# USE AND IMPACT OF SATELLITE DATA IN THE PERIDOT SYSTEM.

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ABSTRACT.

Experiments have been carried out in order to test the use and impact of several kinds of satellite data in the PERIDOT mesoscale assimilation system: radiances, inverted profiles obtained by different methods (3I or NESDIS) and at several horizontal resolutions. In the following, some details are given about the conditions in which the experiments have been conducted. Then the results of assimilation cycles, and of two 24 hours forecasts starting after two days and a half of assimilation are summarized. A small impact of satellite data is observed, which can be partly explained by weaknesses of the analysis scheme; this is discussed it in the conclusion.

## 1 INTRODUCTION

The PERIDOT mesoscale analysis system, used operationally at the French DMN, has been developed to provide initial conditions to the PERIDOT fine-mesh forecast model. It is described in Durand (1985). An original feature of the PERIDOT analysis scheme is its capability to use directly radiance measurements as well as inverted profiles. The decision of using directly radiance measurements has been taken for operational constraints (short cut-off time) and following some resolution considerations: the resolution of the High Resolution Infrared Radiation Sounder (HIRS) is almost equivalent to the PERIDOT resolution.

In the future, satellite data will become more and more important, as only satellite can provide high resolution data with a global coverage. Several scenarii are likely to occur for the dissemination of satellite data: dissemination of profiles inverted by Global Centres at a more or less high resolution, or dissemination of raw measurements, to be inverted locally in each Regional Centre or directly used in assimilation systems.

These considerations have led to a series of experiments, in order to test the impact of satellite information in the assimilation and to compare different methods of insertion of satellite data in the analysis schemes. These impact studies have been conducted using the PERIDOT system, which seemed best suited for it.

Satellite data which were available at ECMWF for the period 15 january/15 february 1987 have been used: 500 km (usually called SATEM) and 250 km (usually called TOVS at ECMWF) resolution routinely available inverted profiles, cleared radiances and 80 km inverted profiles provided by

NESDIS (Smith,1976), and 3I soundings obtained by Laboratoire de Météorologie Dynamique (LMD), Palaiseau, France from raw radiance data (Chedin et al.,1985). During this period, two TIROS-N satellites were operating, NOAA-9 and NOAA-10. For feasibility reasons, the experiments had to be restricted to a five day period, from 30 January to 3 February 1987. The same days were tested at ECMWF.

## 2 USE OF SATELLITE DATA IN THE PERIDOT ANALYSIS

Satellite data can be used in two different ways in the analysis.

### 2.1 Radiance data

They can be directly used in the analysis. The observed increments are obtained by computing guess values, which are then called "synthetic radiances", from the forecast parameters (ground conditions, temperature and humidity profiles) using a radiative transfer model. The use of clear radiances is fully documented in Durand(1985); it has been extended to partly cloudy radiances (see Durand, 1986).

### 2.2 Inverted profiles

These data are used as geopotential thicknesses between two standard pressure levels. The observed increments are obtained in a straightforward way from the forecast parameters.

## 3 IMPACT STUDIES DEFINITION

### 3.1 The different satellite data sets

#### 3.1.1 500 km SATEMs

NOAA/NESDIS routinely produces temperature and water vapour profiles from the TOVS (TIROS Operational Vertical Sounder) measurements. The inversion method operationally used for the data tested in this study is described in Smith (1976). It is a purely statistical method based on a linear regression. Recently, NESDIS has developed a physico-statistical method (see Goldberg et al.,1988 and Fleming et al.,1988), but it was not yet put into operations in January-February 1987. In the PERIDOT analysis, only geopotential thicknesses between two standard adjacent levels are used.

All the inverted profiles produced by NESDIS are not operationally transmitted. 500 km SATEMs are globally exchanged on the GTS. Geopotential thicknesses are provided between all standard levels. Figure 1.a gives an example of the data coverage for 500 km SATEMs over the PERIDOT domain on 1st February 1987, 12 UTC. These data correspond to the ECMWF archives.

### 3.1.2 250 km SATEMs

These are the same data but at a finer horizontal resolution of about 250 km. They are currently called TOVS at ECMWF. Figure 1.b shows the data coverage for 250 km SATEMs over the PERIDOT domain on 1st February 1987, 12 UTC. Data from the ECMWF archives have been used.

We have to give a few details about the use of levels 300 to 100 hPa. These soundings do not include the virtual temperatures of all the slabs located between two adjacent standard levels, but some slabs are larger (for example, 300-200 hPa instead of 300-250 and 250-200 hPa). Thus the original standard slabs had to be reconstructed for the need of the PERIDOT analysis, by Log-linear interpolation of geopotential thicknesses.

### 3.1.3 80 km SATEMs

They include all the soundings which are obtained by NESDIS, at a horizontal resolution of about 80 km. Figure 1.c shows the data coverage for 80 km SATEMs over the PERIDOT domain on 1st February 1987, 12 UTC. These data were provided by NESDIS to ECMWF on a magnetic tape.

### 3.1.4 3I soundings

The 3I method (Improved Initialization Inversion) developped by LMD (Chedin et al.,1985) has been applied at ECMWF to raw radiance data provided by NESDIS (Flobert,1988). The corresponding ECMWF analysis observation files have been used in the PERIDOT experiments. Figure 1.d shows the data coverage for 3I soundings over the Peridot domain on 1st February 1987, 12 UTC. The resolution reaches 80 km in some areas. The same problem as for 250 km SATEMs was met with combined slabs, and missing thicknesses have been computed in the same way.

### 3.1.5 NESDIS cleared radiances

They are given at the same resolution as 80 km SATEMs, so the data coverage is given by figure 3. These data have also been provided on a magnetic tape by NESDIS to ECMWF. It should be noticed that for nearly 40% of the soundings, there was no result from the cloud-clearing algorithm and only four channels were available (1-2-3-17) on the file, giving information only in the upper levels. This is quite detrimental for the impact of radiances in the PERIDOT system, because Microwave Sounding Unit (MSU) data with a much coarser resolution have to be used instead of HIRS data. This is one of the reasons why, in the operational context, raw radiances with a cloudiness diagnostic are directly used.

Fig 1a : experiment "S". 34 obs.

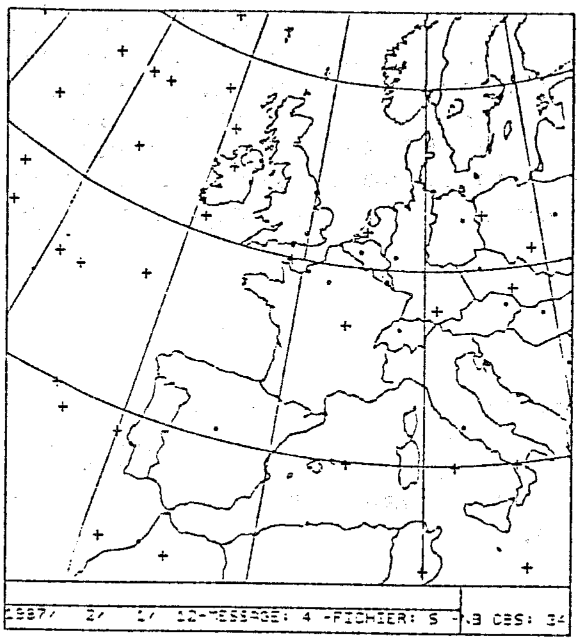


Fig 1b : experiment "T". 91 obs.

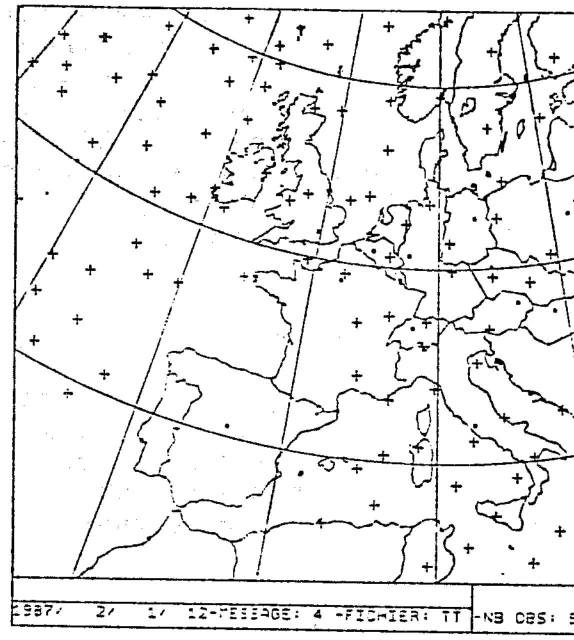


Fig 1c : experiment "N". 562 obs.

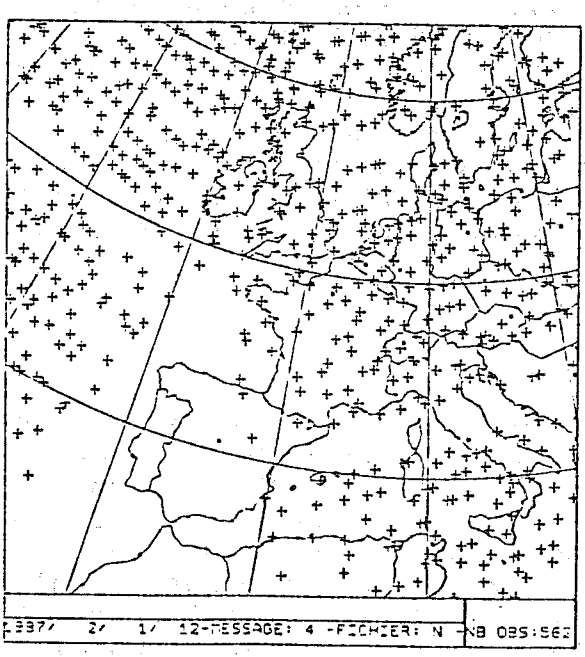


Fig 1d : experiment "I". 286 obs.

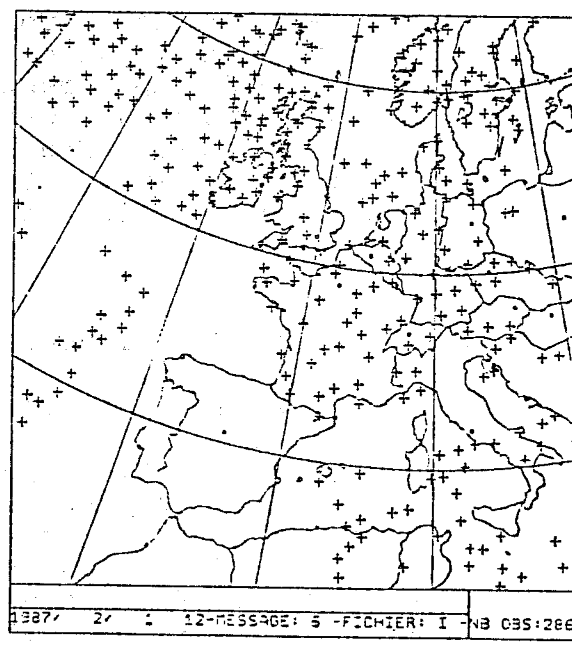


Figure 1:

Spacial localisation of satellite data the 01st of February 87 at 12 UTC in the different experiments.

