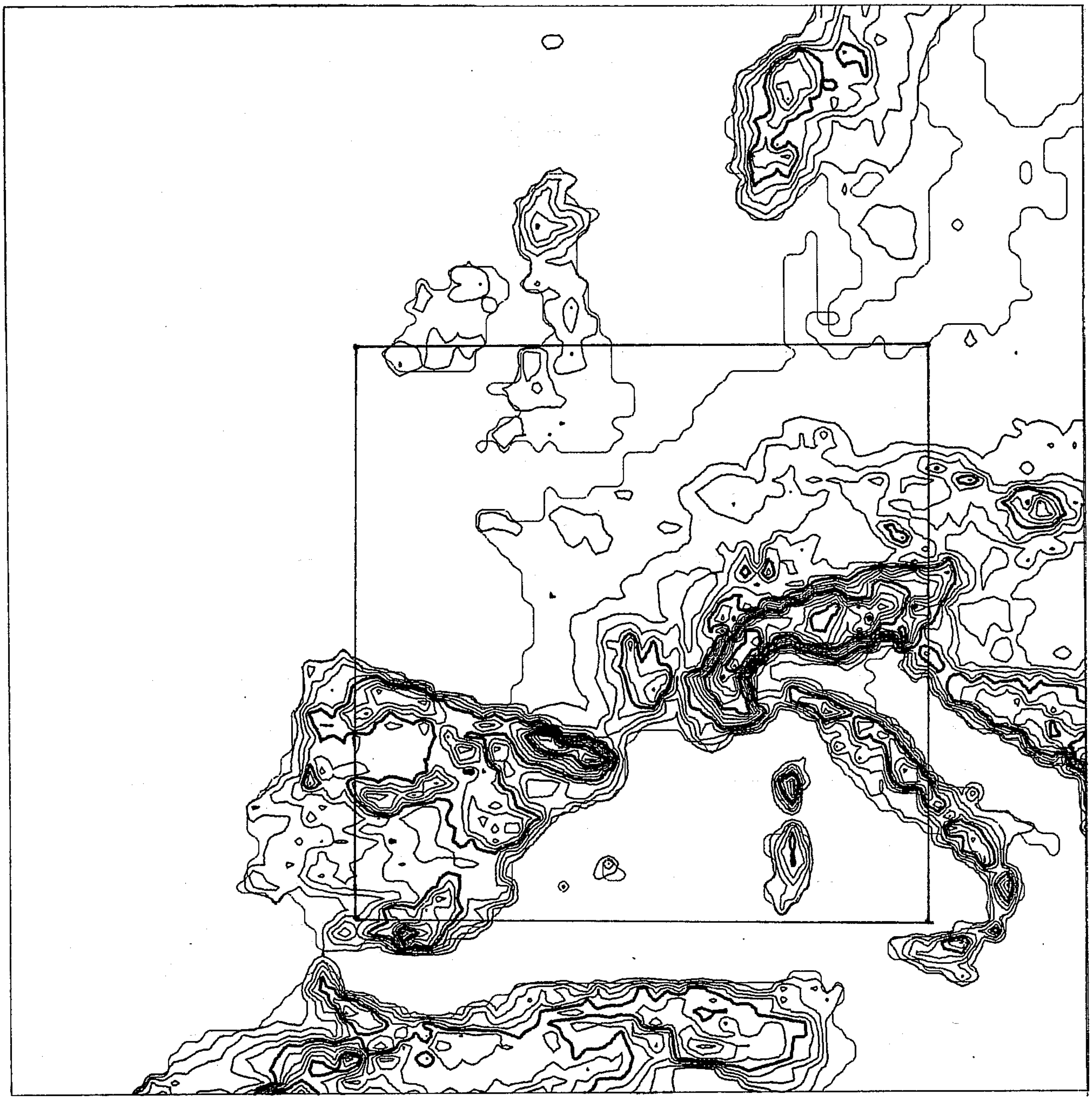
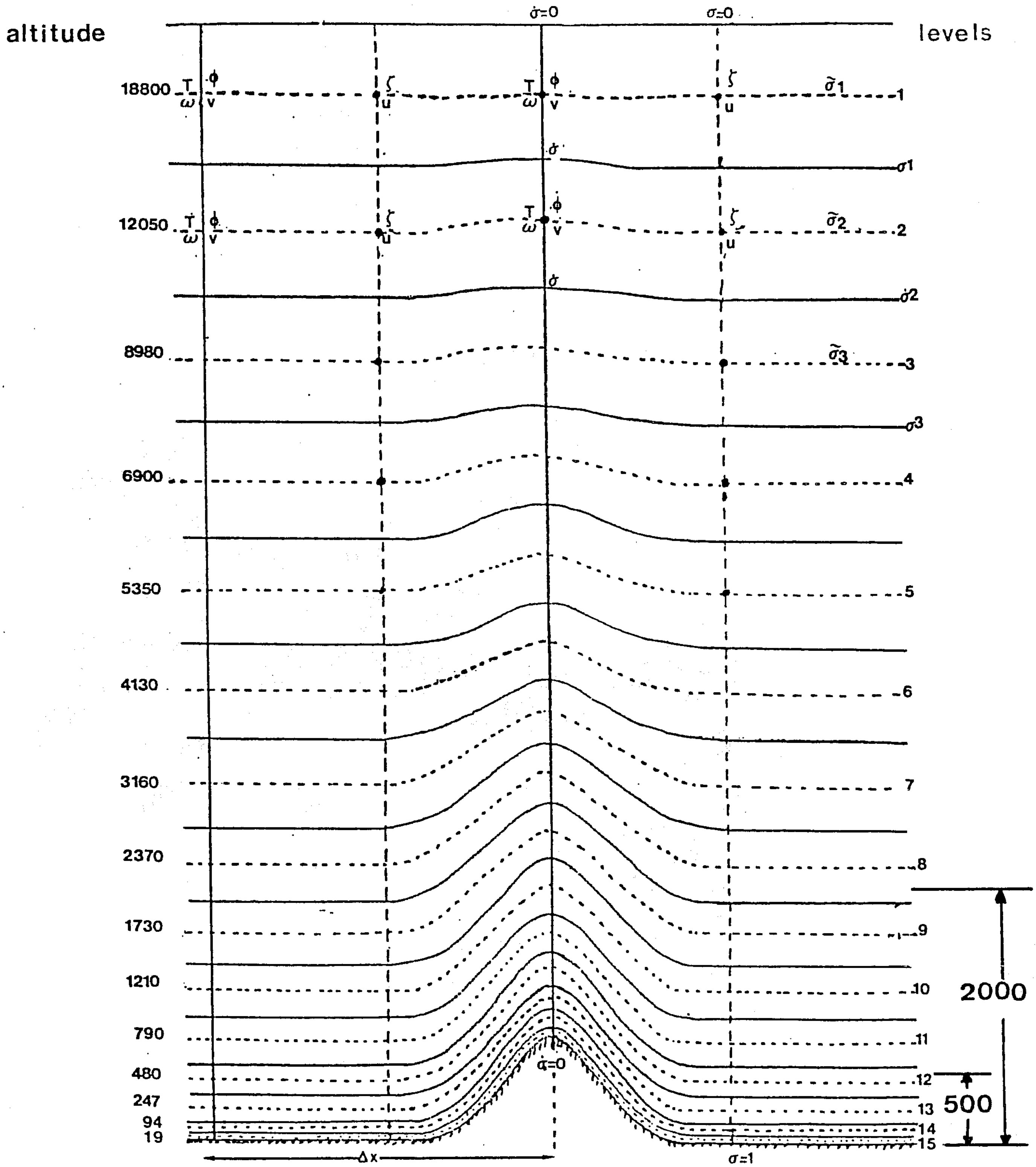


Figure 1 : Today's 95x95 and former 51x51 domains of the operational version of "Peridot". Envelope ($\sqrt{2}$) orography; contouring interval 200 m.



<u>Figure 2</u> : Vertical distribution of the σ levels of "Peridot". Numbers on the left indicate the height above the ground in a standard atmosphere.

for the hemispheric coupling model "Emeraude" - Coiffier et al (1987)) and small scale structures from the fine mesh analysis. This ensures optimal use of all observed data and a better consistency of the analysis with the subsequent evolution of lateral boundary conditions.

Non linear normal model initialization

- Follows the limited area method proposed by Brière (1982);

- Only two vertical modes are initialized;

- Surface pressure and lowest atmospheric temperature are left unchanged in the procedure "modes - physical space";

- Machenhauer's algorithm is slightly modified to ensure full consistency with the semi-implicit time stepping of the forecast model.

Dynamical part of the forecasting model

- Arakawa C grid; grid point technique;

- Davies-Kållberg technique for lateral boundary conditions; these are provided by the spectral hemispheric model "Emeraude" (T79, 15 hybrid levels);

- Polar stereographic projection; mesh size 38.1 Km at 60°N (i.e. 35 Km at the centre of the domain (see Fig. 1)); 95 x 95 square grid since 18 June 1987 (previously 51 x 51);

- 15 σ-levels concentrated in the PBL (equally spaced in $1-\sqrt{1-\sigma}$ (see Fig. 2));

- Semi-implicit leap-frog scheme with a 4 min time step;

- ∇^2 horizontal diffusion with additional divergence damping.

"Physical" part of the forecasting model

- ECMWF-type PBL parametrization (Louis et al. (1982));

- Kessler type evaporation of the rainfall produced by limitation of relative humidity at large scale saturation;

- Highly simplified radiation scheme (only clouds, black body fluxes and solar insulation are fully interactive) called at every time step of the integration;

- Deardorff's force-restore parametrization for land surface;

- Self regulating Kuo-type scheme for deep convection (Geleyn (1985)); apart from a small difference in the computation of "radiative partial cloudiness" this is the only difference between the "Peridot" physical package and the one of "Emeraude" (which uses the mass-flux type scheme of Bougeault (1985) for convection);

- Modified Richardson number's approach to the parametrization of shallow convection (Geleyn, 1987);

- Gravity wave drag parametrized following Rochas and Geleyn (1987); has only very little impact for this type of model; it is only there to ensure maximum possible consistency with the "physical package" of the coupling model.

3. FORECASTING POTENTIAL OF THE "PERIDOT" SYSTEM

This section will be a mixed bag of subjective and objective arguments. We shall start with describing 8 mini-case-studies and conclude with some more solid statistics. In general the picture is as follows: good results for wind, interesting results for temperature and rather disappointing results for moisture. There is an indication that a strong relationship exists between the adaptation to surface forcing (orographic or not) and meso-scale predictability.

3.1 Case-studies

1st case 12 January 1987; Fig. 3 ("old" 51 x 51 domain)

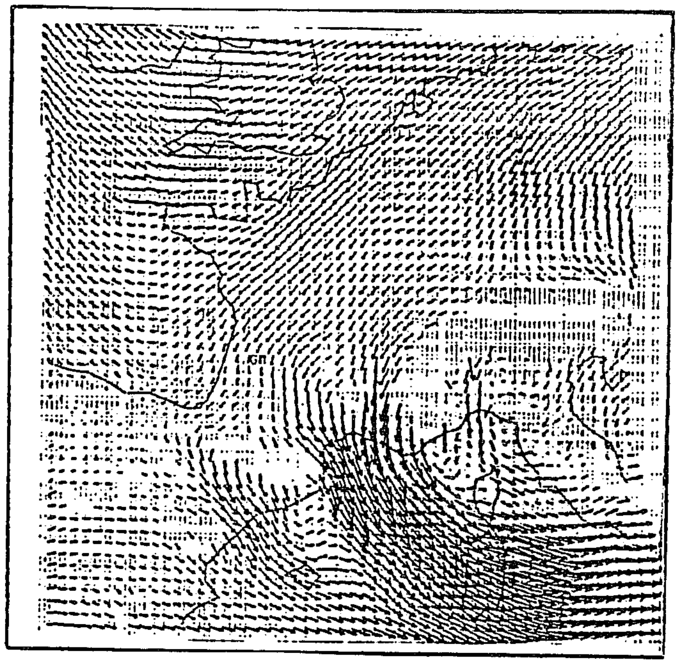
This is a classical case of rapid reversal of the synoptic flow over the French Mediterranean Coast. The analysed situation shows strong Mistral and Tramontane winds between respectively, the Alps and Massif Central, and Massif Central and Pyrennees. After twenty four hours a south westerly flow is established and one can see the good simulation of the channeling effect around the mountain areas. Of course this is the least one can expect from this type of model, but it is still reassuring to see it. Other cases of local winds around the Pyrennees (not shown here) are simulated with surprising skill, albeit not as well and as systematically as the ones mentioned here, owing to their smaller scale ("vent d'Autan" and "entrées maritimes basques").

2nd case 14 January 1986; Fig. 4 ("old" 51 x 51 domain)

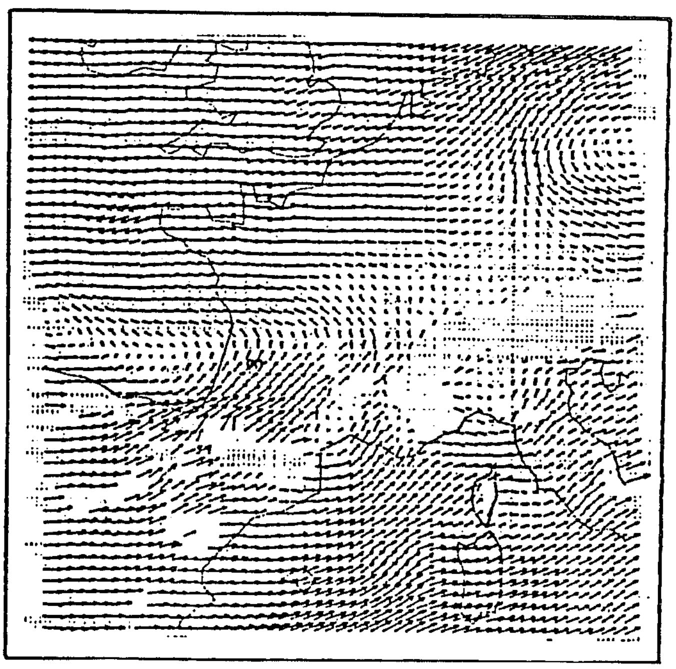
This case struck us by the astonishing similarity between the 36 hour and 12 hour rainfall forecasts issued from the 12th and 13th and verifying on the 14th at 12 UTC. The flow was westerly and the generated rainfall pattern was the direct consequence of orographic lifting. The verification was excellent, especially with regard to the "föhn effect" in the Rhone Valley ("T" and "O" in the observations). We could confirm this with satellite pictures which show a stationary band of clear air. Thus these two first cases are indicating that "Peridot", given a good synoptic scale forcing, can realistically handle the 3-D orographic forcing on the meso-α-scale.