### 3.2 The assimilation system

The PERIDOT assimilation system (analysis+forecast model) has been used on the ECMWF computers in the following way:

- 6 hour cycling;
- lateral boundary conditions provided every 6 hours by the ECMWF analysis. The boundary conditions are identical in all the experiences, in order to ensure that any difference between experiments is due to differences between the data sets;
- 4 1/2 day assimilation, from 30 january 1987, 0 UTC, to 3 february 1987, 12 UTC;
- initial situation obtained by interpolation from the ECMWF analysis;
- the basic set of observations, common to all the experiments, includes: TEMPs, PILOTs, SYNOPs, SHIPs, SATOBs, AIREPs. They were extracted from the ECMWF archives.

Six parallel assimilations have been conducted, each of them will be identified in the following by a capital letter: A, S, T, N, I, R.

A : is the reference run using the basic set only, and no satellite sounding at all.

S : A + 500 km SATEMs.

T : A + 250 km SATEMs.

N : A + 80 km SATEMs.

I : A + 3I soundings.

R : A + cleared radiances.

## 4 RESULTS FROM ASSIMILATION CYCLES

### 4.1 Guess quality

The guess quality has been evaluated by comparison to the observations (SYNOPs, SHIPs, TEMPs, PILOTs). The data which were used satisfied the analysis quality control: this may imply in a few cases slight differences in the results, when a data is "good" for one experiment and "bad" for another one. The RMS of the difference between the observations and the first-guess corresponding values (6-hour forecast) have been computed.

This criterium is mainly representative of land areas, which cover only 1/3 of the PERIDOT domain. Another limitation comes from the fact that the PERIDOT analysis will select conventional data prior to satellite data when they are both available in the neighbouring of the analysis point: so satellite data are in fact less used over lands. As a consequence, the differences between the scores of the experiments are tightened.

#### 4.1.1 Results for geopotential height at 500 hPa (fig.2)

All the runs using inverted satellite soundings give better results than the reference "A"; only "R" gives the same mean RMS as "A", the score for 1st February, 0 UTC being especially bad. Except for this point, the variations from day to day are very similar between the experiments. So we can conclude to a slight positive impact of satellite information at this level.

The high variability that can be noticed on this graph, with two large oscillations, gives indication that stability is not yet reached in the assimilation cycles. As the last value is the lowest one, we can be reasonably optimistic on the results of a longer assimilation.

#### 4.1.2 Results for temperature at 850 hPa (fig.3)

The results are very similar for all the experiments: generally, the scores do not differ by more than 0.1K, and it is difficult to conclude to a real impact. The best cases seem to be "T" and "N".

As for geopotential height, there are two oscillations before reaching stability for the last cycles.

#### 4.1.3 Results for geopotential height at 200 hPa (fig.4)

At this level, experiments "S", "T", "N" and "I" are worse than "A" and "R", which give equivalent results. We can even conclude to a negative impact for "N". This is similar to the results obtained for temperature at the same level.

These bad results can be explained by several reasons: satellite inversion algorithms usually produce bad results near the tropopause; the PERIDOT forecast model is of poor quality at the upper levels, due to the lack of levels; the vertical correlation scheme used in the PERIDOT analysis is not adapted to that vertical variability in the level thicknesses; we had to recompute some temperatures at 250 and 150 hPa because they were not in the ECMWF files.

### 4.2 Analyses intercomparison

The analyses from experiments "S", "T", "N", "I" and "R" have been compared to analyses from experiment "A" (without satellite data). A new criterium is thus obtained, which measures the impact of satellite data over the whole domain, over sea as well as over land, but without any indication of its sign (positive or negative impact). It complements the previous results.

| Date\Exp | A | S | T | N | I | R |
|---|---|---|---|---|---|---|
| 3000 | 13,25 | 13,25 | 13,25 | 13,25 | 13,25 | 13,25 |
| 3012 | 14,88 | 14,65 | 14,93 | 14,79 | 14,58 | 14,76 |
| 3100 | 19,05 | 18,17 | 18,25 | 17,92 | 19,20 | 18,88 |
| 3112 | 20,22 | 19,44 | 19,44 | 19,69 | 19,61 | 20,44 |
| 0100 | 16,02 | 15,52 | 15,10 | 15,40 | 15,73 | 17,32 |
| 0112 | 14,55 | 13,95 | 14,33 | 14,92 | 15,06 | 14,97 |
| 0200 | 11,74 | 11,16 | 11,20 | 11,93 | 12,13 | 11,63 |
| 0212 | 18,97 | 18,12 | 17,98 | 18,61 | 18,81 | 18,24 |
| 0300 | 18,19 | 17,05 | 17,10 | 16,35 | 17,32 | 17,43 |
| 0312 | 10,68 | 10,72 | 10,24 | 11,05 | 11,06 | 10,81 |
| AVG | 16,03 | 15,42 | 15,40 | 15,63 | 15,94 | 16,05 |

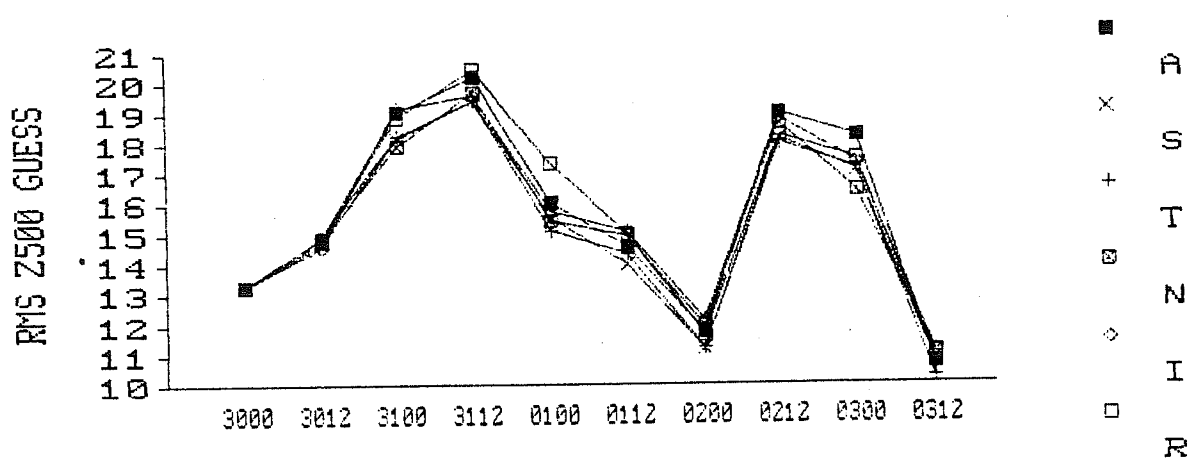



Figure 2:

RMS of the guess Z500 (forecast 6h) compared with TEMP.
(table + graphix) unity : mgp

| Date\Exp | A | S | T | N | I | R |
|---|---|---|---|---|---|---|
| 3000 | 1,40 | 1,40 | 1,40 | 1,40 | 1,40 | 1,40 |
| 3012 | 1,63 | 1,63 | 1,63 | 1,65 | 1,63 | 1,63 |
| 3100 | 2,10 | 2,10 | 2 | 2,00 | 2,10 | 2,10 |
| 3112 | 1,51 | 1,51 | 1,41 | 1,41 | 1,53 | 1,51 |
| 0100 | 1,61 | 1,61 | 1,50 | 1,60 | 1,63 | 1,61 |
| 0112 | 1,50 | 1,61 | 1,61 | 1,60 | 1,60 | 1,60 |
| 0200 | 1,91 | 1,91 | 1,92 | 1,81 | 2,04 | 1,91 |
| 0212 | 1,43 | 1,41 | 1,41 | 1,40 | 1,50 | 1,41 |
| 0300 | 1,51 | 1,50 | 1,50 | 1,50 | 1,60 | 1,50 |
| 0312 | 1,51 | 1,51 | 1,51 | 1,41 | 1,50 | 1,51 |
| AVG | 1,64 | 1,65 | 1,61 | 1,60 | 1,68 | 1,64 |

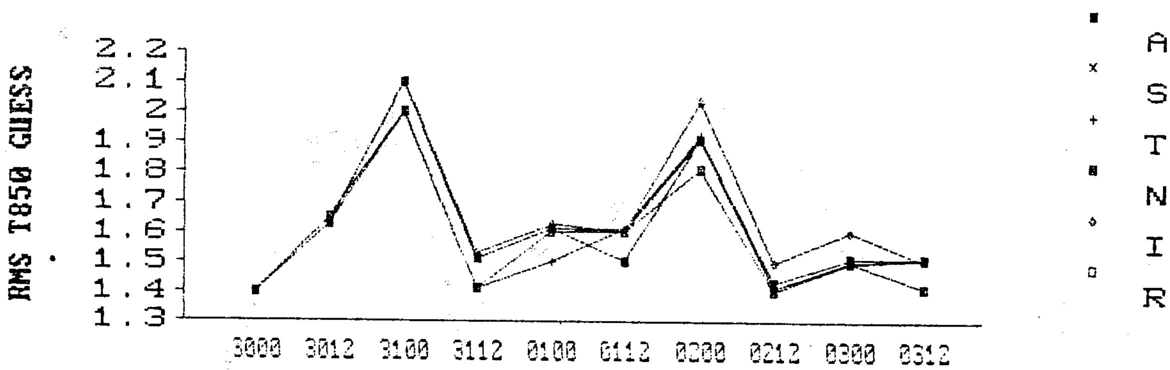



Figure 3:

RMS of the guess T850 (forecast 6h) compared with TEMP.
(table + graphix) unity : K

| Date\Exp | A | S | T | N | I | R |
|---|---|---|---|---|---|---|
| 3000 | 25,31 | 25,31 | 25,31 | 25,31 | 25,31 | 25,31 |
| 3012 | 27,69 | 28,06 | 28,23 | 30,75 | 28,81 | 27,31 |
| 3100 | 34,16 | 34,41 | 33,69 | 35,39 | 34,39 | 34,32 |
| 3112 | 29,11 | 29,57 | 29,37 | 30,77 | 30,13 | 28,77 |
| 0100 | 36,50 | 37,91 | 37,57 | 39,69 | 39,34 | 37,13 |
| 0112 | 37,48 | 38,39 | 38,50 | 39,41 | 39,32 | 38,51 |
| 0200 | 32,09 | 34,72 | 33,60 | 36,37 | 36,67 | 32,80 |
| 0212 | 34,28 | 36,16 | 34,63 | 37,20 | 36,58 | 34,81 |
| 0300 | 35,08 | 35,78 | 33,43 | 37,23 | 36,31 | 34,67 |
| 0312 | 21,19 | 22,05 | 21,43 | 22,64 | 22,90 | 20,82 |
| AVG | 31,95 | 33,01 | 32,27 | 34,38 | 33,83 | 32,12 |

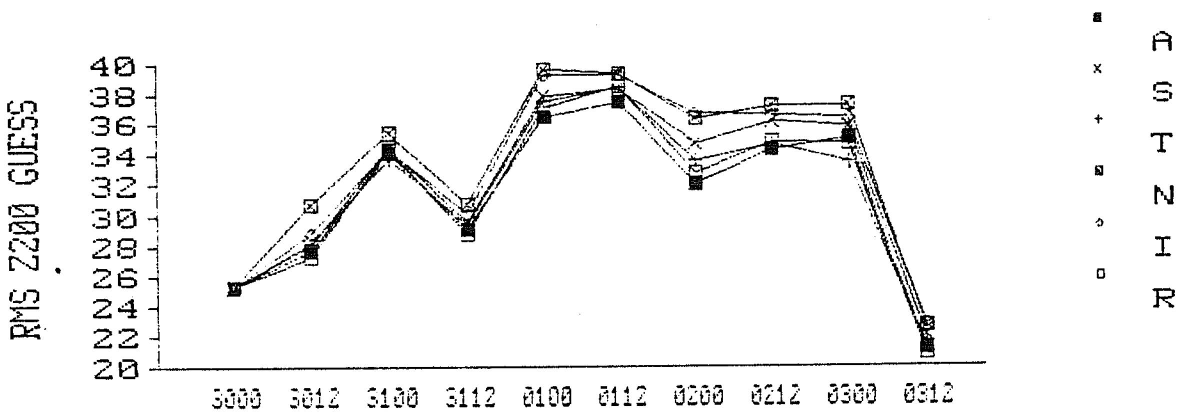



Figure 4:

RMS of the guess Z200 (forecast 6h) compared with TEMP.
(table + graphix) unity : mgp

This intercomparison minimizes observed differences because satellite data are not spread over the entire domain at each cycle, while the scores are averaged over all grid points at the model levels.

### 4.2.1 RMS differences on temperature fields (fig.5)

Results are presented for three levels: σ15 (about 18 meters above ground), σ5 (around 500 hPa) and σ3 (about 300 hPa). They logically show an impact of satellite data, proportional to their horizontal resolution. Thus 500 km SATEMs make less modifications than 250 km SATEMs, which themselves make less modifications than 80 km SATEMs; besides, the distance is smaller between "N" and "T" than between "S" and "T". Results for "I" are more similar to results for "T" than to results for "N".

The impact of radiances is not negligible, even near the ground; it is greater than the impact of 500 km SATEMs and similar to the impact of 250 km SATEMs. As we have seen in 4.1.4, this impact disappears during the forecast.

### 4.2.2 Synoptic differences (fig. 6 and 7)

Difference maps between the different analyses and analysis "A" have been drawn. They reach 1 or 2 K for temperature and several hPa for pressure.

Maps of differences obtained for sea level pressure generally show coherent differences between the analyses with and without satellite data: large differences are located at the same place and have the same sign. For example, figure 6 show differences on the sea level pressure field for 2 February 1987, 0 UTC. The amplitude of differences has the same order of magnitude for "S-A" and "R-A", it increases for "T-A" and "I-A", the largest values are obtained for "N-A". The area located North-West of Ireland indicates a consistent impact of satellite data, increasing with respect to their resolution. We can recall that the effective resolution of radiances in "R" is not 80 km, as about 40% of the soundings are cloudy.

It is interesting to notice that for this date, satellite data are quite sparse: 3 500 km SATEMs, 25 250 km SATEMs, 156 80 km SATEMs and radiances, 76 3I soundings. These numbers are about mean numbers of data for 0 UTC; they are more numerous for other times, as could be seen on figures 1 to 4. So the impact that is observed on 2 February 1987, 0 UTC, comes also from the assimilation of satellite data during the previous cycles.

The differences obtained for temperature are not so homogeneous, as can be seen on the maps of differences on the temperature field at 850 hPa (see figure 7). There is a negative difference in the north-western part of the domain for "S-A", "T-A" and "N-A", that is for the three experiments using NESDIS inverted profiles; the amplitude of the difference

| | S-A | T-A | N-A | I-A | R-A |
|---|---|---|---|---|---|
| AVG To15 | ,28 | ,42 | ,59 | ,37 | ,32 |
| AVG To5 | ,26 | ,45 | ,51 | ,49 | ,44 |
| AVG To3 | ,51 | ,99 | 1,13 | ,91 | ,73 |

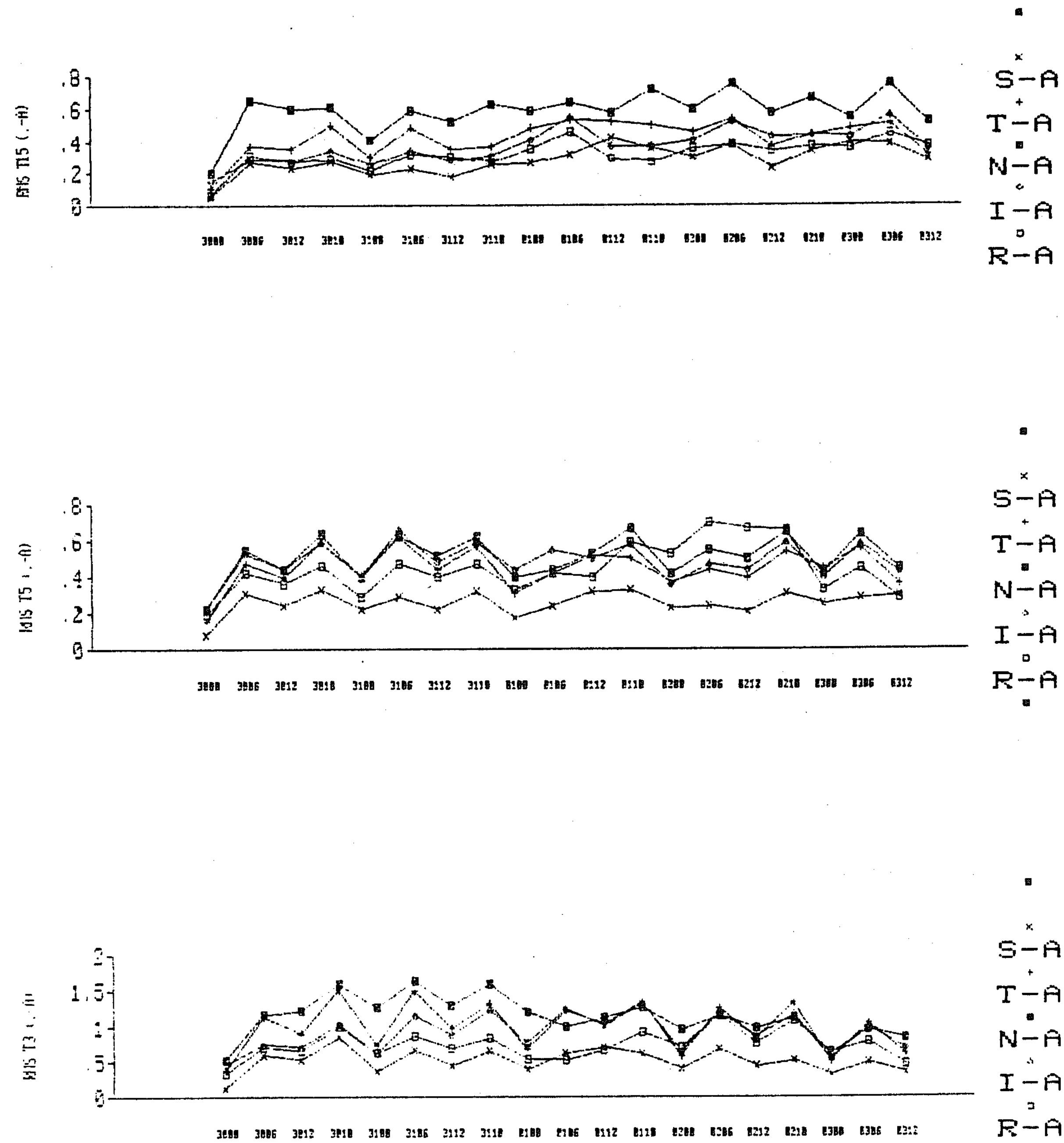



Figure 5:

RMS of the temperature differences between "satellite" analysis (experiments S/T/N/I/R) and the "reference" analysis (experiment A) at sigma levels 15, 5 and 3. unity : K

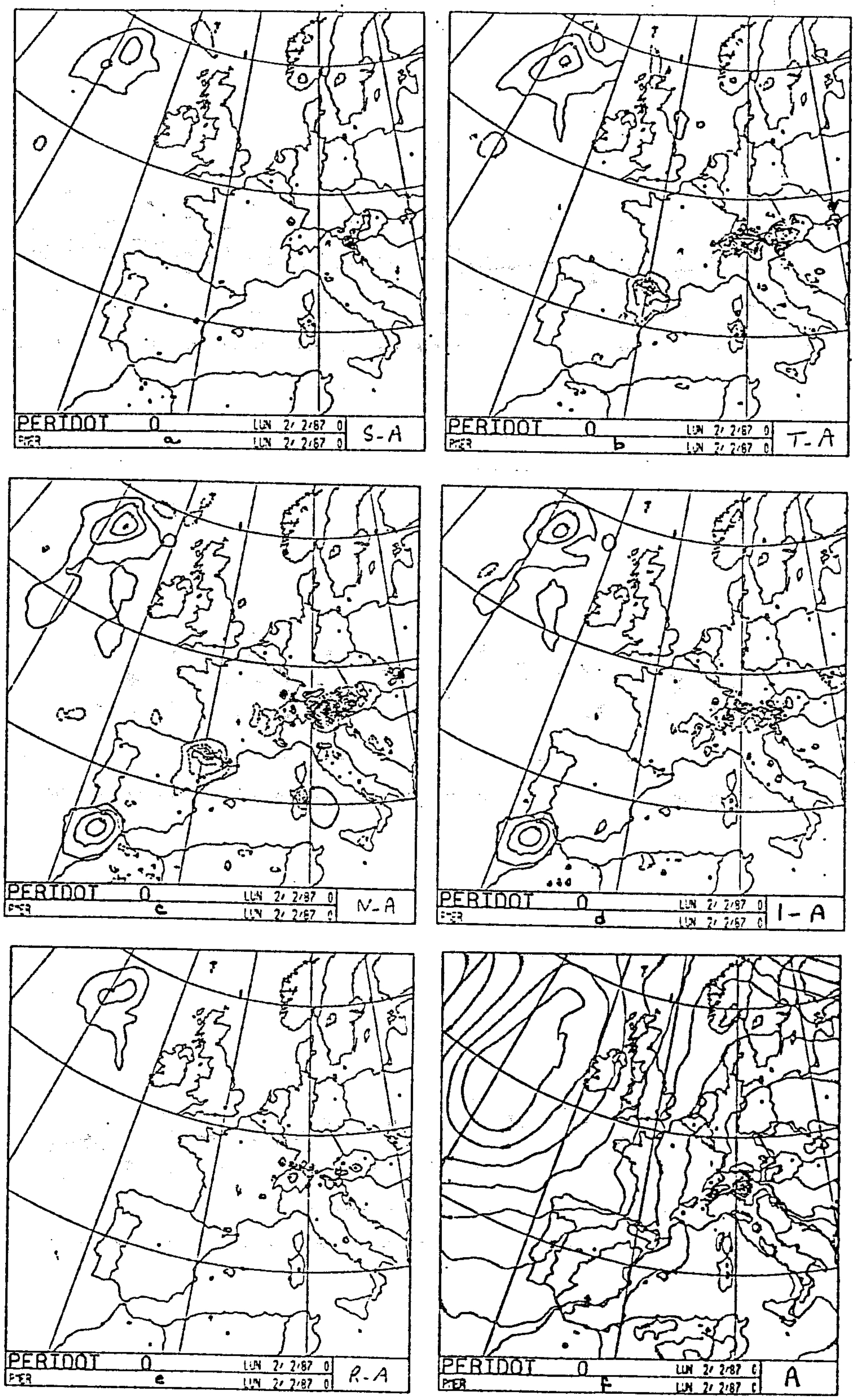
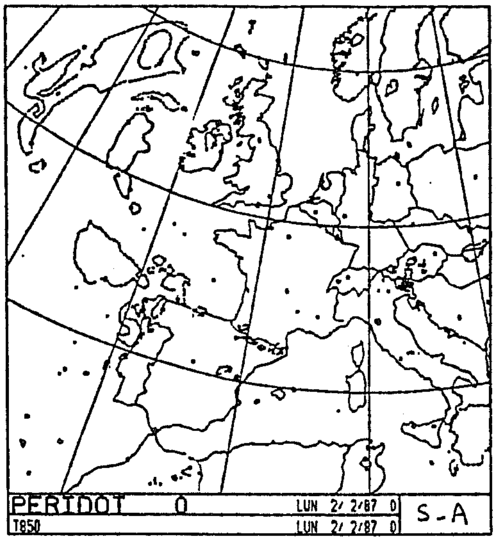


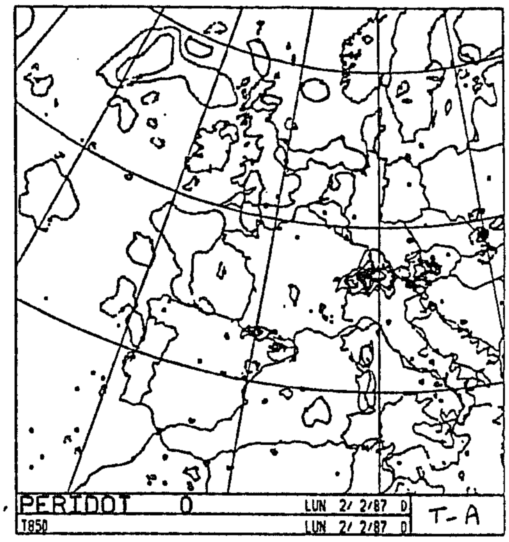

Figure 6:

Maps of differences in sea-level pressure between the different "satellite" analyses (maps: a=S-A, b=T-A, c=N-A, d=I-A, e=R-A) and the "reference" analysis "A", the 02nd of February 87. The corresponding analysis for "A" is shown in f.
(interline = 1 hPa, reference = 0.5 hPa, val < 0 dashed)

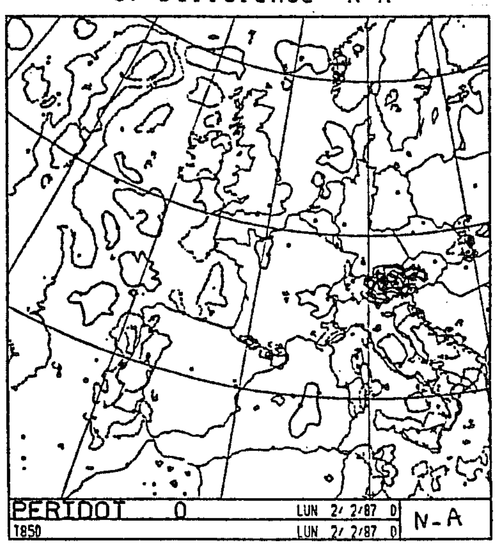
a) Difference "S-A"



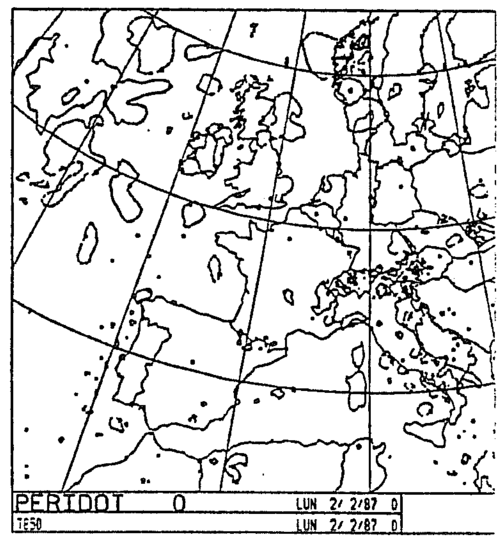

b) Difference "T-A"




c) Difference "N-A"




d) Difference "I-A"




e) Difference "R-A"

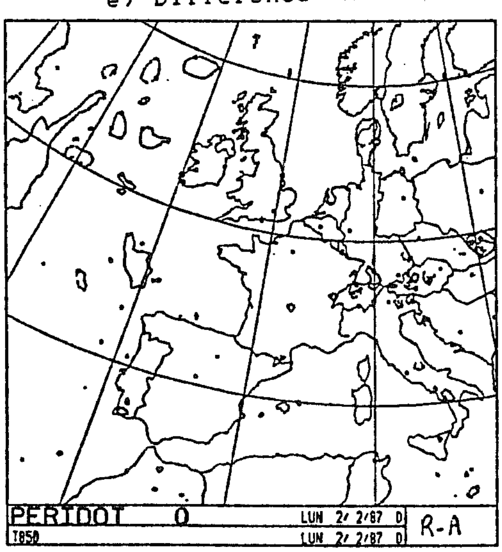



Figure 7:

Maps of 850 hPa Temperature differences between "satellite" analyses (maps: a=S-A, b=T-A, c=N-A, d=I-A, e=R-A) and the "reference" ("A") analysis, the 02nd February 87 00 UTC.

(interline : 0.5 K)
( val < 0 dashed)

increases with respect to the resolution of data. There is not an equivalent feature for "I-A"; the small differences obtained for "R-A" can be explained by the poor information coming from the radiances in the lower levels.

The sea level pressure maps can be compared to the maps which are produced operationally, where observed values are plotted and used together with satellite imagery to obtain a manual drawing (figure 8). The depression situated abroad Ireland is well located in our experiments. The deepening seems to be too much weak for "A", as there are few surface observations to confirm it; apart from this point, isolines show a good consistency with available observations. As the depression is less deepened with satellite data, it looks like a negative impact.

### 4.3 Conclusion on the impact in the assimilation cycles.

We could not find any positive or negative impact of cleared radiances. We only showed that they did not have the same negative influence as inverted profiles around 200 hPa. Inverted data did not prove to have a large positive impact: there is only the indication of a slight positive impact at 500 hPa for geopotential height. Nevertheless, as seen in 4.2, all the satellite data are used and modify the analysis result, but they can have a rather detrimental impact on the lower levels.

## 5 RESULTS OBTAINED IN FORECASTS

In order to further evaluate the impact of satellite data, two sets of 24 hours forecasts have been conducted: one starting from 1st February 1987, 12 UTC, the other starting from 2nd February 1987, 0 UTC. The results of the forecasts have been evaluated in three different ways: verification against observations, verification against analyses, and synoptic verification against plotted maps.

### 5.1 Verification against observations

The scores are produced in the same way as in 4.1 and have the same limitations.

#### 5.1.1 1st February 1987, 12 UTC (fig.9 and 10)

Results for geopotential height at 500 hPa are presented on figure 9 for range 0,12 and 24 hours. In the starting analyses, the deterioration for "I" is noticeable, coming mainly from a bias problem. The problem diminishes at 12 hours, and vanishes at 24 hours. At 12 hours, "S", "T" and "N" (NESDIS data) show a slight improvement, "T" being the best one. At 24 hours, all the satellite data forecasts are better than "A", a slight positive impact being visible for "T" and "N" essentially.