3rd case 16 January 1985; Figs 5 and 6 ("old" 51 x 51 domain)

This is an example of surface non-orographic forcing. During the very cold January 1985 month there was a short break of the cold spell that started on



a



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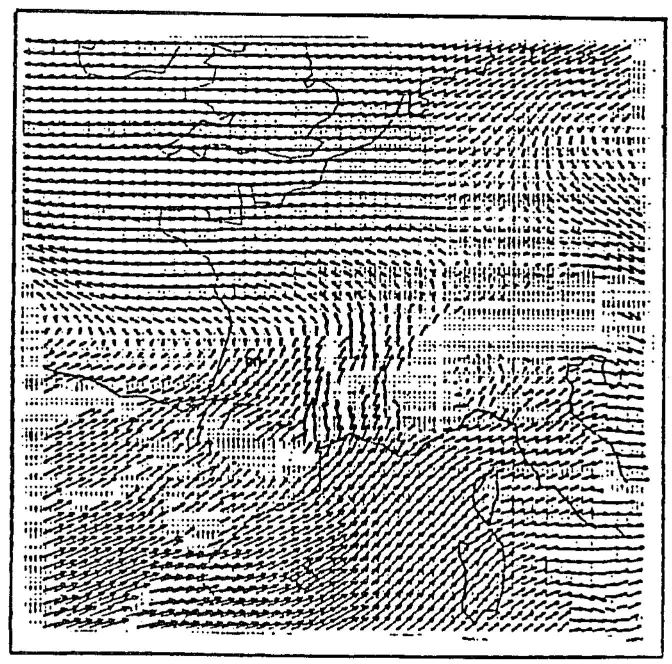


c

Figure 3 : 24 hour forecast of the adaptation to orography of a synoptic change of flow ; a) Analysis 87-01-12 00Z for 850 hPa winds ; b) Verifying analysis 87-01-13 00Z ; c) 24 hour forecast.

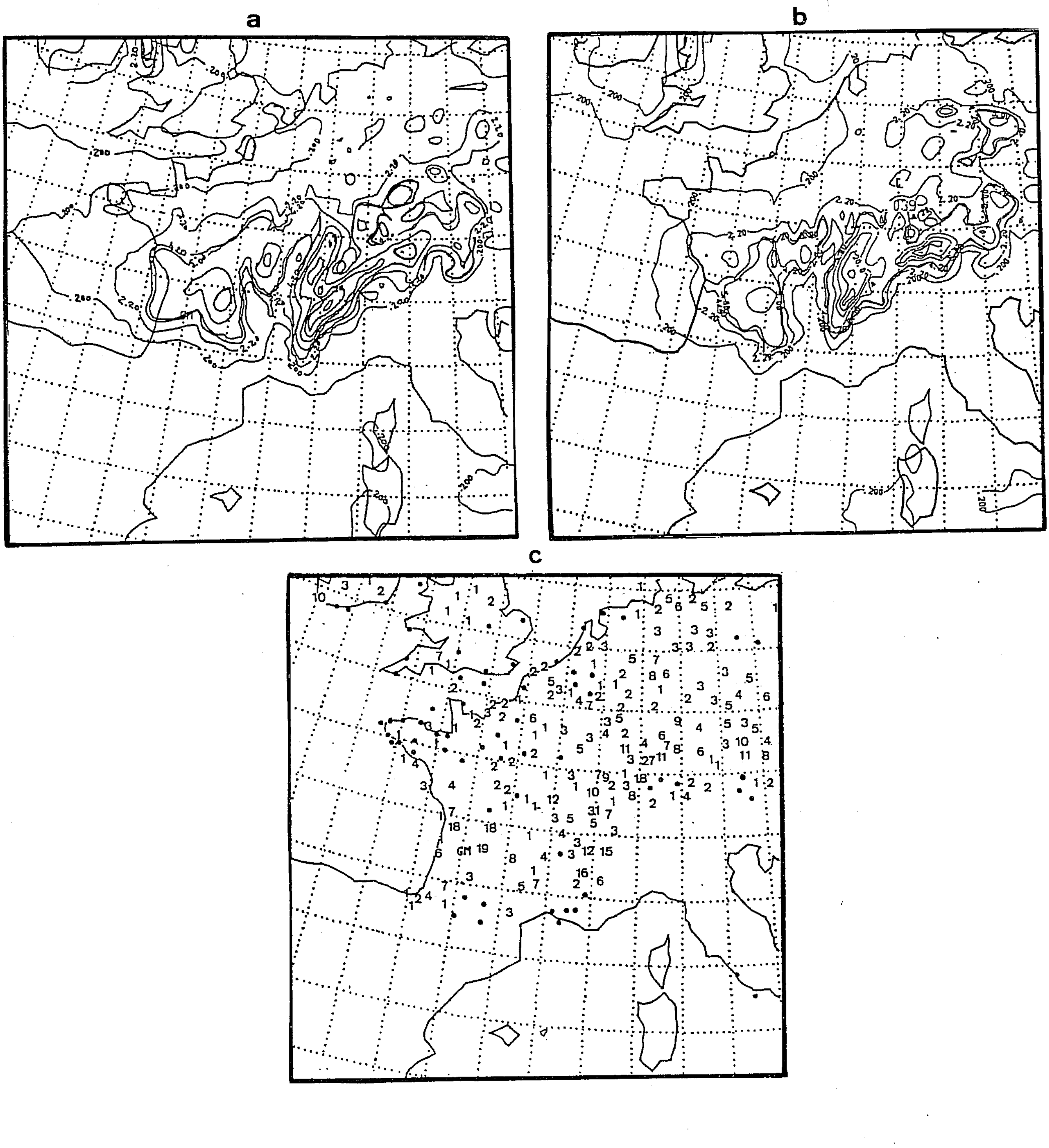
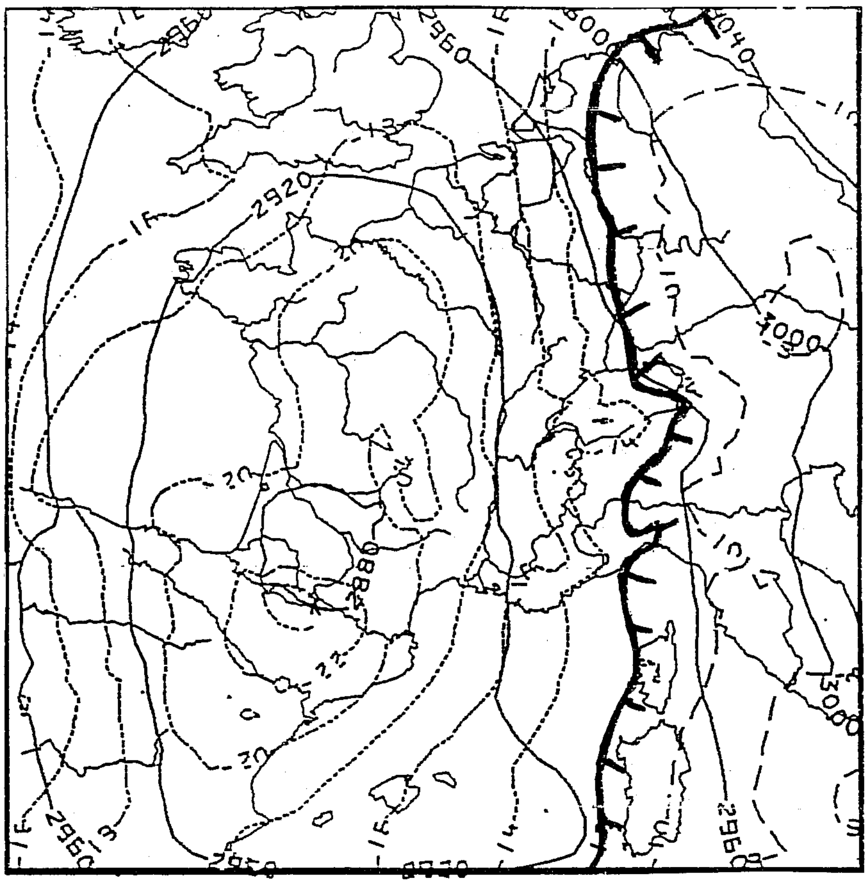


Figure 4 : Orographically forced rainfall ; a) 36 hour forecast of 6 hour accumulated precipitations verifying 86-01-14 12Z ; b) 12 hour forecast verifying at the same time ; c) 12 hour integrated station reports.

a



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b

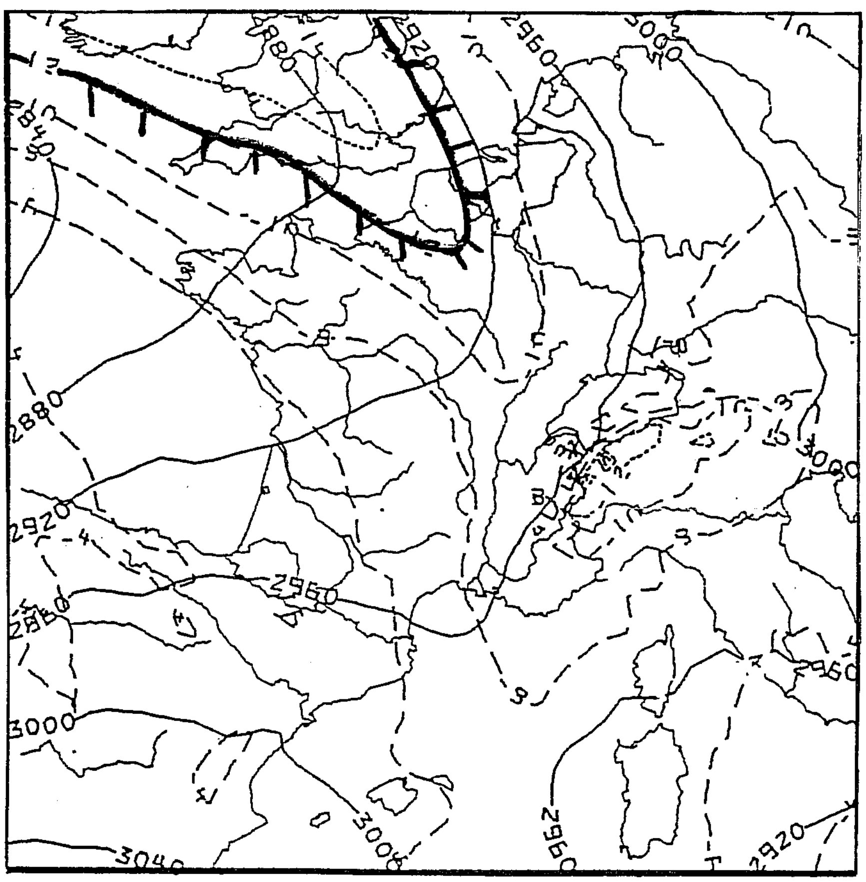

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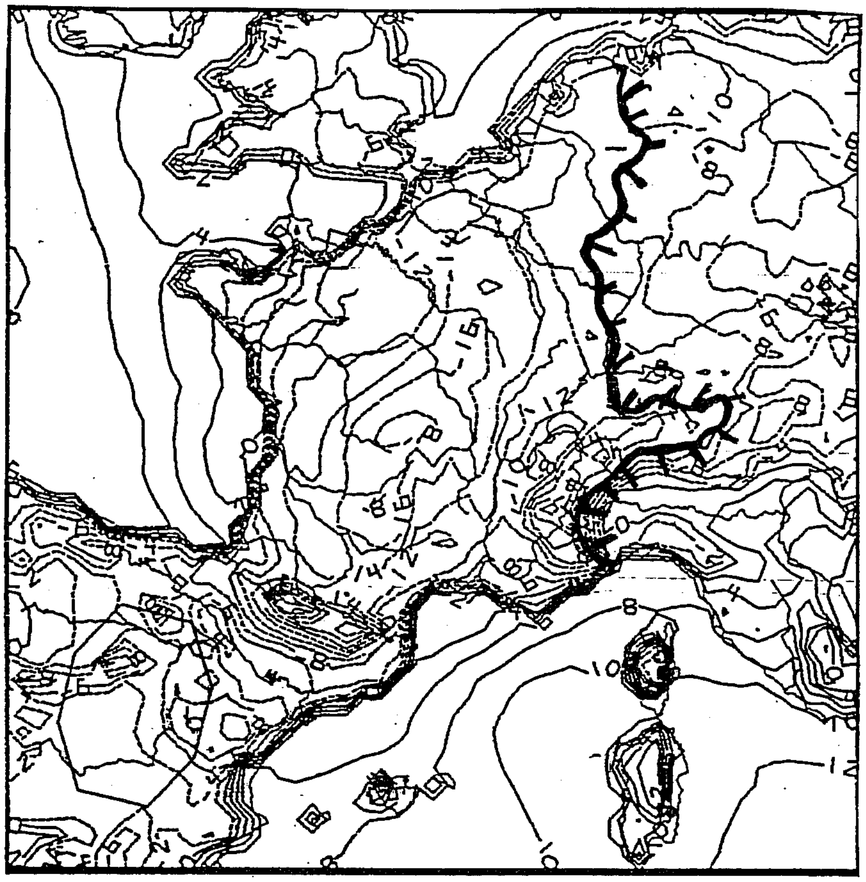
Figure 5 : Warm air advection at 850 hPa ; a) Temperature analysis 85-01-16 00Z ; b) 36 hour forecast for 85-01-17 12Z ; the -12°C contour is reinforced. Full lines correspond to the height field.