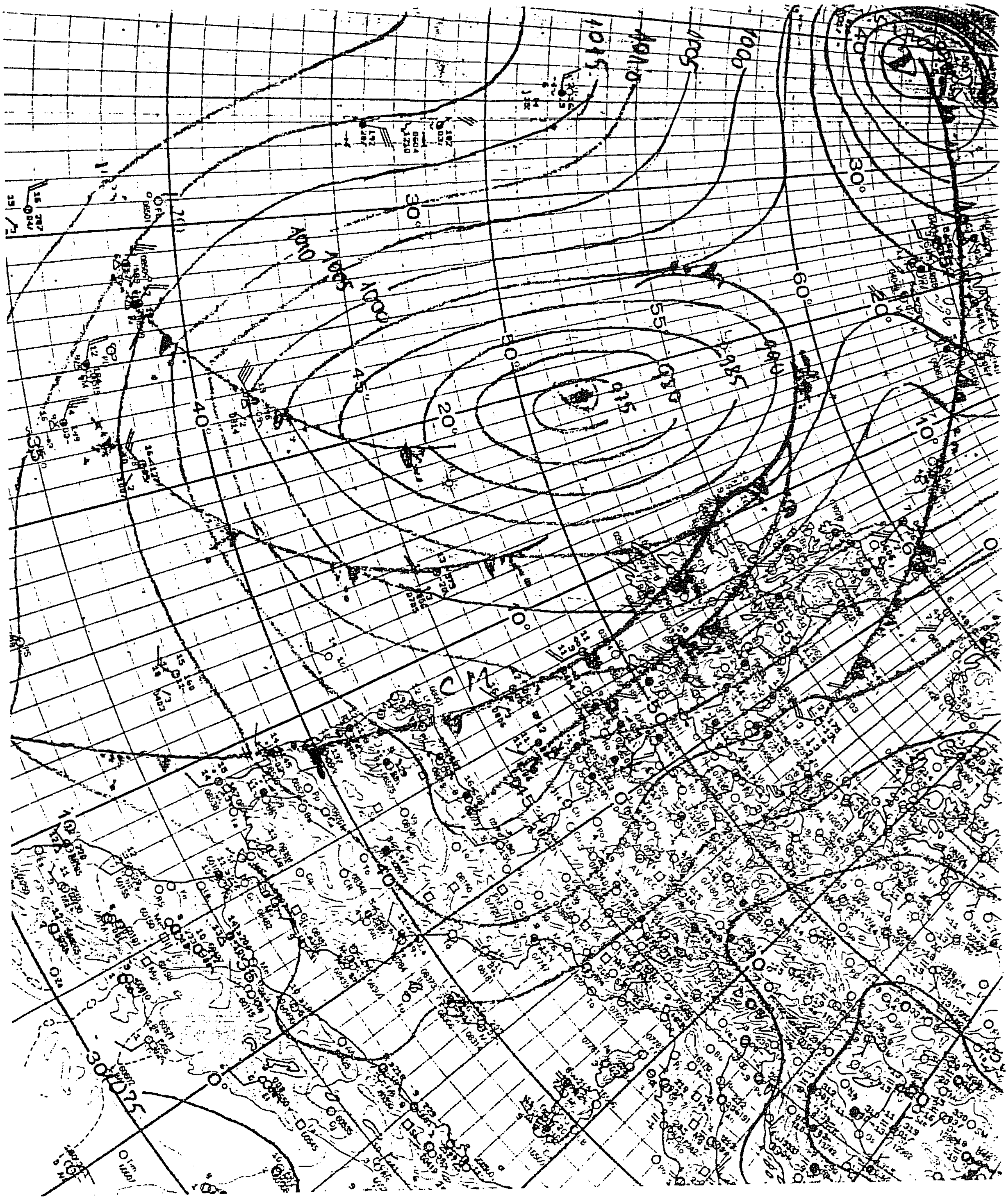



Figure 8: Synoptic situation the 02/02 87 00 UTC.

GEOPOTENTIAL 500 hPa

| | 0 H FORECAST | | | | 12 H FORECAST | | | | 24 H FORECAST | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | S | N | R | B | S | N | R | B | S | N | R |
| A | 2 | 9,50 | 72 | 9,71 | ,50 | 11,70 | 65 | 11,71 | -5,10 | 18,60 | 72 | 19,29 |
| S | 1,50 | 9,40 | 72 | 9,52 | ,20 | 11,40 | 65 | 11,40 | -5,20 | 18,40 | 72 | 19,12 |
| T | 1 | 9,80 | 72 | 9,85 | 0 | 11,10 | 65 | 11,10 | -5,40 | 17,90 | 72 | 18,70 |
| N | 1,60 | 10 | 72 | 10,13 | ,60 | 11,40 | 65 | 11,42 | -4,40 | 17,60 | 72 | 18,14 |
| I | 4,20 | 9,60 | 72 | 10,48 | 2,10 | 12,20 | 65 | 12,38 | -3,70 | 18,80 | 72 | 19,16 |
| R | 1,90 | 9,70 | 72 | 9,88 | 1,10 | 11,90 | 65 | 11,95 | -4,40 | 18,50 | 72 | 19,02 |

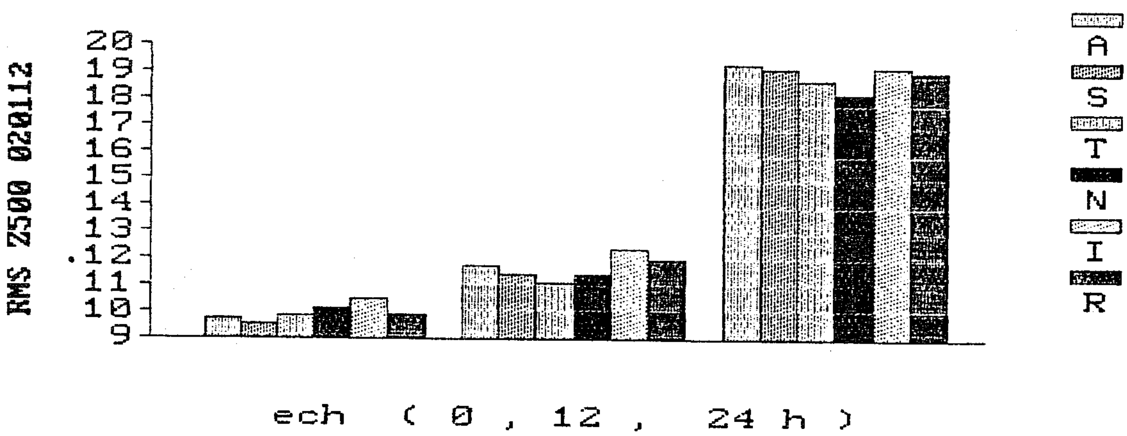



Figure 9:

Verification of the Z500 forecasts from 01/02 12UTC with TEMP data. (1 complete table + 1 RMS histogram).
(in the table : B = bias, S = standard deviation , N = nbre of comparaisons, R = RMS) unity = mgp

TEMPERATURE 850 hPa

| | 0 H FORECAST | | | | 12 H FORECAST | | | | 24 H FORECAST | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | S | N | R | B | S | N | R | B | S | N | R |
| A | ,10 | 1,30 | 72 | 1,30 | -,20 | 1,70 | 65 | 1,71 | -,40 | 1,60 | 73 | 1,65 |
| S | 0 | 1,30 | 72 | 1,30 | -,10 | 1,70 | 65 | 1,70 | -,30 | 1,60 | 73 | 1,63 |
| T | 0 | 1,40 | 72 | 1,40 | -,10 | 1,60 | 65 | 1,60 | -,40 | 1,50 | 73 | 1,55 |
| N | 0 | 1,40 | 72 | 1,40 | -,10 | 1,60 | 65 | 1,60 | -,30 | 1,50 | 73 | 1,53 |
| I | ,20 | 1,40 | 72 | 1,41 | 0 | 1,70 | 65 | 1,70 | -,30 | 1,60 | 73 | 1,63 |
| R | ,10 | 1,30 | 72 | 1,30 | -,10 | 1,70 | 65 | 1,70 | -,30 | 1,60 | 73 | 1,63 |

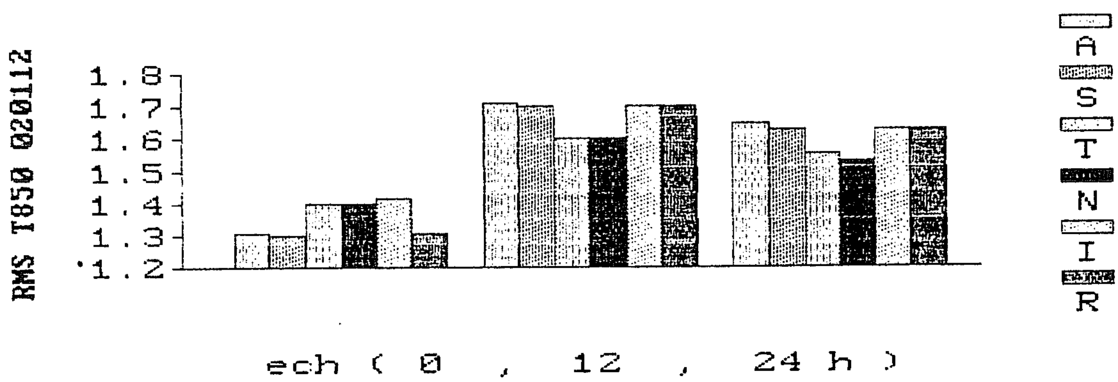



Figure 10:

Verification of the T850 forecasts from 01/02 12UTC with TEMP data. (1 complete table + 1 RMS histogram).
(in the table : B = bias, S = standard deviation , N = nbre of comparaisons, R = RMS) unity = K

The same results are shown for temperature at 850 hPa on figure 10. We can see a slight deterioration in the analyses "T", "N" and "I". At 12 hours and 24 hours, "T" and "N" show a slight improvement, the other experiments staying at the same level as "A".

5.1.2 2nd February 1987, 0 UTC (fig.11 and 12)

As for the previous case, results are presented first for geopotential height at 500 hPa on figure 11. All the analyses give almost the same result. At 12 hours, all the experiments but "I" give better results than "A", the best one being "T". At 24 hours, the deterioration for "I" is worse, the other experiments being equivalent to "A", except "T" which is slightly better.

Results for temperature at 850 hPa are shown on figure 12. No positive impact can be seen, and there is a slight deterioration for "I" and "R" both in the analyses, 12 hours and 24 hours forecasts.

5.1.3 Synthesis of results for the two cases (fig.13)

A mean RMS has been computed over the two sets of forecasts in order to obtain an average score. The results have been weighted by the number of observations, which is not the same for the two cases. They are displayed for geopotential height and temperature at several levels. They can be summarized as follows:

*"Good scores".*

| | P surf | Z 850 | Z 500 | Z 200 |
|---|---|---|---|---|
| Analysis | T | N/S | S | . |
| 6h forecast | S/R | . | S/T/N | . |
| 12h forecast | . | . | T | . |
| 24h forecast | . | . | N/T | . |

| | T surf | T 850 | T 500 | T 200 |
|---|---|---|---|---|
| Analysis | . | . | . | . |
| 6h forecast | . | . | . | . |
| 12h forecast | . | T/N | . | . |
| 24h forecast | . | N/T | . | . |

GEOPOTENTIAL 500 hPa

| | 0 H FORECAST | | | | 12 H FORECAST | | | | 24 H FORECAST | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | S | N | R | B | S | N | R | B | S | N | R |
| A | ,10 | 10,30 | 65 | 10,30 | -5,50 | 18,30 | 72 | 19,11 | -7,60 | 19,01 | 66 | 20,47 |
| S | ,20 | 10 | 65 | 10,00 | -5,10 | 17,70 | 72 | 18,42 | -7,30 | 19,10 | 66 | 20,45 |
| T | -,50 | 10,30 | 65 | 10,31 | -5,10 | 17,20 | 72 | 17,94 | -7,50 | 18,70 | 66 | 20,15 |
| N | 0 | 10,60 | 65 | 10,60 | -4,30 | 17,70 | 72 | 18,21 | -7,01 | 19,30 | 66 | 20,53 |
| I | 1,50 | 10,40 | 65 | 10,51 | -4,90 | 18,90 | 72 | 19,52 | -8,20 | 20,20 | 66 | 21,80 |
| R | -,60 | 10,20 | 65 | 10,22 | -5,10 | 18,20 | 72 | 18,90 | -7,70 | 19,30 | 66 | 20,78 |

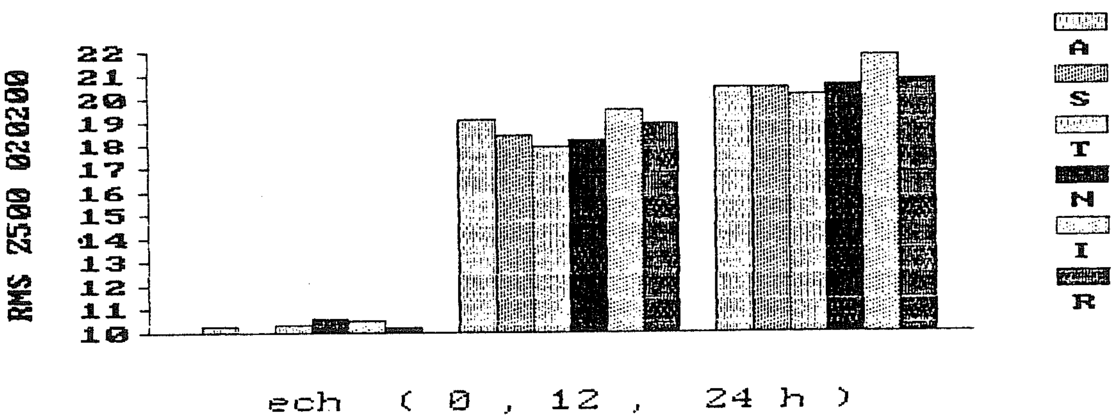



Figure 11:

Verification of the Z500 forecasts from 02/02 00UTC with TEMP data. (1 complete table + 1 RMS histogram).
(in the table : B = bias, S = standard deviation , N = nbre of comparaisons, R = RMS) unity = mgp

TEMPERATURE 850 hPa

| | 0 H FORECAST | | | | FORECAST 12 H | | | | FORECAST 24 H | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | S | N | R | B | S | N | R | B | S | N | R |
| A | 0 | 1,10 | 64 | 1,10 | -,20 | 1,40 | 73 | 1,41 | -,30 | 1,50 | 66 | 1,53 |
| S | 0 | 1,10 | 64 | 1,10 | -,20 | 1,40 | 73 | 1,41 | -,20 | 1,50 | 66 | 1,51 |
| T | 0 | 1,10 | 64 | 1,10 | -,20 | 1,40 | 73 | 1,41 | -,20 | 1,50 | 66 | 1,51 |
| N | 0 | 1,10 | 64 | 1,10 | -,20 | 1,40 | 73 | 1,41 | -,20 | 1,50 | 66 | 1,51 |
| I | ,10 | 1,20 | 64 | 1,20 | -,10 | 1,50 | 73 | 1,50 | -,20 | 1,60 | 66 | 1,61 |
| R | 0 | 1,20 | 64 | 1,20 | -,20 | 1,50 | 73 | 1,51 | -,20 | 1,70 | 66 | 1,71 |

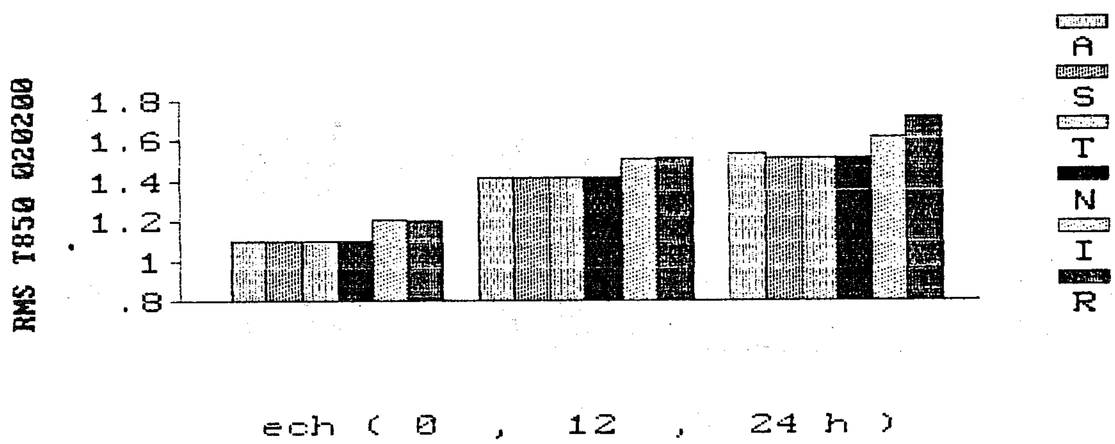



Figure 12:

Verification of the T850 forecasts from 02/02 00UTC with TEMP data. (1 complete table + 1 RMS histogram).
(in the table : B = bias, S = standard deviation , N = nbre of comparaisons, R = RMS) unity = K

| | Zsurf 0 | Z850 0 | Z500 0 | Z200 0 | Tsurf 0 | T850 0 | T500 0 | T200 0 |
|---|---|---|---|---|---|---|---|---|
| A | 8,77 | 7,74 | 9,99 | 31,98 | 2,26 | 1,21 | ,51 | 2,63 |
| S | 8,75 | 7,39 | 9,75 | 32,39 | 2,24 | 1,21 | ,56 | 2,67 |
| T | 8,46 | 7,69 | 10,07 | 32,34 | 2,24 | 1,27 | ,56 | 2,75 |
| N | 8,63 | 7,38 | 10,35 | 32,83 | 2,25 | 1,27 | ,57 | 2,82 |
| I | 8,80 | 7,49 | 10,49 | 31,29 | 2,26 | 1,32 | ,56 | 2,63 |
| R | 8,78 | 7,78 | 10,04 | 31,87 | 2,28 | 1,26 | ,56 | 2,63 |

| | Zsurf 6 | Z850 6 | Z500 6 | Z200 6 | Tsurf 6 | T850 6 | T500 6 | T200 6 |
|---|---|---|---|---|---|---|---|---|
| A | 12,23 | 10,61 | 16,03 | 31,95 | . | 1,64 | 1,08 | 3,02 |
| S | 12,08 | 10,73 | 15,42 | 33,01 | . | 1,65 | 1,08 | 3,29 |
| T | 12,24 | 10,70 | 15,40 | 32,27 | . | 1,61 | 1,03 | 3,74 |
| N | 12,33 | 11 | 15,63 | 34,38 | . | 1,60 | 1.06 | 3,68 |
| I | 12,16 | 10,73 | 15,94 | 33,83 | . | 1,68 | 1,06 | 3,40 |
| R | 12,07 | 10,78 | 16,05 | 32,12 | . | 1,64 | 1,09 | 3,04 |

| | Zsurf 12 | Z850 12 | Z500 12 | Z200 12 | Tsurf 12 | T850 12 | T500 12 | T200 12 |
|---|---|---|---|---|---|---|---|---|
| A | 12,79 | 11,74 | 16,03 | 31,43 | 3,67 | 1,56 | 1,15 | 3,75 |
| S | 13,11 | 11,93 | 15,49 | 32,69 | 3,66 | 1,56 | 1,19 | 3,93 |
| T | 13,08 | 11,94 | 15,09 | 32,96 | 3,64 | 1,51 | 1,18 | 4,17 |
| N | 13,36 | 11,95 | 15,37 | 34,24 | 3,64 | 1,51 | 1,19 | 4,28 |
| I | 13,31 | 12,34 | 16,52 | 34,75 | 3,65 | 1,60 | 1,18 | 3,99 |
| R | 12,75 | 11,73 | 15,98 | 31,79 | 3,67 | 1,61 | 1,19 | 3,85 |

| | Zsurf 24 | Z850 24 | Z500 24 | Z200 24 | Tsurf 24 | T850 24 | T500 24 | T200 24 |
|---|---|---|---|---|---|---|---|---|
| A | 13,69 | 13,40 | 19,86 | 33,24 | 3,68 | 1,59 | 1,38 | 3,91 |
| S | 14,71 | 13,40 | 19,77 | 33,53 | 3,67 | 1,57 | 1,38 | 4,06 |
| T | 14,51 | 13,40 | 19,40 | 33,67 | 3,65 | 1,53 | 1,38 | 4,19 |
| N | 15,04 | 13,40 | 19,32 | 34,42 | 3,65 | 1,52 | 1,38 | 4,28 |
| I | 14,32 | 13,40 | 20,47 | 34,66 | 3,69 | 1,62 | 1,38 | 4,08 |
| R | 13,90 | 13,40 | 19,88 | 33,77 | 3,68 | 1,67 | 1,38 | 4,06 |

Figure 13 :

RMS of the different tested fields against observations at different ranges for the 6 experiments. Results at ranges 0,12,24 h are the synthesis of cases from 0102 12 UTC and 0202 00 UTC; those at 6h come from the study of the assimilation cycle.

unities : mgp and K

*"Bad scores".*

| | P surf | Z 850 | Z 500 | Z 200 |
|---|---|---|---|---|
| Analysis | . | . | I/N | . |
| 6h forecast | . | N | . | N/I |
| 12h forecast | N/I | I | I | N/I |
| 24h forecast | N/S | N | I | . |

| | T surf | T 850 | T 500 | T 200 |
|---|---|---|---|---|
| Analysis | . | . | . | N/T |
| 6h forecast | . | . | . | T/N |
| 12h forecast | . | I/R | . | N/T |
| 24h forecast | . | R | . | N/T |

Globally, we observe a positive impact of "T" and "N" on temperature at 850 hPa, but these two experiments are also the worst ones at 200 hPa. For geopotential height, there is a positive impact of "T" and "N" at 500 hPa, in good agreement with the positive impact on temperature at 850 hPa, but "N" gives also a negative impact in the lower levels and at 200 hPa. The most deceiving result is that "I" looks bad or mediocre at all levels.