a



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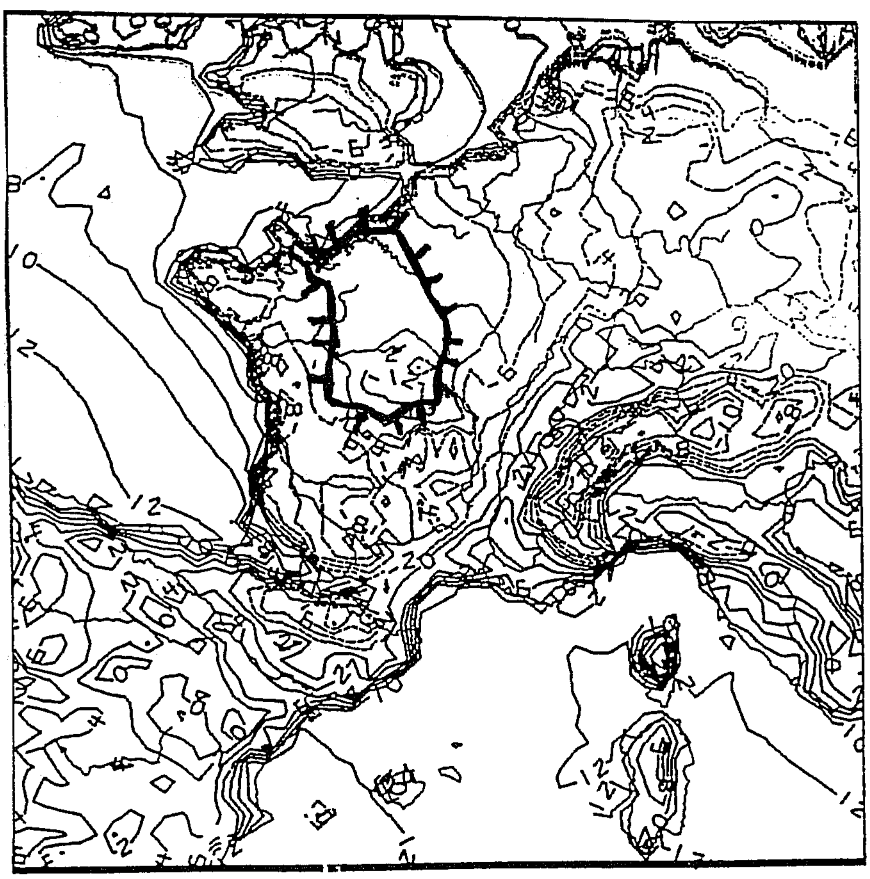
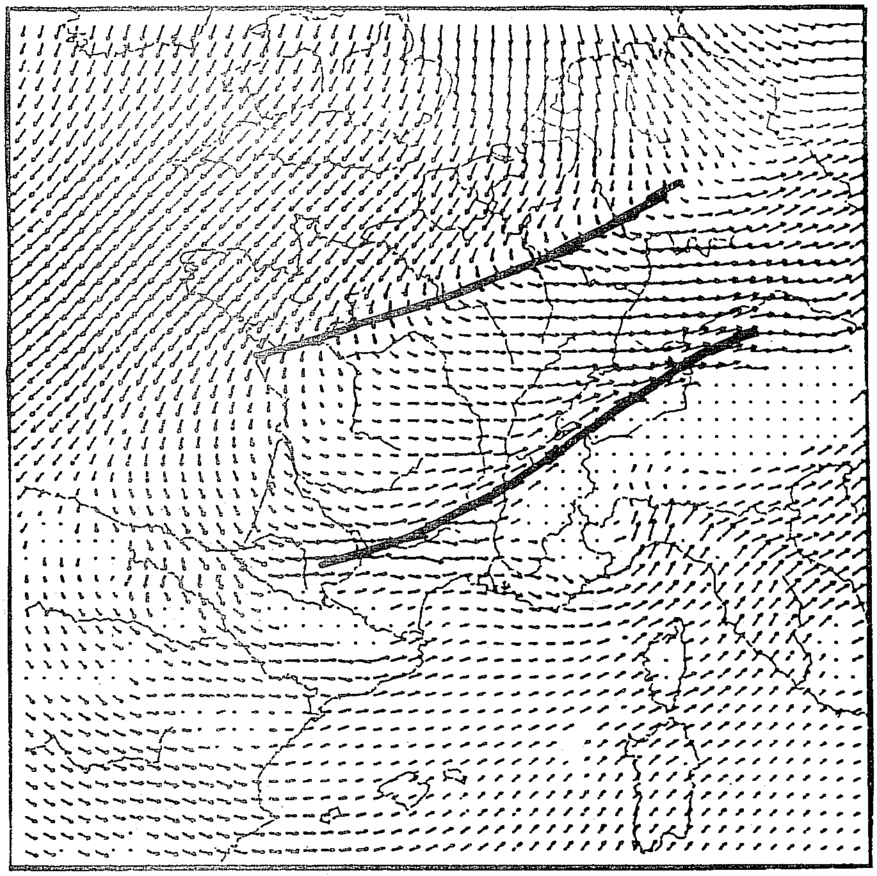


PERIDOT LE 17/ 1/85 A 12TU ECH. 36 EX.85016 TEMPE. 2M / D.C

Figure 6 : Same as Figure 5 but for the 2m temperature ; the -10°C contour is reinforced ;note that the diurnal cycle partly exaggerates the warming between a) and b).

30h



6h

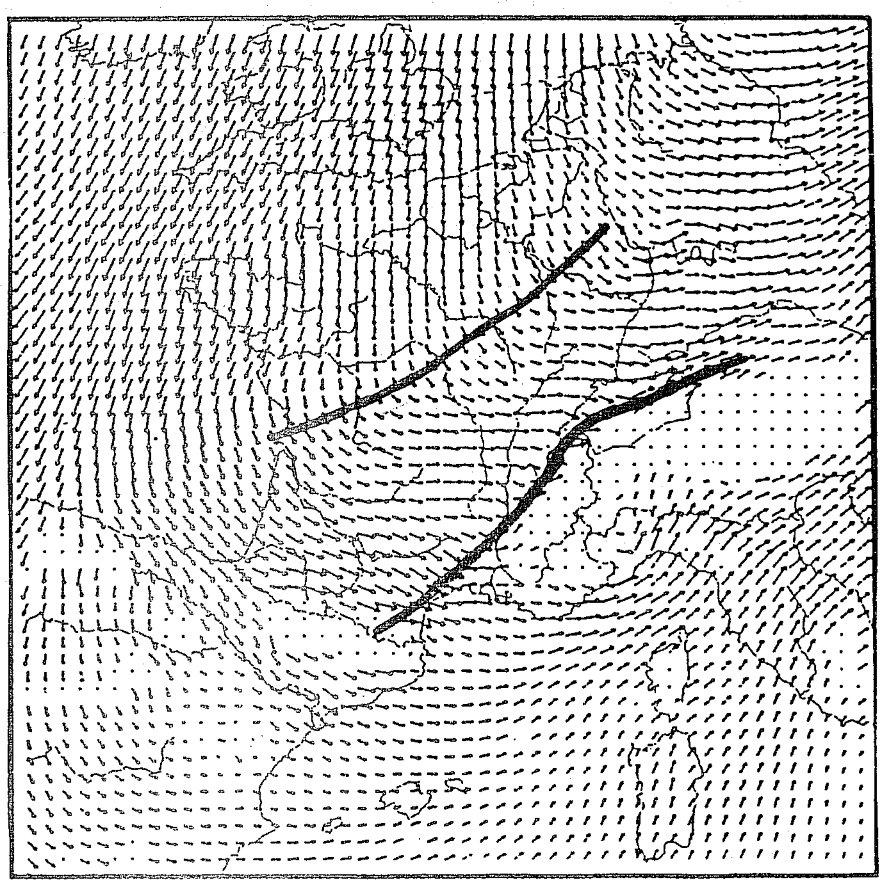


Figure 7 : Verification of a 30 hour 850 hPa wind forecast by a 6 hour one, both verifying 84-09-05 06Z ; the frontal structures have been hand-indicated.

the 16th. The 850 mb temperature maps (Fig. 5) at 0 and 36 hours range for the 16/1/85 00 UTC forecast, clearly show the easterly invasion of warm air. But the 2 metre temperature maps (Fig. 6) for the same ranges clearly demonstrate the potential of the system for simulating the longer lasting surface "cold air skin" and its location would have been a rather correct forecasting guidance had the system been operational (it was still in preoperational tests then).

4th case 5 September 1984; Fig. 7 ("old" 51 x 51 domain)

Yet another case from preoperational testing, but we leave the surface forcing problem for that of meso-scale dynamical features. This case will also be treated in Section 4 for other reasons, but our aim is to show here that (using a 6 hour forecast as verification) the system can predict a double frontal structure - indicated here by two (hand reinforced) vorticity maxima - 30 hours in advance, even if a bit late in the forecast. Such good cases have however been rather rare with operational 51 x 51 forecasts (probably due to a too small domain for their development) and we still lack long enough 95 x 95 practice to assess the actual frequency of such successful pure meso-scale forecasting. Nevertheless, the "Peridot" model surely did not produce this structure only by chance and this example clearly indicates that such features are intrinsically predictable. See Section 4 for more details on this case.

5th case 8 November 1985; Fig. 8 (51 x 51 "old" domain)

We have here another example of multi-frontal structures where the sensitivity of some meso-scale forecasts to "physical" forcing even at short range is evident. One forecast does not reproduce the observed treble frontal structure while the other does. The only difference between the two is the parametrization of convection. The second forecast includes shallow convection and a provision for non-precipitating thin convective clouds. The fact that these more realistic features of the parametrization lead, in this case, to a better forecast is encouraging, but the most important point is the sensitivity of the forecast to such details of the physical forcing. It means that there is hope to use this sensitivity in order to systematically improve the forecast once the mechanism of physical/dynamical interactions at the meso-α-scale becomes more familiar to us.

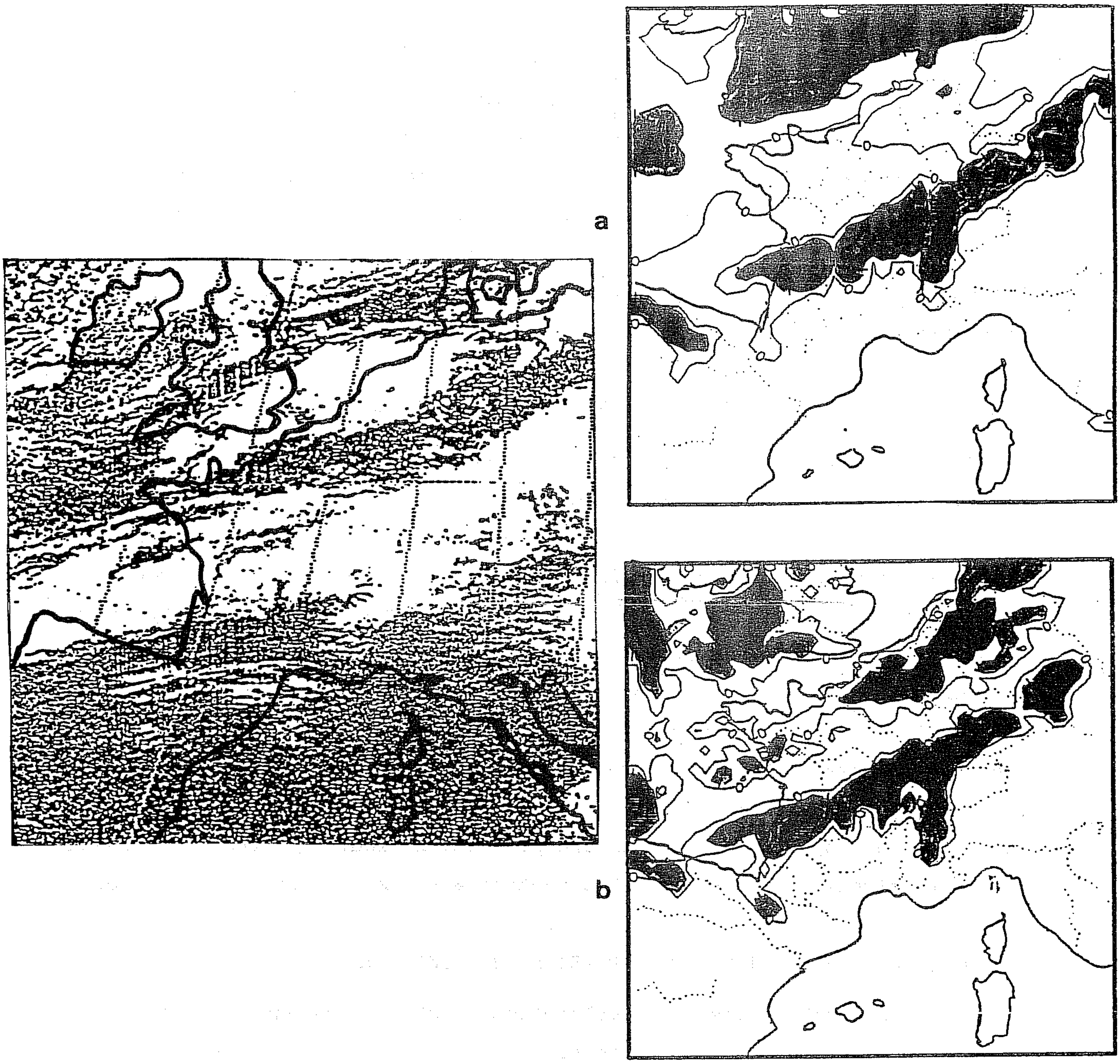


Figure 8 : Satellite picture verification of two 18 hour rainfall forecasts (6 hour accumulated) verifying 85-11-09 18Z ; a) classical Kuo-type scheme for deep convection ; b) Kuo-type scheme with liquid water present in the cloud model and with shallow convection also parametrized . In this case the forecast seems ahead of the truth.

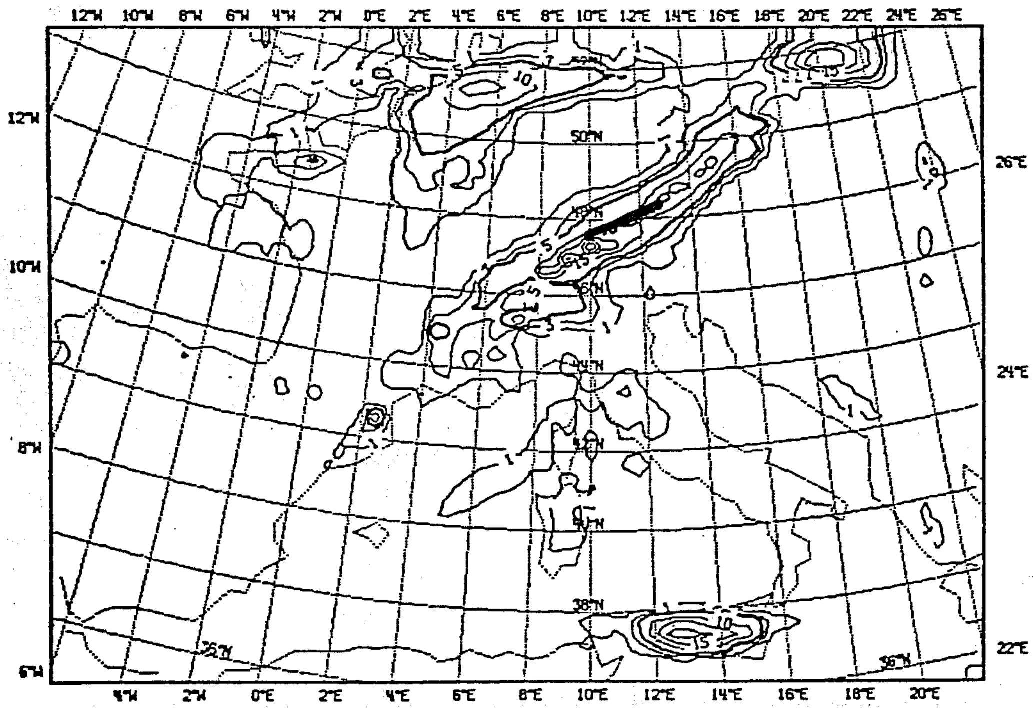


Figure 9 : Simulated (with ECMWF analysed lateral boundary conditions) 12 hour accumulated precipitations for a 72 hour forecast verifying 84-07-13 00Z ; the area of the main hail damage near Munich has been hand-indicated.

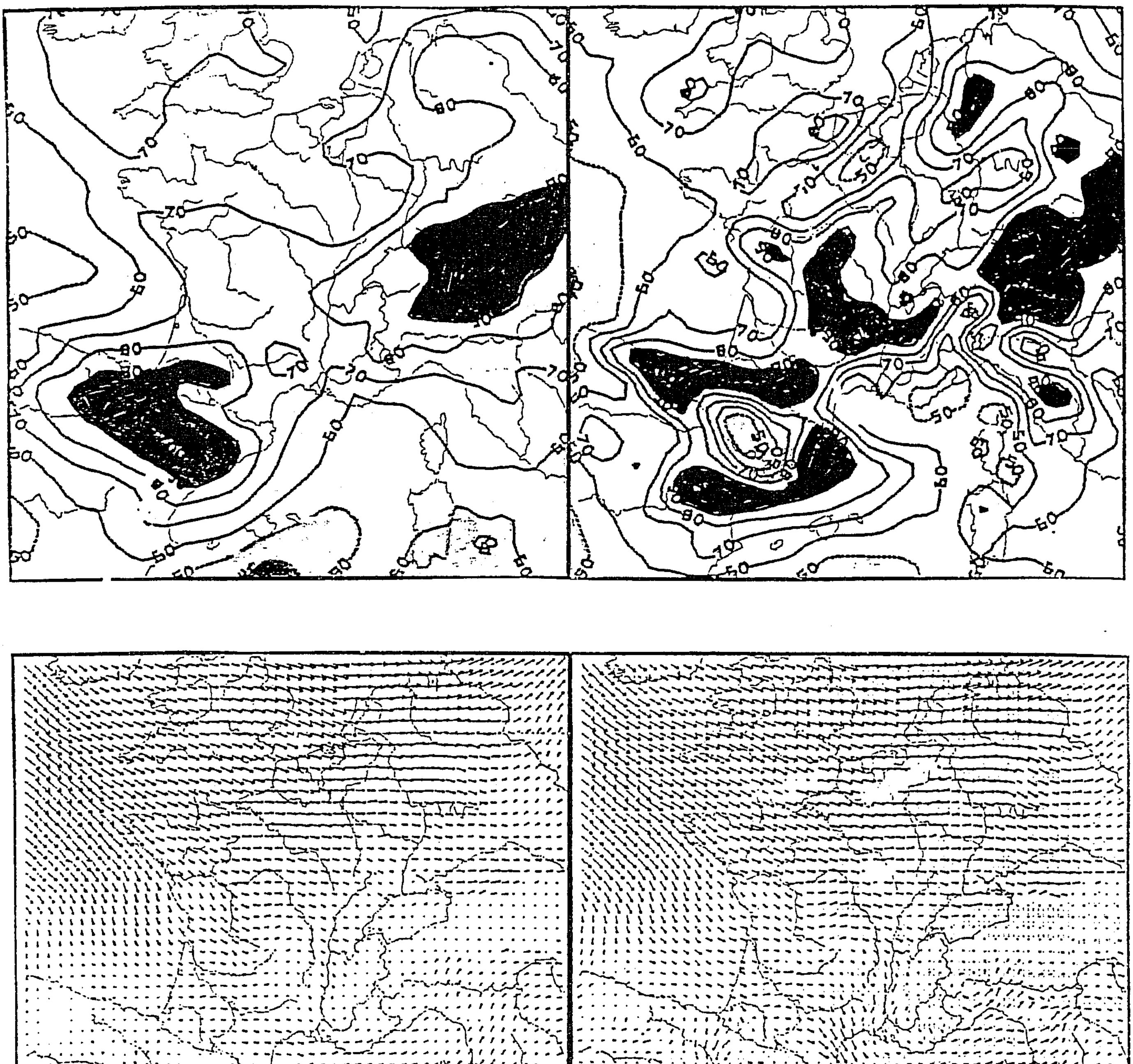


Figure 10 : 850 hPa analysis of relative humidity and wind for 86-05-28 00Z ; left = with background taken from an "Emeraude" analysis ; right = with background taken from a 12 hour "Peridot" forecast.

6th case 13 July 1984; Fig. 9 (Special Alpex research 55 x 79 points domain)
This is an astonishing 72 hour simulation of strong precipitation of convective origin which is also known as the famous Munich hail storm (Heimann and Kurz (1985)). The 48 hour simulation was as successful with the strong storms that struck East and North East France on the 12th. We speak here of a simulation rather than a forecast since the lateral boundary conditions were provided by a sequence of ECMWF analyses. It should be stressed that both a change in the convective parametrization (Geleyn et al., 1986) or in orography (from envelope to mean) can significantly diminish the quality of the forecast. Thus it appears that the predictability of this case is linked to the exceptional instability of the situation and to the "guiding" effect of the northern edge of the Alps on the storm trajectory both in reality and in the model. This is not likely to be the case in general, but the example clearly shows that there is meso-scale predictability beyond a range where the influence of lateral boundary conditions should in principle have made it disappear.

7th case 28 May 1986; Fig. 10 (51 x 51 "old" domain)

We now venture into the area of analysis potential and start with an example of the benefit of fine mesh cycling in data assimilation (i.e. background field for the analysis taken from the latest fine-mesh forecast). At 850 hPa the comparison of two analyses (for relative humidity and wind), differing only through their respective background fields (large scale analysis in one case, fine mesh forecast in the other), clearly shows the advantage of realistic small scale features available in addition to observed data. The frontal structure stretching from the Netherlands to the French Atlantic Coast is clearly visible by its contrast between wet ascent and dry subsidence behind. The drying föhn effect over the Ebra valley is also probably quite a realistic feature given the North Westerly flow over the Pyrennees. Finally the wind adaptation to orography around the Mediterranean is obviously better reproduced in the second experiment.

8th case 30 September 1987; Fig. 11 (95 x 95 operational domain)

The previous argument in favour of fine mesh data assimilation is reinforced by this example of a sharp Atlantic frontal structure in the analysis; this realistic looking feature indicates a good blend of fine scale forecasted structures, available observations (including high resolution HIRS satellite

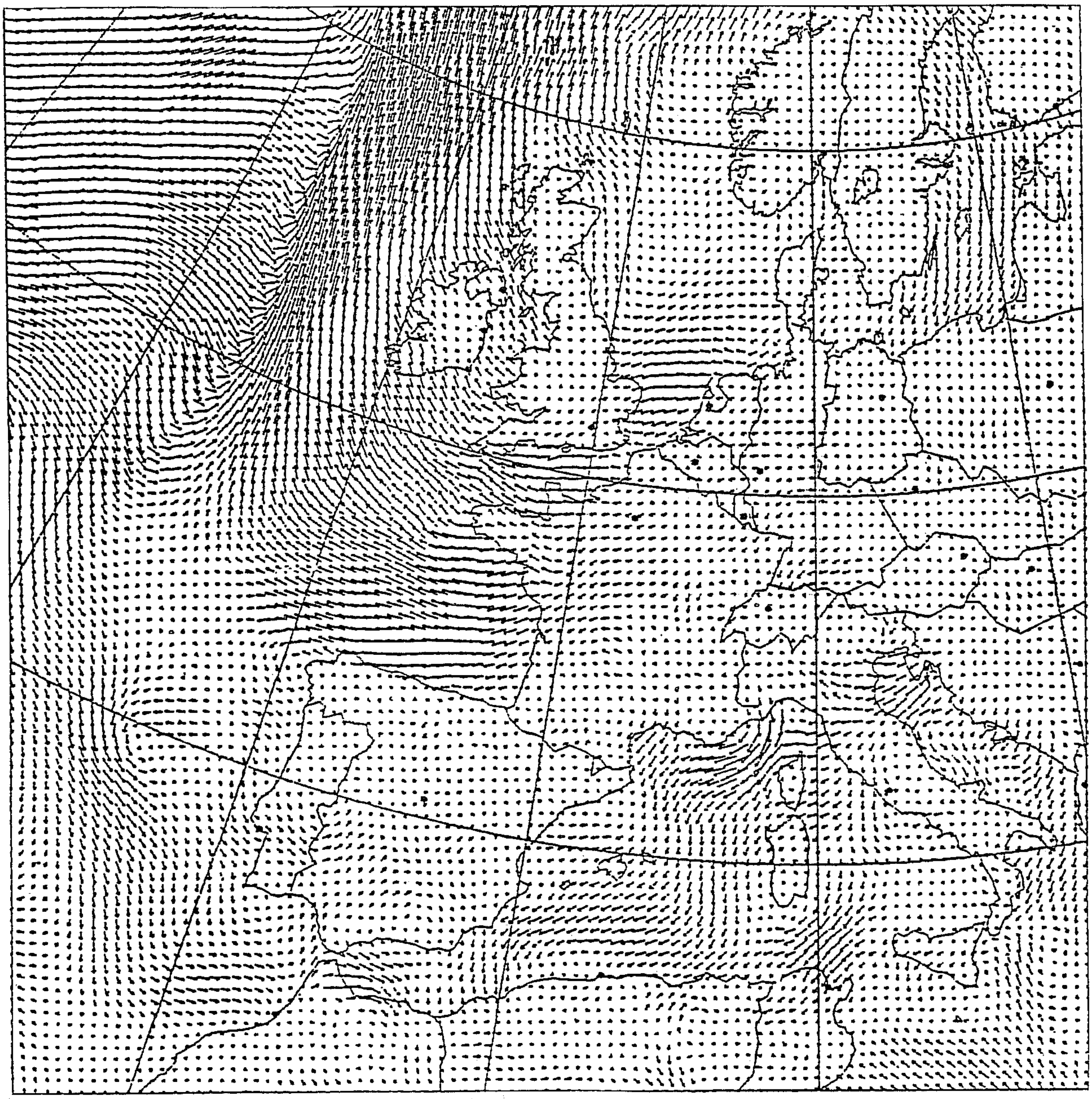


Figure 11 : 10 m wind analysis for 87-09-30 00Z.

data) and large scale analysed structures. Of course one seldom get such a spectacular combination of these three ingredients but the potential of the technique is here clearly demonstrated. Also notice the orographically forced small scale structures of the wind field in the Mediterranean and the Adriatic.