## 5.2 Verification against analyses

We computed scores of forecast against the analysis. It was impossible to choose a priori one analysis to compute the scores, because it would have given an advantage to the forecast issued from this analysis. So, as it is classical, we computed cross-scores between all the forecasts and all the analyses.

### 5.2.1 Results for 1st February 1987, 12 UTC (fig.14)

RMS differences between analysed temperature, forecasted temperatures at 12 hours, forecasted temperatures at 24 hours and analysed temperatures, for all the experiments, are shown. Results are displayed for the 9th level of the PERIDOT model, which is near 850 hPa. The "reference" analyses are on the horizontal entry of the tables, the analyses or forecasts to be compared are on the vertical entry. There is also an additional column, giving the mean score of a forecast against all the analyses, and an additional line, giving the mean score of all the forecasts against one analysis.

ANALYSIS OF THE 1ST FEBRUARY 87 AT 12UTC.
LEVEL 9

| \Ana<br>Ana\ | A | S | T | N | I | R | average |
|---|---|---|---|---|---|---|---|
| A | 0 | ,39 | ,64 | ,72 | ,63 | ,25 | ,61 |
| S | ,39 | 0 | ,56 | ,66 | ,65 | ,42 | ,60 |
| T | ,64 | ,56 | 0 | ,58 | ,74 | ,63 | ,69 |
| N | ,72 | ,66 | ,58 | 0 | ,68 | ,72 | ,74 |
| I | ,63 | ,65 | ,74 | ,68 | 0 | ,59 | ,72 |
| R | ,25 | ,42 | ,63 | ,72 | ,59 | 0 | ,60 |
| average | ,61 | ,60 | ,69 | ,74 | ,72 | ,60 | |

12 H FORECASTS FROM THE 1ST FEBRUARY 87 AT 12 UTC.
LEVEL 9

| \Ana<br>Fore\ | A | S | T | N | I | R | average |
|---|---|---|---|---|---|---|---|
| A | ,85 | ,89 | ,99 | 1,06 | ,91 | ,86 | ,93 |
| S | ,84 | ,85 | ,96 | 1,02 | ,89 | ,85 | ,90 |
| T | ,85 | ,87 | ,92 | 1,01 | ,89 | ,85 | ,90 |
| N | ,80 | ,81 | ,87 | ,93 | ,84 | ,80 | ,84 |
| I | ,91 | ,95 | 1,02 | 1,10 | ,88 | ,91 | ,96 |
| R | ,87 | ,91 | 1 | 1,09 | ,92 | ,86 | ,95 |
| average | ,85 | ,88 | ,96 | 1,04 | ,89 | ,86 | |

24 H FORECASTS FROM THE 1ST FEBRUARY 87 AT 12 UTC.
LEVEL 9

| \Ana<br>Fore\ | A | S | T | N | I | R | average |
|---|---|---|---|---|---|---|---|
| A | ,88 | ,90 | ,96 | 1,03 | ,96 | ,90 | ,94 |
| S | ,84 | ,85 | ,92 | 1 | ,89 | ,85 | ,89 |
| T | ,81 | ,82 | ,88 | ,98 | ,90 | ,82 | ,87 |
| N | ,80 | ,82 | ,89 | ,97 | ,90 | ,81 | ,87 |
| I | ,89 | ,91 | ,98 | 1,05 | ,91 | ,90 | ,94 |
| R | ,88 | ,89 | ,97 | 1,04 | ,95 | ,89 | ,94 |
| average | ,85 | ,87 | ,93 | 1,01 | ,92 | ,86 | |

Figure 14 :

Cross RMS on the forecasts temperature differences from 0102 12 UTC at σ9 between all experiments at ranges 0,12 and 24h and all the analysis of every experiments.

unity : K

When looking in each column which forecast produces the best score, "N" is always the first one, at 12 hours range as well as at 24 hours range. It is followed by "T" and "S", while "I" often produces the worst scores. Values for "A" and "R" are near the mean. Besides, when comparing scores on each line, the highest values are obtained against the "N" analyses. This is not contradictory and it is a consequence of the impact of satellite ta. For all cases, the model forecasts are further from the "N" analyses; it has been seen in paragraph 4 that satellite data influence analyses in the medium levels (850 to 500 hPa), although their impact can be damped during the forecast, due to boundary conditions for example.

Thus, we can conclude to a positive impact of NESDIS soundings for mid-levels, increasing with respect to their resolution. Radiances give a negligible impact. On the other hand, results obtained for "I" compared to "N" and "T" are difficult to explain.

### 5.2.2 Results for 2nd February 1987, 0 UTC (fig.15)

Results are presented under the same format. At 12 hours range, results are less clear than for 1st February 1987, 12 UTC. The impact of NESDIS soundings and of radiances is very feeble, but results for "I" still look bad. At 24 hours range, "N" becomes the best in all cases, "I" becomes equivalent to other configurations, "T", "S" and "R" show nearly no impact. The highest scores are again obtained against the "N" analyses. For this date, we cannot conclude to a clear impact; there is only a preconceived favourable to "N".

## 5.3 Synoptic verifications

As it has been done previously for the analyses, maps of differences between the various forecasts and the "A" forecasts have been drawn. Usually, the amplitude of differences decreases during the forecast. This can be explained by the effect of boundary conditions, which are identical for all the runs and which influence a large part of the domain in 24 hours.

The comparison with plotted maps is very difficult, especially because the frontal system is over sea. There is no very interesting phenomena to forecast: the period has been chosen regardless of any meteorological interest, but only because some data were available. Nevertheless, the impact of satellite data seems to be detrimental on lower levels, as it was already seen on the analyses. As an example of a slight positive impact, we show rainfall differences maps for the case of 1st February 1987,12 UTC. Forecasted rainfall is one of the most sensitive parameter of the PERIDOT system.

The rain system associated to the Atlantic depression is first located over sea where few observations are available. It reaches coasts during the night from 1 to 2 February, and heavy precipitations are observed over Cornwalls, Brittany and

ANALYSIS OF THE 2ND FEBRUARY 87 AT 00 UTC.
LEVEL 9

| \Ana<br>Ana\ | A | S | T | N | I | R | average |
|---|---|---|---|---|---|---|---|
| A | 0 | ,28 | ,43 | ,60 | ,42 | ,25 | ,45 |
| S | ,28 | 0 | ,42 | ,57 | ,44 | ,34 | ,46 |
| T | ,43 | ,42 | 0 | ,49 | ,48 | ,47 | ,50 |
| N | ,60 | ,57 | ,49 | 0 | ,56 | ,61 | ,62 |
| I | ,42 | ,44 | ,48 | ,56 | 0 | ,45 | ,52 |
| R | ,25 | ,34 | ,47 | ,61 | ,45 | 0 | ,48 |
| average | ,45 | ,46 | ,50 | ,62 | ,52 | ,48 | |

12 H FORECASTS FROM THE 2ND FEBRUARY 87 AT 00 UTC.
LEVEL 9

| \Ana<br>Fore\ | A | S | T | N | I | R | average |
|---|---|---|---|---|---|---|---|
| A | ,72 | ,75 | ,83 | ,92 | ,86 | ,73 | ,81 |
| S | ,72 | ,73 | ,82 | ,90 | ,83 | ,73 | ,79 |
| T | ,74 | ,75 | ,81 | ,90 | ,85 | ,73 | ,80 |
| N | ,76 | ,76 | ,81 | ,84 | ,82 | ,75 | ,79 |
| I | ,78 | ,79 | ,87 | ,94 | ,82 | ,78 | ,83 |
| R | ,73 | ,75 | ,84 | ,92 | ,87 | ,72 | ,81 |
| average | ,74 | ,76 | ,83 | ,90 | ,84 | ,74 | |

24 H FORECASTS FROM THE 2ND FEBRUARY 87 AT 00 UTC.
LEVEL 9

| \Ana<br>Fore\ | A | S | T | N | I | R | average |
|---|---|---|---|---|---|---|---|
| A | ,82 | ,81 | ,86 | ,92 | ,89 | ,84 | ,86 |
| S | ,82 | ,82 | ,86 | ,91 | ,88 | ,84 | ,86 |
| T | ,81 | ,80 | ,85 | ,91 | ,87 | ,83 | ,85 |
| N | ,79 | ,78 | ,82 | ,87 | ,84 | ,80 | ,82 |
| I | ,84 | ,83 | ,87 | ,93 | ,88 | ,85 | ,87 |
| R | ,83 | ,83 | ,88 | ,93 | ,91 | ,84 | ,87 |
| average | ,82 | ,81 | ,86 | ,91 | ,88 | ,83 | |

Figure 15 :

Cross RMS on the forecasts temperature differences from 0202 00 UTC at o9 between all experiments at ranges 0,12 and 24h and all the analysis of every experiments.

unity : K

Portugal at 0 UTC. As the PERIDOT model usually underforecasts rainfalls, an increase in the rainfall can be considered as a positive impact. Figure 16 shows the diferences between rainfall forecasts for the period 18-0 UTC. There is a trend to increase the rainfalls with satellite data over the western end of Brittany ("S-A"), over the English Chanel ("T-A") and over Wales ("N-A"), but to decrease them over the Bay of Biscay and near Corona. The comparison "R-A" shows a phase lead of the rain system in "R": this is positive, as it is late in "A", where it has not reached the coasts at 0 UTC.

Between 18 and 24 hours range (period 6-12 UTC, see figure 17), the amplitude of differences has a little decreased but the previous remarks are still valuable. The trend to underestimation over the Bay of Biscay is less visible, while the improvement over the northern half of France is stronger. There is a better description of the system in intensity (stronger) as well as in location (more in advance) in all the experiments with satellite data.

### 5.4 Conclusion on the impact on forecasts

There is indication of a positive impact of NESDIS profiles on mid-levels and on rainfall; the same data seem to have a negative impact on lower levels. It must be stressed that the boundary conditions, coming from operational ECMWF analyses which use routinely NESDIS 250 km soundings, are more consistent with our experiments using NESDIS products and can favour them.

Results are less favourable to 3I data at all levels. Radiances have a small impact, which can be detected on rainfall.

## 6 CONCLUSIONS

### 6.1 Conclusion on the PERIDOT system

If we suppose that there is some information in the satellite data, we can be deceived by the use of this information in our system. Several weaknesses can be pointed out:

- first, these data are not used for the surface pressure analysis. The consequence is that the vertical localisation of the sigma levels does not take into account this information.