3.2 Statistics

Forecasting statistics (Fig. 12)

Using the verification package of "Peridot" (against SYNOP data) it was possible to make a comparison with similar forecasts of the large scale coupling NWP system "Emeraude" (Juvanon du Vachat et al., 1987). To make this comparison as fair as possible the Emeraude forecasts were first interpolated to the Peridot grid. Then the relevant parameters were obtained in a consistent way by running one time step of "Peridot". Finally both forecasts were debiased from their 0 hour errors in order not to favour the more realistic orography of Peridot. The most spectacular improvements linked with fine mesh forecasting are seen for the surface wind and to a lesser extent for the screen level temperature. On the other hand, the humidity at screen level does not improve when going from large scale to fine mesh but the positive indication of the cloudiness score may be reflecting an improved humidity forecast in the free atmosphere through better dynamical structures.

Analysis/Forecasting statistics (Fig. 13)

Using the same techniques as described in the previous paragraph Juvanon du Vachat et al. (1987) addressed the problem of measurement representativity in the "SYNOP verifications". They compared one flat land station near Paris (Orly) with another one (Villacoublay) less than 35 Km away, and compared this estimate of natural variability and instrumental error with the forecast error at one of the two locations (Orly). This comparison clearly shows that both wind and temperature fields are smoothly relaxed to by the analysis procedure (better in fact than surface pressure). The humidity analysis is however at least as as deficient the humidity forecast (perhaps not surprisingly so). Furthermore the wind forecast error remains close to the level of natural variability for 36 hours, thus indicating excellent forecasting skill for this parameter over flat land. On the less encouraging side, one notices the very rapid saturation of the temperature error (~ 12 hour), a behaviour totally different from the more classical linear growth of the surface pressure error. We have as yet no indication why this worrying discrepancy occurs.

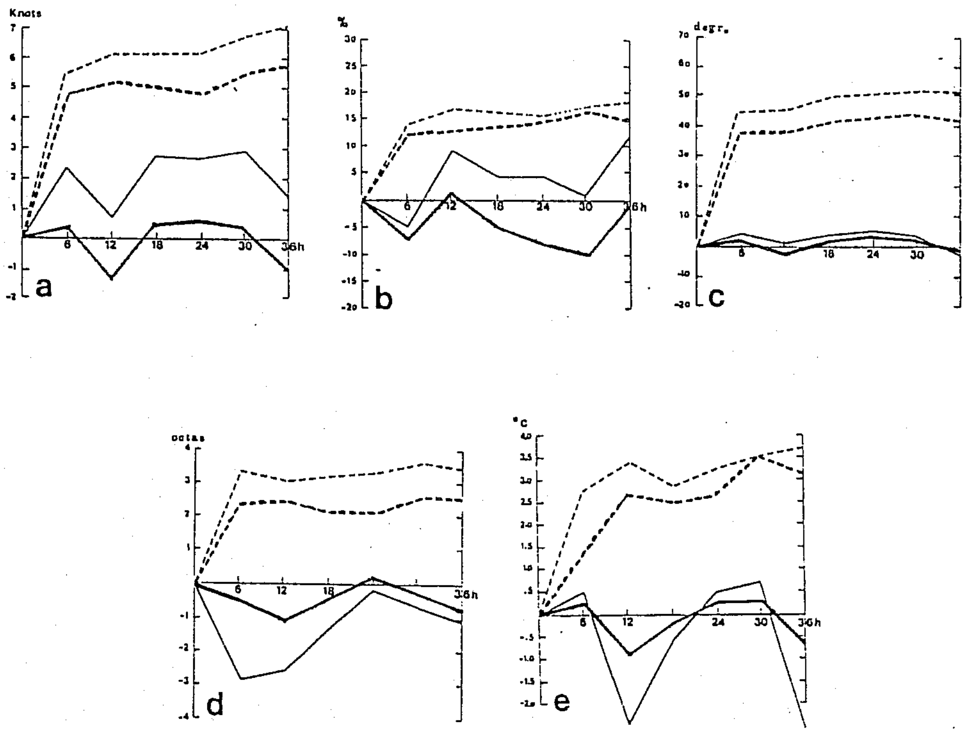


Figure 12 : Comparison of operational "Emeraude" and "Peridot" forecasts both verified against the same surface observations within France in November 1986 ; a) 10m wind speed ; b) 2m relative humidity ; c) 10m wind direction ; d) total cloudiness ; e) 2m temperature . Thin lines = "Emeraude" ; thick lines = "Peridot" . Full lines = biases ; dashed lines = standard deviations . Forecasting range 0 to 36 hour.

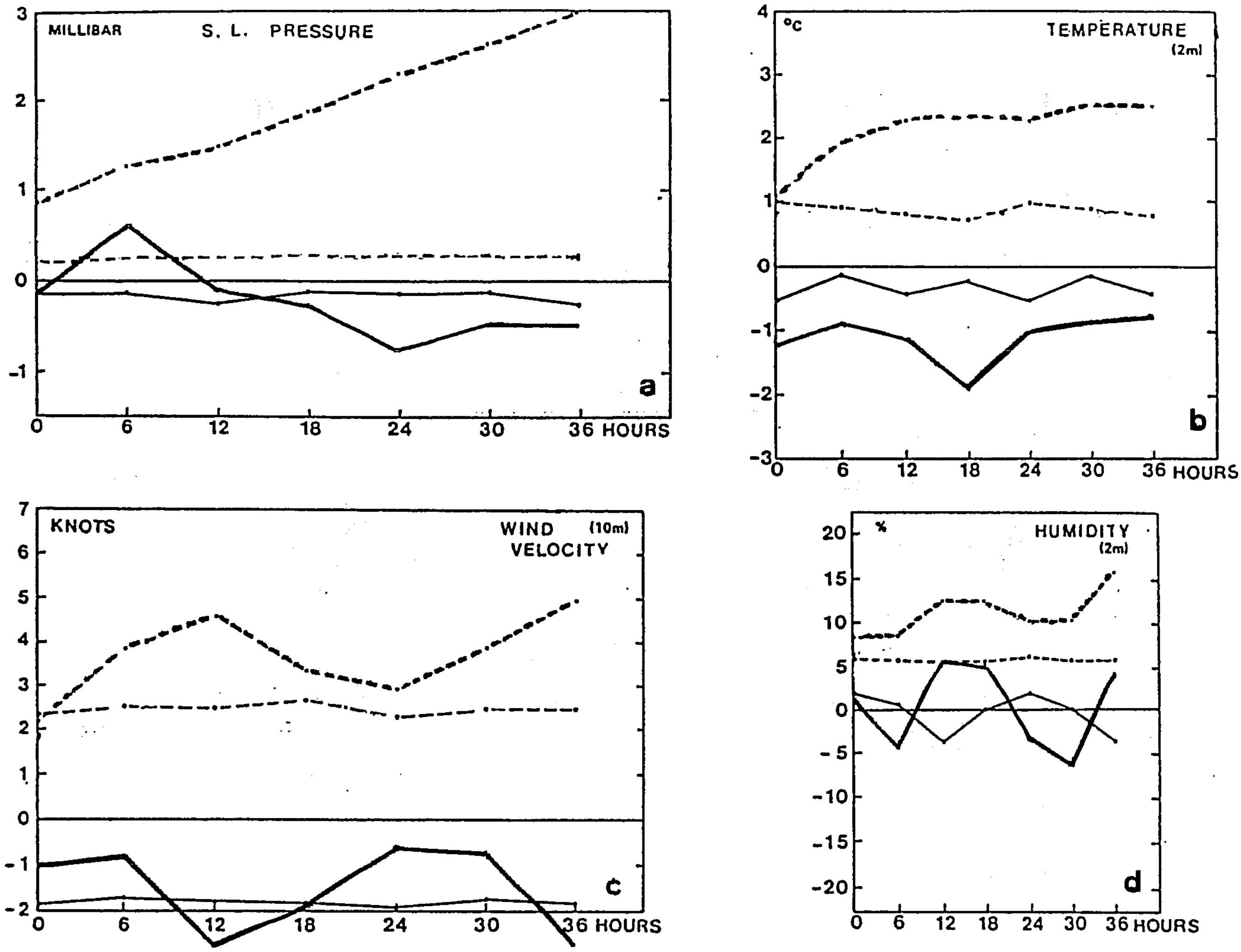


Figure 13 : "Peridot" verification at Orly for the year 1986 (thick lines) compared with the "Orly vs. Villacoublay" measure of natural variability (thin lines) . a) surface pressure ; b) 2m temperature ; c) 10m wind speed ; d) 2m relative humidity . Full lines = biases ; dashed lines = standard deviations . Forecasting range 0 to 36 hour.

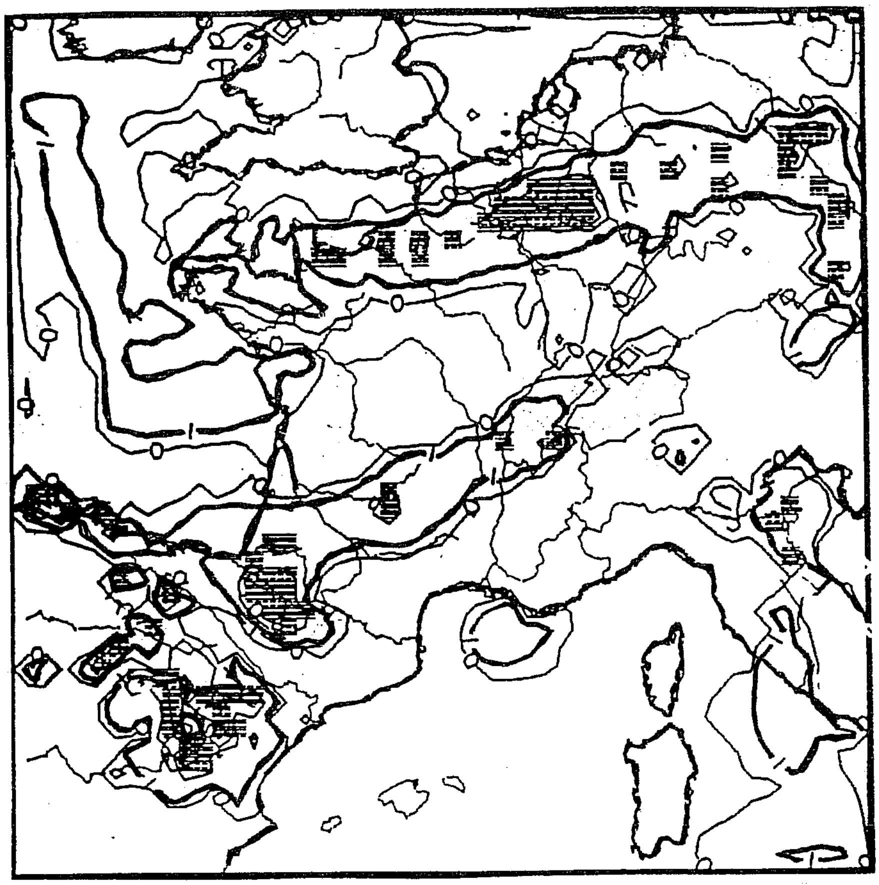


Figure 14 : 30 hour forecast of 6 hour accumulated precipitations verifying 84-09-05 06Z (see Figure 7 for the associated wind field) ; initial state and lateral boundary conditions provided by a T42 preoperational "Emeraude" forecast.

4. PRACTICAL EXAMPLES OF KNOWN PROBLEMS

Lateral boundary conditions

We come back to the 5 September 1984 case. The double frontal structure was not only apparent in the wind field but also in the 6 hour rainfall field (Fig. 14). Inspection of the time series of wind forecast maps (Fig. 15) clearly showed that it was developing from a single frontal structure just present inside the North Western corner of the area on the 4th at 00 UTC (analysis time). Since we had no archiving at that pre-operational time we wanted to try this case again with ECMWF analyses as boundary conditions, in order to study the reasons for the frontal splitting. Unfortunately, when we did so, the double frontal structure started to collapse into a single one in the first part of the forecast (Fig. 16). Inspection of the rainfall map (Fig. 17) immediately showed the reasons for this different behaviour: a lack of consistency between the thermodynamical structure of the ECMWF-imposed lateral boundary conditions and the internal diabatic forcing of "Peridot" creates an area of unrealistically high convective precipitation in the South-Eastern corner of the domain. This in turn affects the dynamical structure of the whole domain and the meso-scale quality of the double frontal forecast is lost. The lesson from this example is two-fold: lateral boundary conditions can have a strong detrimental effect on a limited area forecast and maximum consistency between the physical forcings "inside" and "outside" is surely helping to alleviate these kinds of problems.

Parametrization of deep convection

Using NCAR-provided analysis and boundary conditions for the so called OSCAR case (22 April 1981), we did a range of forecast experiments over the Eastern United States. We shall here concentrate on one aspect of the results: the high sensitivity of the forecasted rainfall amounts both to the choice of the convective parametrization (Bougeault (1985) - the "Emeraude" operational one - or Geleyn (1985) - the "Peridot" operational one) and to the grid size (160, 80 or 40 Km). Several interesting features can be found in Fig. 18: as resolution increases more fine scale intense features become apparent, like for instance a double rain band structure for Δx=40 Km that was not observed in reality; this logical increase of detailed structures is unfortunately coupled with an overall increase of the averaged level of precipitation - i.e. the parametrizations are too scale-dependent in their results; finally and more worrying: as resolution increases so does the difference of the

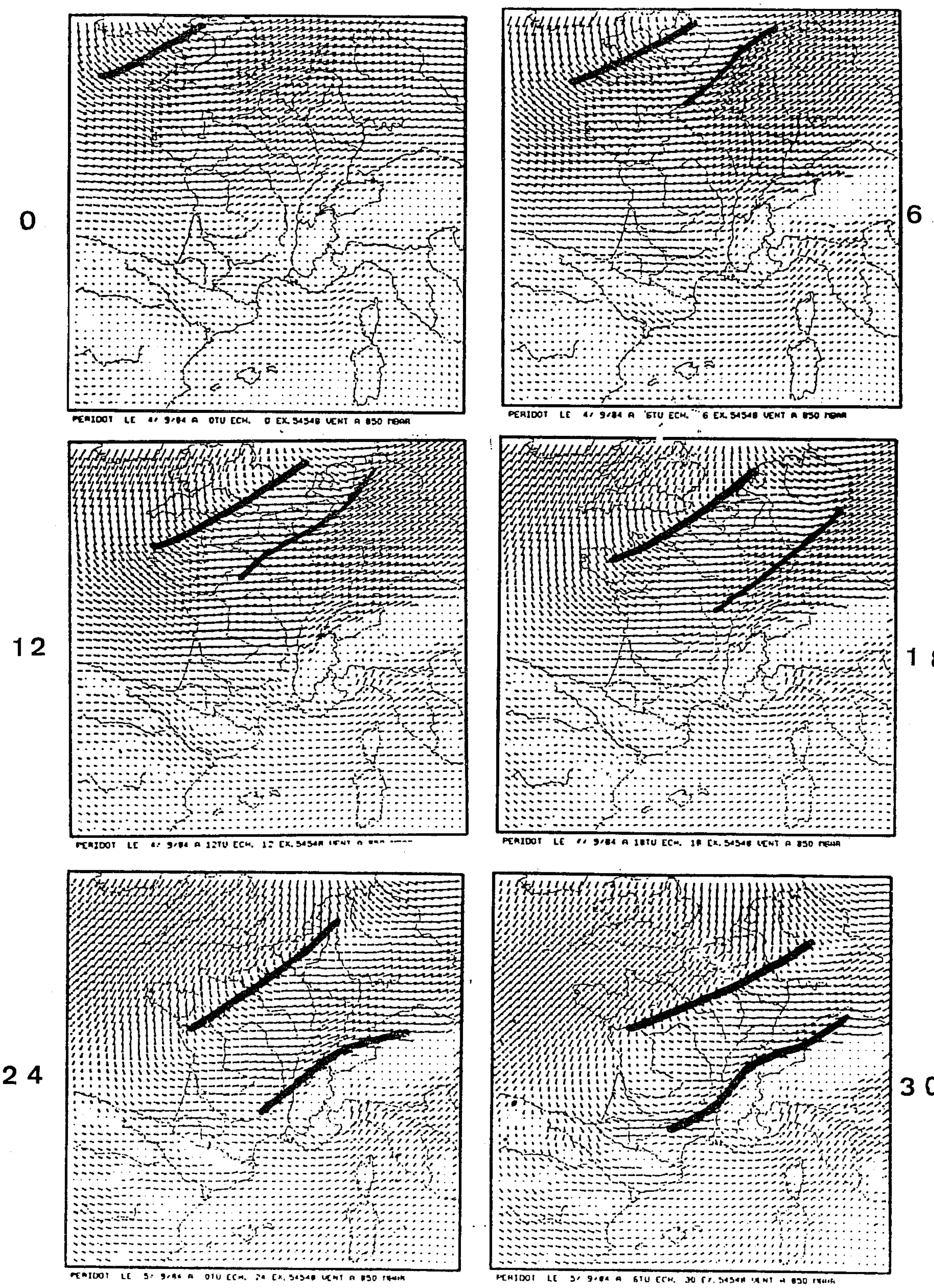


Figure 15 : 0 to 30 hour (6 by 6) 850 hPa wind fields for the forecast of Figure 14 ; the frontal structures have been hand-indicated.

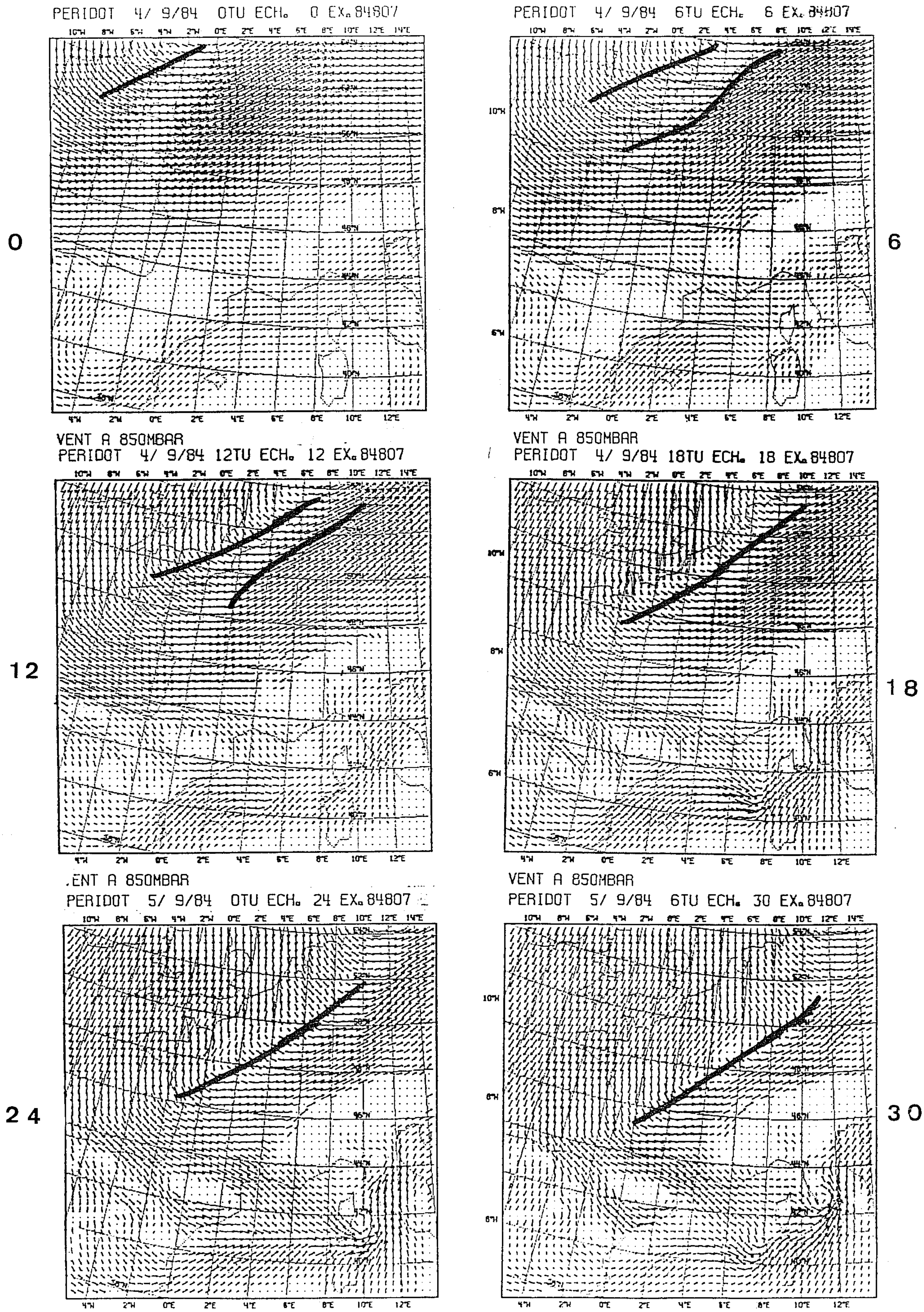
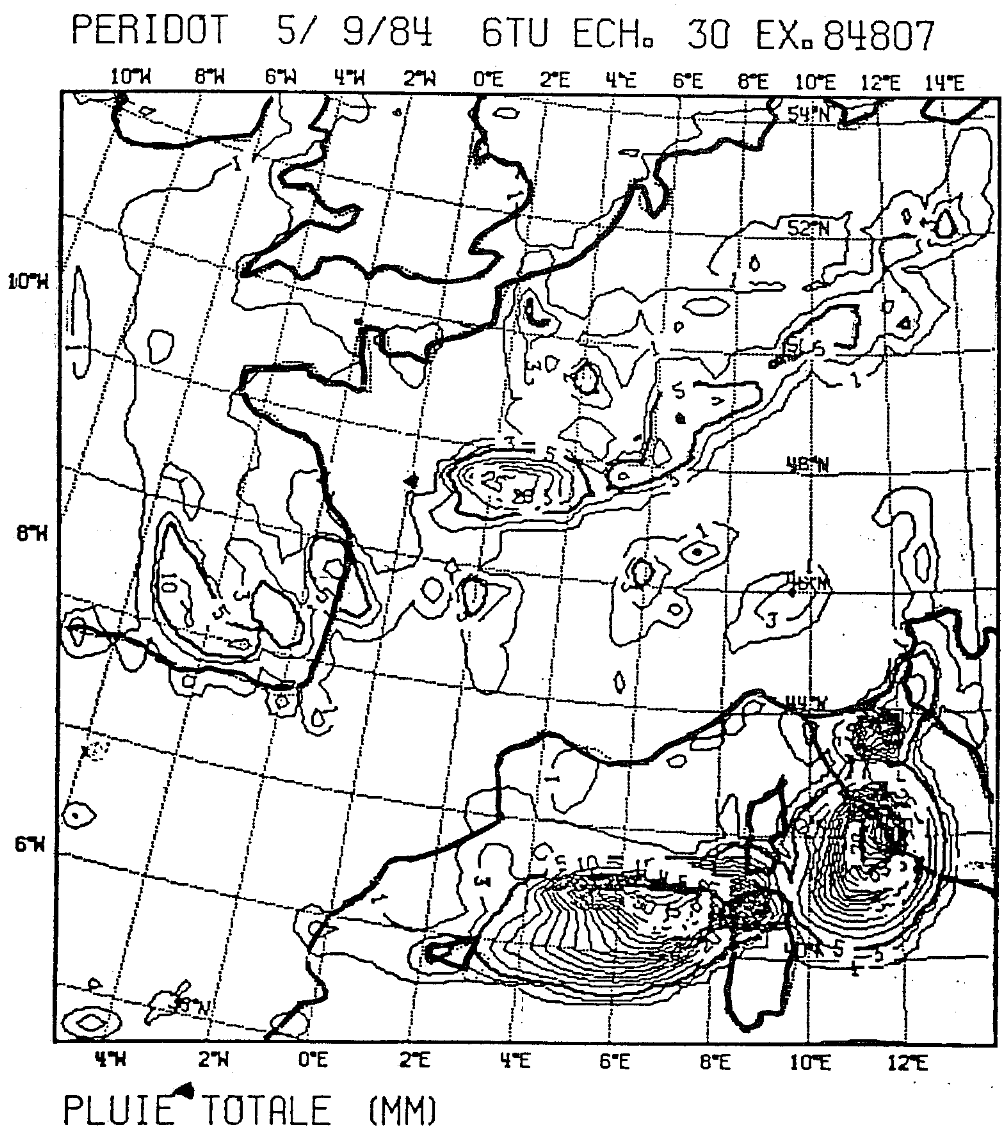


Figure 16 : Same as Figure 15 but for a forecast with ECMWF analysed initial and boundary conditions.



<u>Figure 17</u> : Same as Figure 14 but for the forecast of Figure 16 (different plotting package than that from Figure 14).