- another weakness stays around 200 hPa. Satellite data themselves are of poor quality at this level, but the PERIDOT system too. It comes from the fact that there are too few levels in the analysis and in the model: hence a large error on the guess values at these levels, and especially on the extrapolation up to 1 hPa which is necessary to compute synthetic radiances.

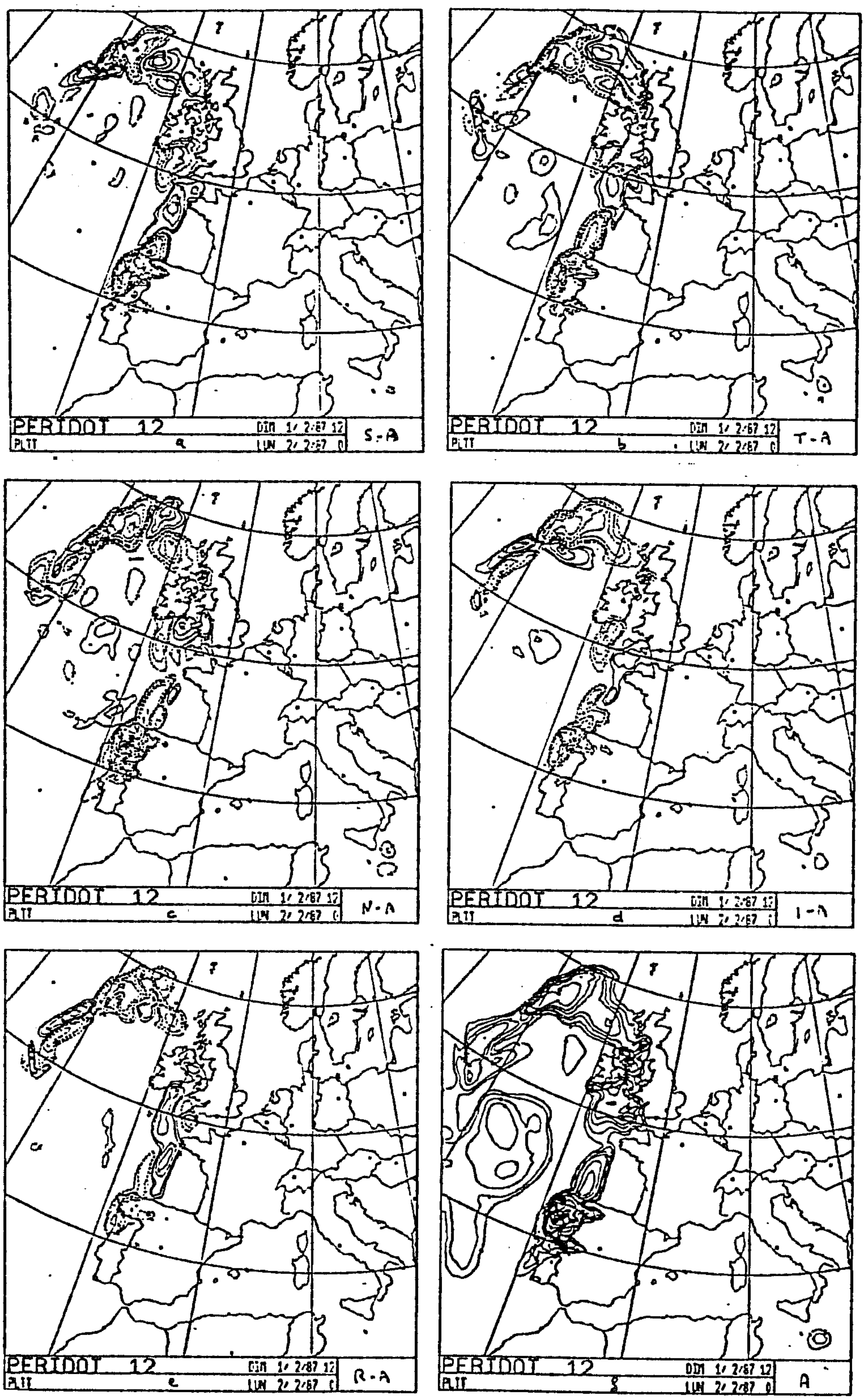



Figure 16:

Maps of differences between rainfalls 6-12h forecasts in the different experiments (maps: a=S-A, b=T-A, c=N-A, d=I-A, e=R-A) issued from 1/2 12UTC and the corresponding forecast in the experiment "A" (map f).
(unity : mm/6h, interline=2 mm, reference=0 mm, val <0 dashed)

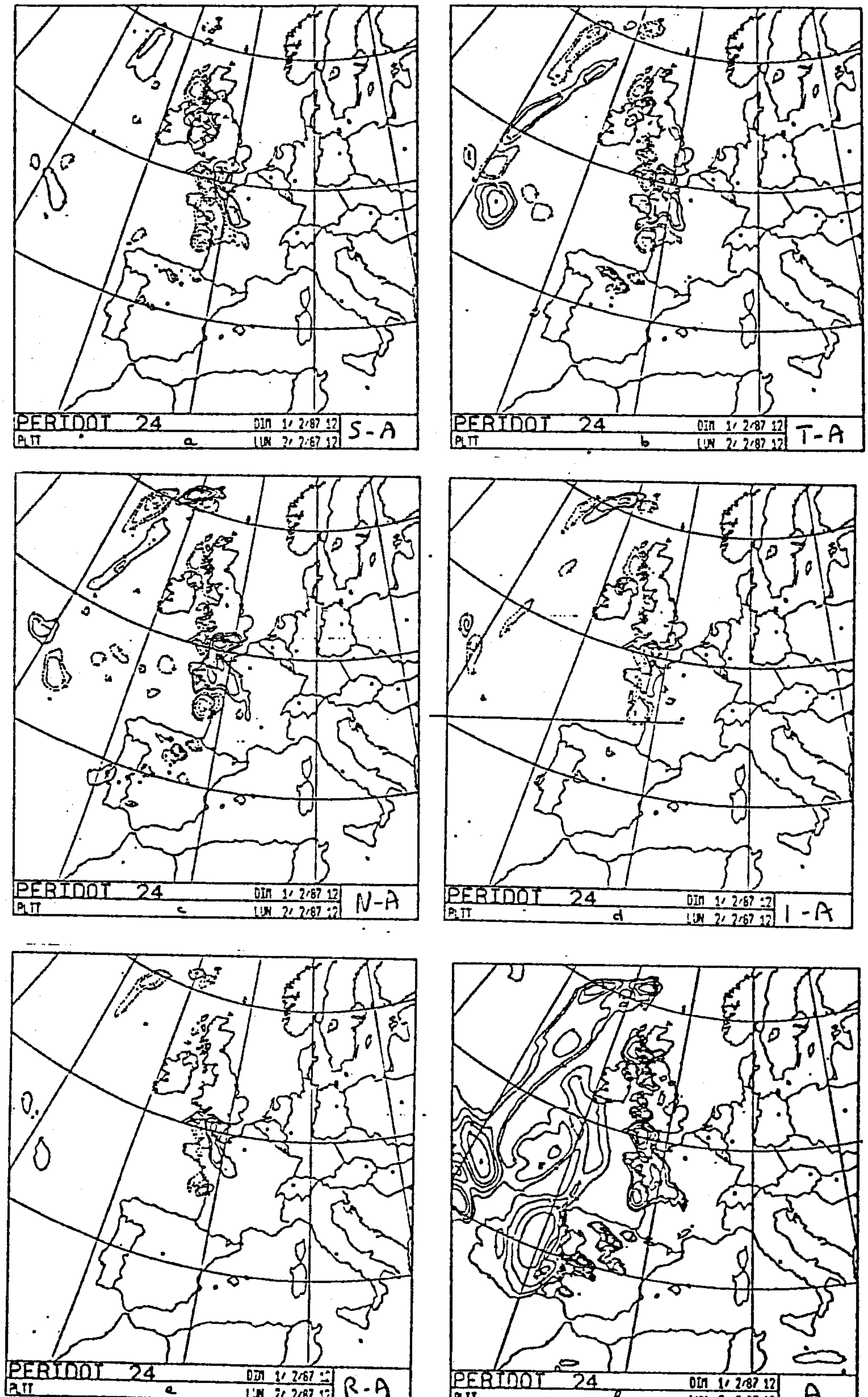



Figure 17:

Maps of differences between rainfalls 18-24h forecasts in the different experiments (maps: a=S-A, b=T-A, c=N-A, d=I-A, e=R-A) issued from 1/2 12UTC and the corresponding forecast in the experiment "A" (map f).
(unity : mm/6h, interline=2 mm, reference=0 mm, val <0 dashed)

- the statistical model is rather crude and does not depend on the meteorological situation. The modelisation of the vertical correlation of the error of geopotential height have some defaults when differentiating it. Linearity hypotheses that are made in the use of radiances are a large constraint and can occult the impact of these data.

- the 6-hour cycling that has been used in this impact study can meet a spin-up problem in the forecast model. That is what comes out of a recent comparison between 6-hour and 12-hour cycling with the PERIDOT system.

## 6.2 Conclusion on the impact of satellite data

All the results that we obtained lead to the conclusion that the system is rather insensitive to the direct use of cleared radiances as they were available for this study. These data do have an impact on the analysis, but it rapidly vanishes during the forecast and the scores for "R" are rather similar to the scores for "A", even at the levels where the other experiments prove some weaknesses (200 hPa). Though, other studies (see Durand,1985 or Juvanon du Vachat,1988) show that for some situations there is a positive impact on the PERIDOT forecasts, especially on physical terms. We have an example of a slight impact here with the precipitations on 1st February. We recall that the soundings of cleared radiances were not complete, especially in the lower levels; operationally, we use complete raw radiances together with a cloudiness diagnostic.

We did not succeed in drawing information out of experiment "I". The study of the assimilation cycles show that something happened around 1st February 1987, 0 UTC, producing mediocre results, often worse than without satellite data. It is the only experiment that does not produce a positive impact on geopotentiel height at 500 hPa. Other evaluations seem to be necessary for these data.

The results obtained with SATEMs are all compatible, those with "S" (500 km SATEMs) being damped due to the number of data. Apart from the results at 200 hPa, there are some positive elements in the results for "T"(250 km) and for "N"(80 km), especially around 850-500 hPa. Near the ground, the impact is rather negative, but rainfall forecasts seem to be better. The bad results obtained in the lower levels may come from the low quality of the MSU of NOAA-9 at this time; it totally failed out one month later.

Anyway, the PERIDOT system proved to be sensitive to satellite data, and sometimes successfully. So there is some useful information to be treated. It will be necessary in the future to obtain the positive impact at all levels and for all cases.

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