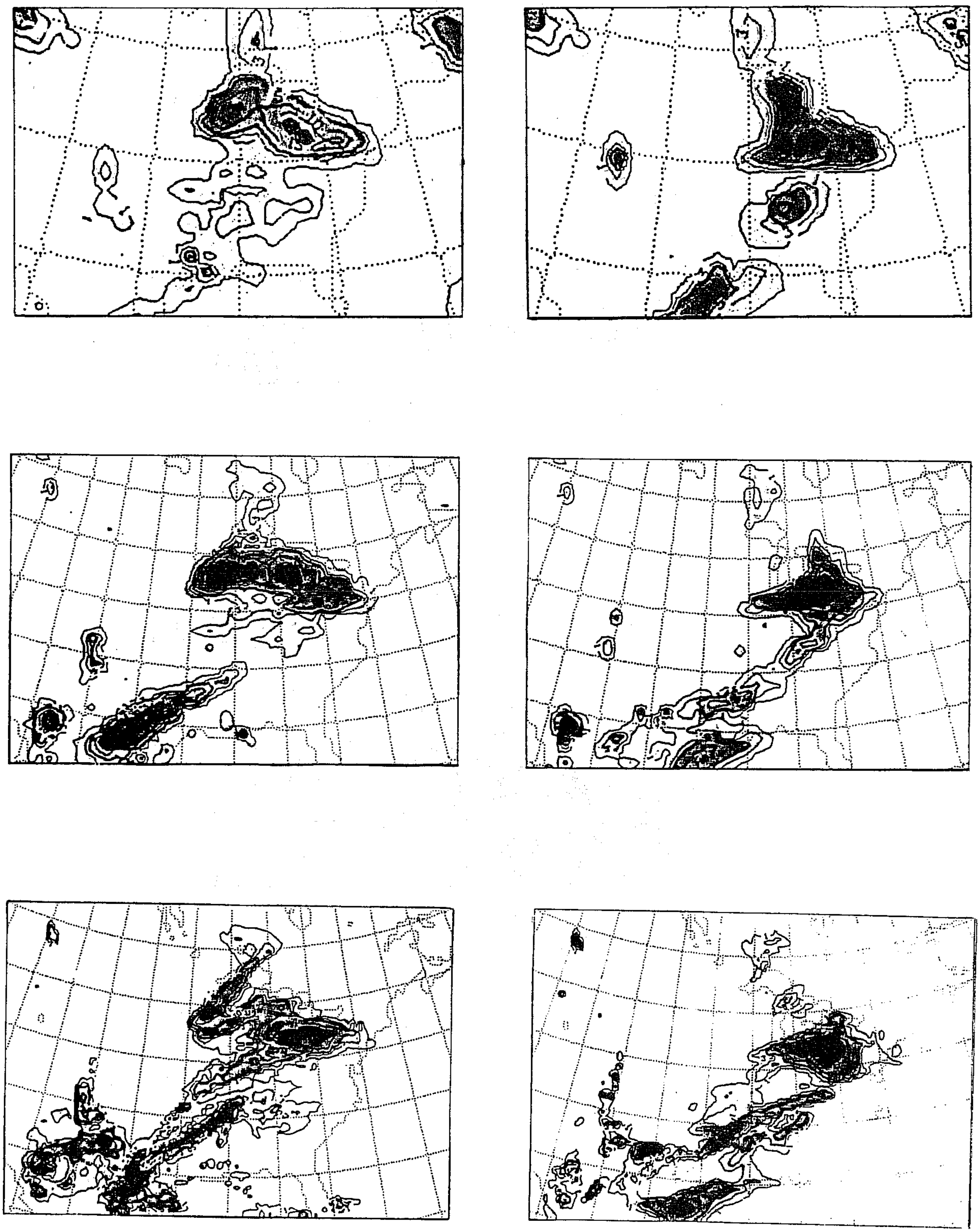
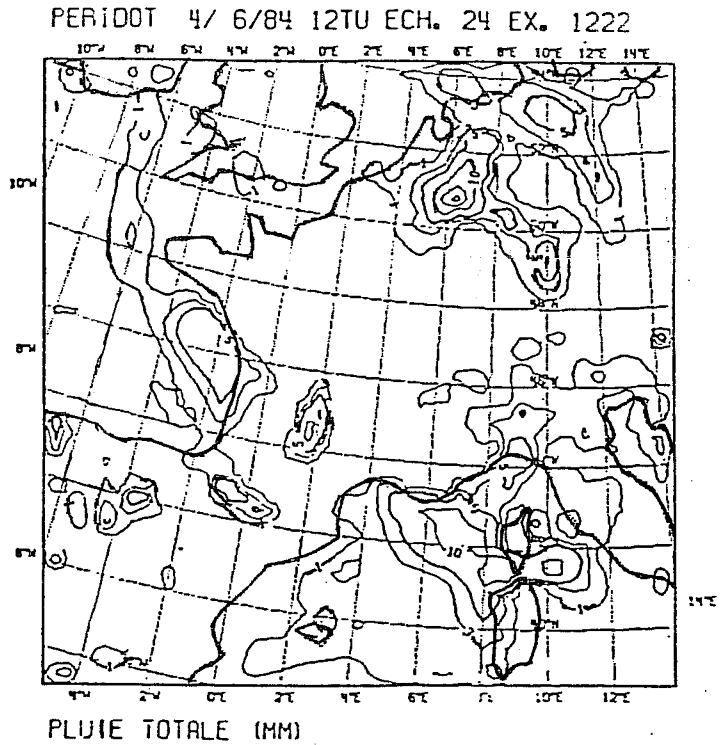


Figure 18 : 12 hour accumulated precipitations for six 48 hour forecasts verifying 81-04-24 00Z over the eastern United States. Left column = parametrization of deep convection following Bougeault (1985) ; right column = parametrization of deep convection following Geleyn (1985) . Top row = 160 km mesh size ; middle row = 80 km mesh size ; bottom row = 40 km mesh size.



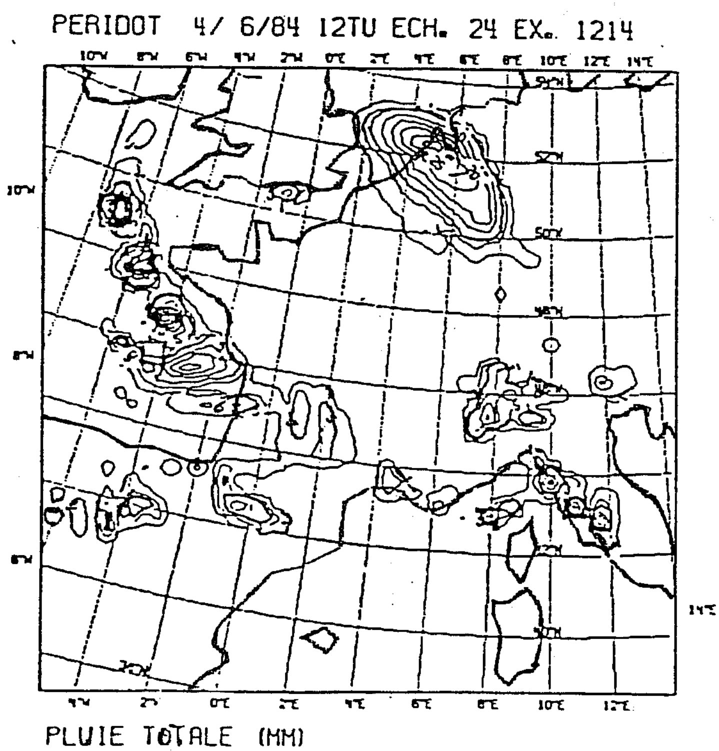


Figure 19 : 6 hour accumulated precipitation for two 24 hour forecasts verifying 84-06-04 12Z . Top = operational convective parametrization ; bottom = no explicit parametrization of deep convection included.

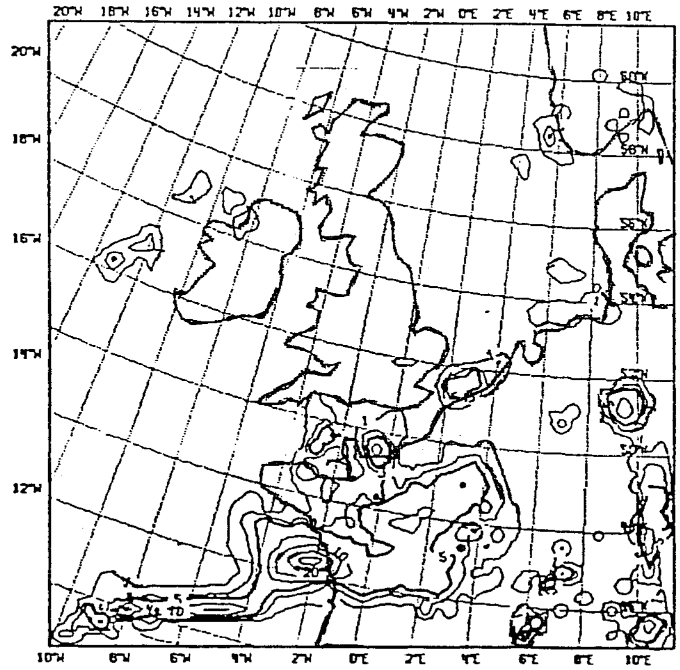
results in response to the change of parametrization. Contrary to what should be the basic philosophy of parametrization, the more the model dynamics resolves, the more the choice of the convection scheme matters. This paradoxical behaviour is linked with the special character of the convective closure assumption in NWP (Bougeault and Geleyn (1988)) and, together with the above-mentioned scale over-sensitivity, it poses a great challenge to meso-scale operational forecasting.

One answer to that challenge might be, as often advocated, to simply remove the convective parametrization from "Peridot", in the hope that the large scale rain parametrization should "do the job" instead. The example of the forecast from 3 June 1984 12 UTC shown in Fig. 19, clearly indicates that it is not yet the case at a grid size of 35 Km. While this solution is quite successful for the system over Germany and Belgium and succeeds in decreasing the precipitation over the Mediterranean, it totally fails to find a realistic solution for the Atlantic frontal structure. The model reaches a state of quasi-numerical instability.

Before going to the other problems it should be mentioned that the parametrization(s) used in the two previous examples were already much improved when compared to our original choices for "Peridot". Figs. 20 and 21 respectively show how we managed to get rid of most "grid point storms" (through a horizontal smoothing of the dynamical part of the moisture convergence before use in the Kuo-type closure assumptions) and to avoid systematic rainfall over evaporating surfaces in the case of shallow moist unstable layers (through the inclusion of liquid water representation in the cloud profile of the convection schemes).

Influence of mesh size and domain extension on forecasting skills

Since this part could warrant a full report in itself we shall simply state very quickly the main results of two studies: the one on the above mentioned OSCAR case by two of us (P. Degardin and M. Imbard) and one of 9 combinations of three domains with three mesh sizes over four cases by one of us (A. Craplet). In the first case it was found that the best forecast was on average the one with the Bougeault scheme and the 80 Km mesh (slightly better than with the 40 Km one) and in the second case that fine mesh leads to forecast improvement but much more when going from 90 to 60 Km than from 60 to 35 Km. Furthermore an enlargement of the integration area also improves the



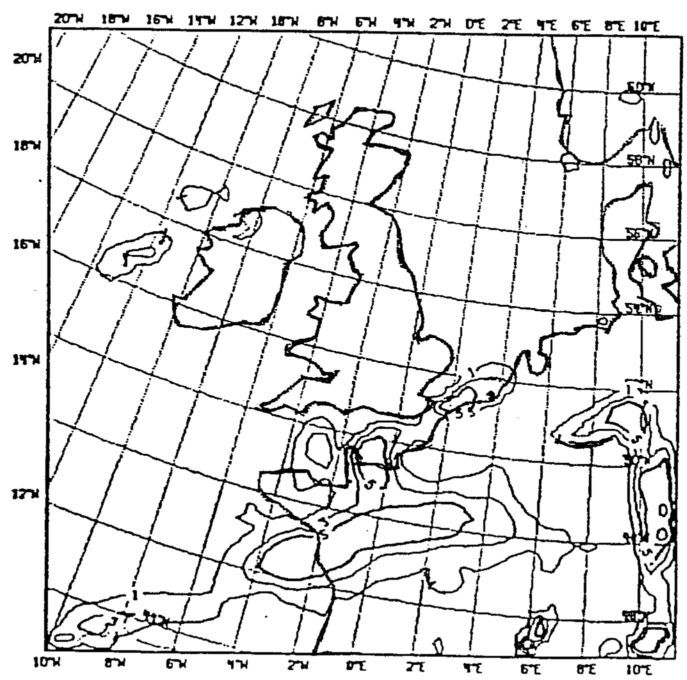


Figure 20 : 6 hour accumulated precipitation for two 24 hour forecasts verifying 86-06-05 12Z over a "British Peridot domain (51x51)" . Top = without smoothing of the dynamical moisture convergence before convective computations ; bottom = with it included.

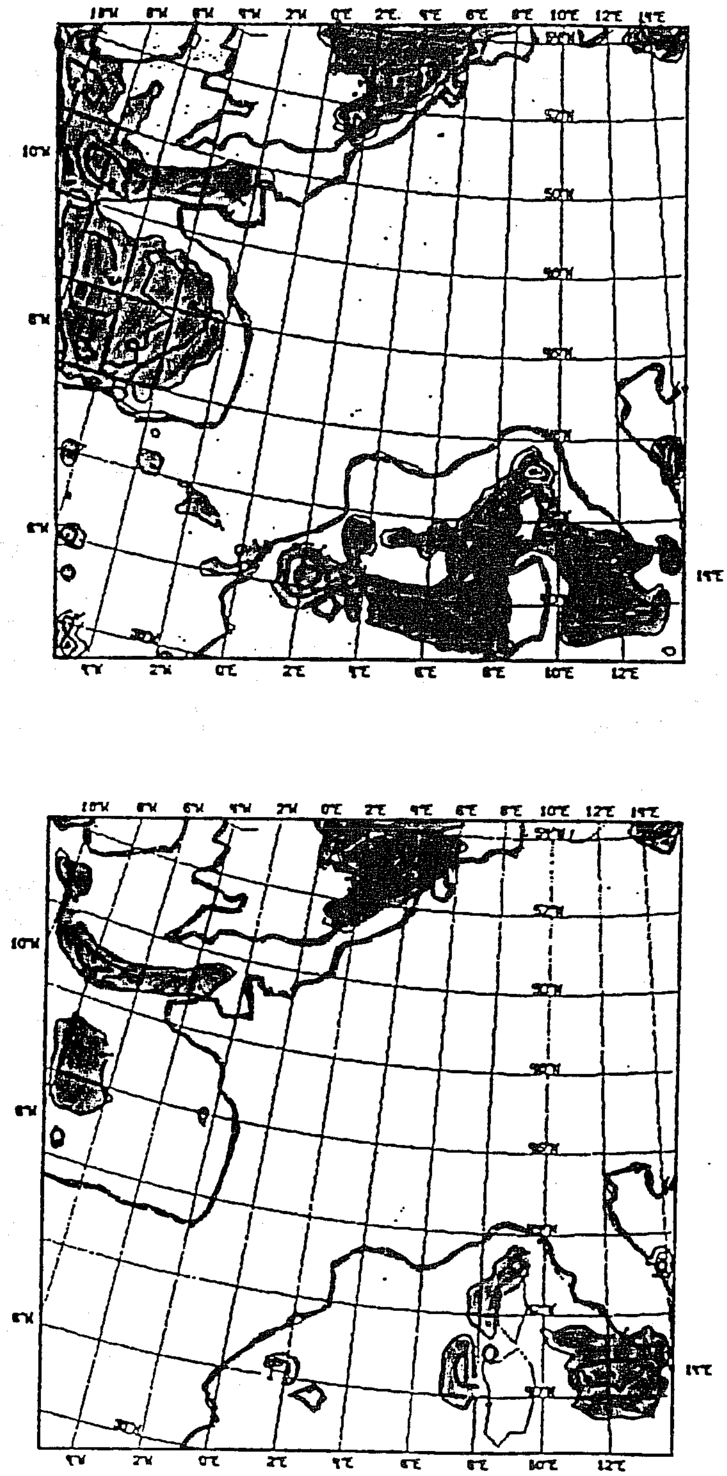


Figure 21 : 6 hour accumulated precipitation for two 24 hour forecasts verifying 85-01-05 00Z . Top = without sustentation of liquid water in the cloud model used as relaxation target for the Kuo-type convection scheme ; bottom = with it included.

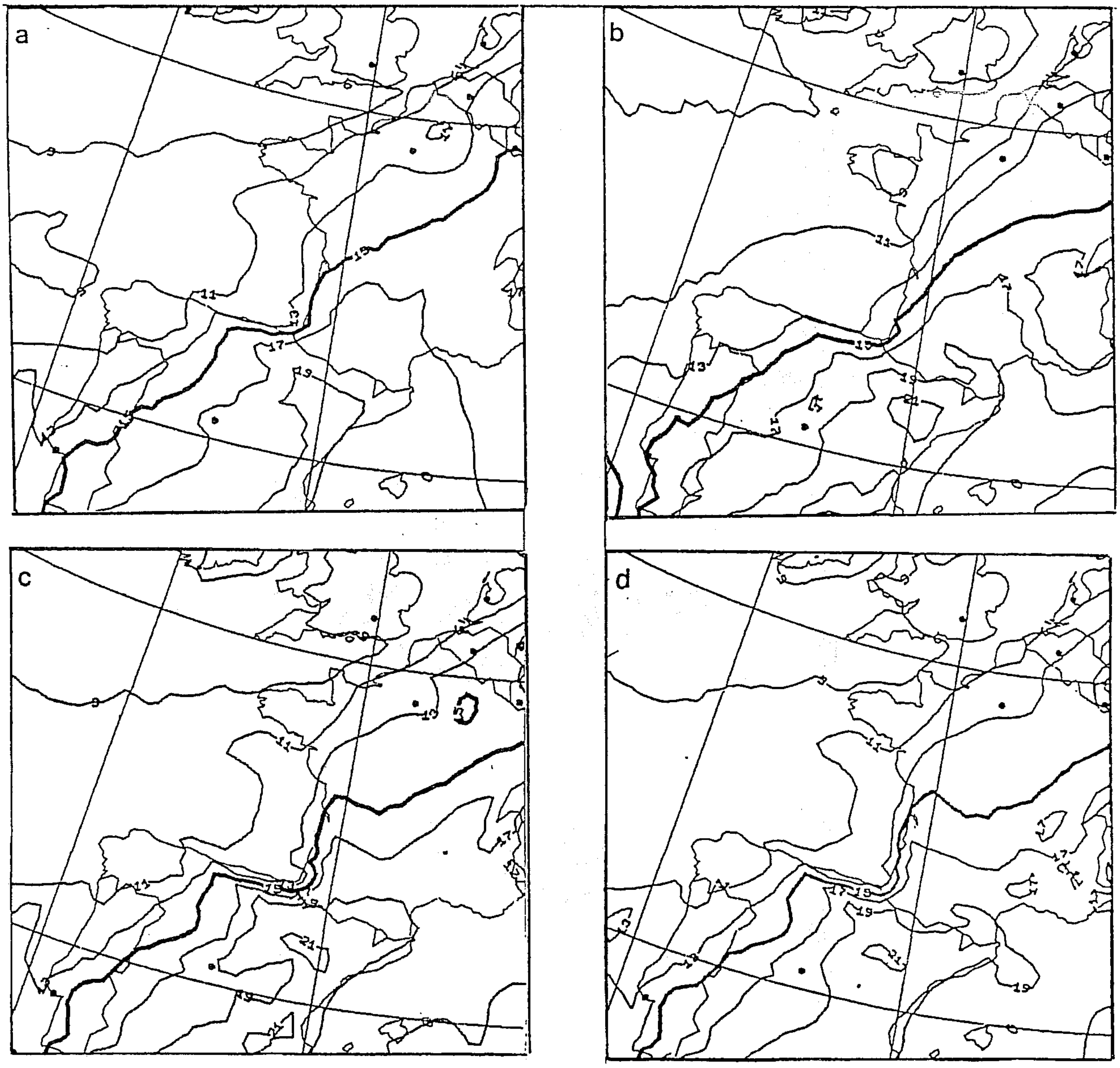


Figure 22 : Maps of 6 hour forecasts of PBL moist equivalent potential temperatures verifying 87-06-07 18Z . The forecasts differ only by their initial states : a) interpolated large scale analysis ; b) fine mesh analysis with large scale forecast as background ; c) fine mesh analysis with fine mesh forecast as background (no satellite data included) ; d) as c) but with satellite data in the fine mesh analysis. Contouring interval 2° (reinforced 15°C isoline). Only part of the 95x95 integration area is shown here.

forecasting skill, except for rainfall where the extra freedom is apparently "misused", a fact that fits rather well with our remarks about convective parametrization. Thus, in summary, perhaps because of the difficulties in handling the interaction between dynamics and deep convection, mid-latitude meso-scale forecasting seems to benefit little if at all from mesh size reductions under a limit of about 50 Km. However, it should be stressed that this concerns only the "free" part of the flow since the results of Section 3 about orographic forcing still hold at the smallest model scale.

Sensitivity to initial conditions

On 7 June 1987 15.30 UTC, a violent squall line developed ahead of a North-South oriented front, just before the latter reached the French "Landes" coast between Bordeaux and the Spanish border. The strength and orientation of the front were the consequences of a secondary development along a primary front of South West/North East orientation. While it is surely out of the scope of "Peridot" with its 35 Km mesh to forecast a squall line we could expect it to give an indication of the secondary development and of a strong frontal structure. Despite several trials it has been impossible up to now to do this from 00 UTC data, this explaining why the operational forecast (still with the 51 x 51 domain at that time) gave a poor guidance on that case. However, far better results are obtained when starting from 12 UTC data. Two things should first be stressed. Such a forecast would have arrived too late to be useful in these circumstances and, probably owing to spin-up problems, the forecasted evolution is lagging behind the real one. Nevertheless, looking at the fundamental question of predictability for this type of events, such a study remains worth doing.

The most interesting result out of all the 12 UTC 6 hour forecasts that we did, is, for this exceptional case, the high sensitivity with respect to initial conditions (Figs. 22 and 23). One can see that all ingredients that should contribute to a better forecast (fine mesh forecasted background, large scale analysis for the larger scales and for lateral boundary conditions, fine mesh analysis, HIRS data) indeed do so. The best forecast shows a moist potential temperature gradient of 1 K/15 Km across the front and a marked discontinuity in the wind speed. It is reassuring that the whole picture is consistent but, on the other hand, the high sensitivity shows the crucial importance of an optimal - and therefore expensive - data assimilation procedure for accurate meso-scale forecasting.

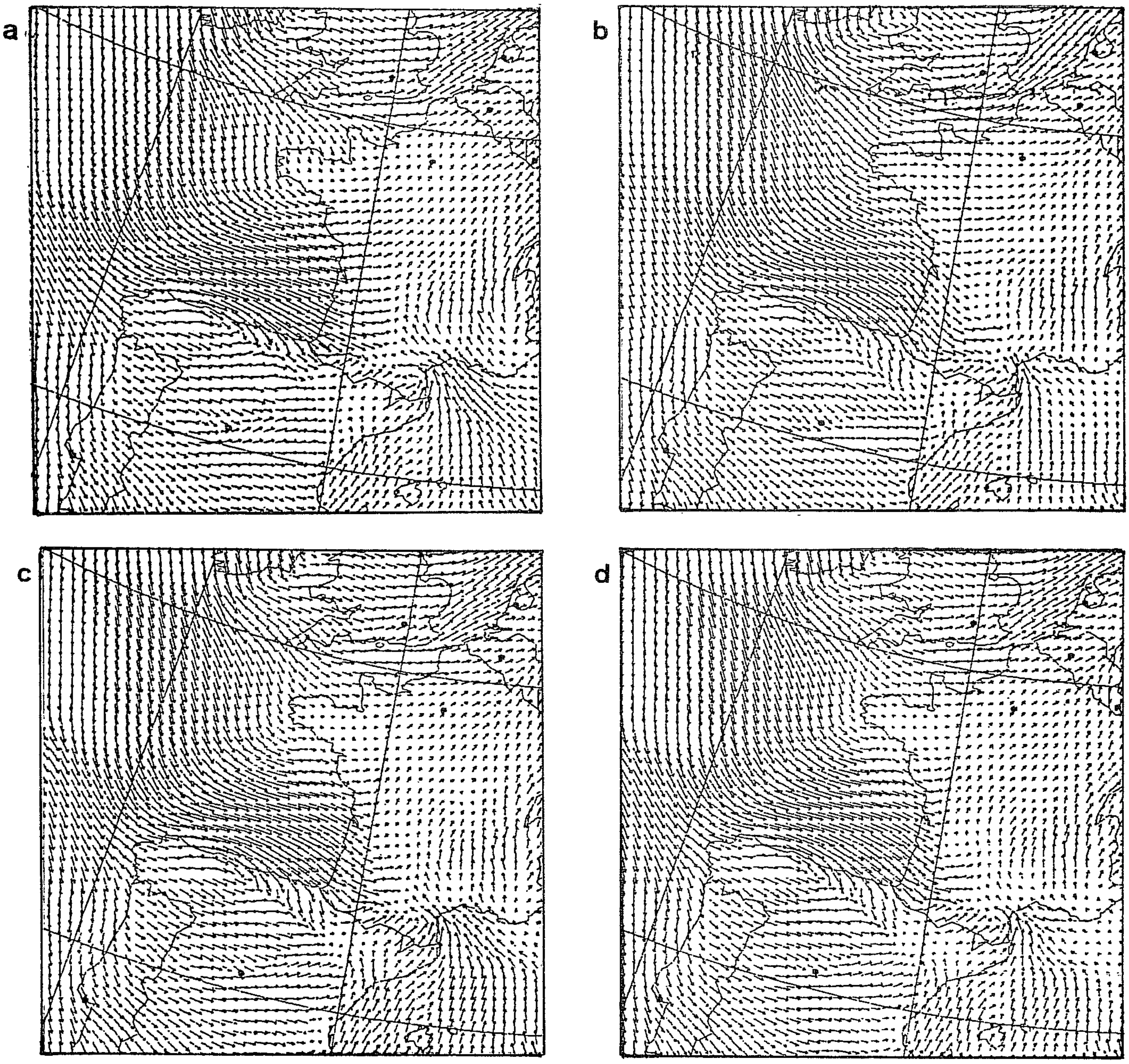


Figure 23 : Same as Figure 22 but for the 10m wind field.

5. SUMMARY OF OUR OPERATIONAL EXPERIENCE SINCE FEBRUARY 1985

Since its operational implementation in February 1985 the "Peridot" system has progressively gained the approval of most French "weathermen" and their subjective assessments overlap by and large with our own ones:

- The system should be judged as a result of a pioneering effort and thus only as a promising first step in a new area of numerical weather prediction; for example, its reliability should not be directly compared to that of more "mature" synoptic scale forecasting systems (ECMWF or "Emeraude");

- Objective verification indicates a better skill for surface parameters than that of the "Emeraude" forecast;

- The improvement (modest for humidity, larger for temperature, and substantial for wind) coincides with an independent measure of usefulness (relative to natural variability) for the same surface parameters;

- Most of this specific meso-scale skill is the result of adaptation to orography and land surface forcing but more marginal improvements are apparently resulting from the special meso-scale features of the data assimilation procedure and from "physical forcing";

- Sometimes unexpected meso-scale predictability (either by its scale or by its range) becomes apparent; this might indicate that spectacular progress could be achieved in coming years (like the 70's - 80's explosion of synoptic scale predictability) but the examples are too rare to be conclusive on this account.

Finally we can identify four main areas of problems that are likely to slow down the above-mentioned forthcoming progress:

a) The negative influence of lateral boundary conditions;

b) The erratic character of deep convective forcing and its too great scale dependency in the models;

c) The fact that increased resolution beyond mesh sizes of about 50 Km does not seem to bring anything more than better adaptation to local orography (one should keep in mind that this may only be a consequence of b), but this point needs further investigation);

d) The necessity to have the most coherent (and thus most expensive) data assimilation system to blend large-scale and meso-scale observed informations.

Rather than ending the lecture with this quick summary we shall try in the final section to outline the main original features of our planned next generation NWP system "Arpege" which, not surprisingly, aim at giving some answers to the points of concern a), b), c) and d).

6. OUTLOOK ON THE ARPEGE PROJECT

The main features that we hope to incorporate into the future "Arpege" forecasting system are the following:

- Variational analysis techniques (first 3-D as a step towards eventual 4-D "adjoint technique" assimilation (Talagrand and Courtier (1987)) as an answer to d);

- Semi-Lagrangian time schemes allowing, in a certain sense, a more appropriate scale distinction between advection and adaptation that might not be detrimental to the results (according to c) and would help saving computing resources, thus making other system-improvements feasible (see Robert (1982), and Ritchie (1987), for information on these techniques);

- Scale dependent formulation of the parametrization schemes especially for convection. This choice leads to a more integrated approach for the handling of the hydrological cycle and to a unified cloud concept. This strategy, in answer to b), is anyhow a prerequisite (as well as semi-lagrangian techniques) for the success of the next and last of our choices;

- End of strategy of coupling global (or hemispheric) systems with limited area ones and replacement by a unique code: spectral and global with varying horizontal resolution according to the "spectral transform" proposed by Schmidt (1977); for more details see Courtier and Geleyn (1988); answer to a).

Although "Arpege" represents a major departure from the existing system, it should be stressed that our choices are based on the experience accumulated with Peridot and would not have been feasible without it (see Jarraud and Geleyn (1988) and Geleyn and Jarraud (1988)).

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