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An Investigation of the Parameters used in the Analysis Scheme of the Mesoscale Model

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Abstract

This report describes results of a study of the analysis scheme used in the generation of the initial fields for the mesoscale model: a two-dimensional Recursive Filter, which approximates a Gaussian smoothing of the data. The study was carried out to investigate ways in which the scheme might be improved. Particular emphasis was placed on trying to increase the spread of information from sparse observations over the sea to produce smoother analyses, whilst maintaining the detail provided by the dense observation network over land. Ultimately, it is hoped that this work can also be used to improve the cloud analysis. The study solely considers the analysis of mean sea level pressure, and uses two different cases.

It is found that the area of influence of the observations can be most easily increased by reducing the background weighting; a relaxation of the tolerance (background minus observation acceptance) can also assist the fit to observations over the sea area, which may be significantly different to the background field. A smoother analysis can be achieved by increasing the smoothing radius, either by increasing the half-width of the Gaussian or by increasing an empirical scaling factor which describes the "flatness" of the Gaussian; an alternative would be to analyse the variable rather than observation-minus-background increments, but this would require the addition of a quality control procedure, and the analysis would remove small-scale detail present in the background field.

1 Introduction

One of the great difficulties in the mesoscale model is the lack of observational data. While the model gridpoints are 15 kilometres apart horizontally, the resolution of the observation network is of the order of 50 kilometres at best (i.e. over land), and is far greater over the sea. For example, in the model, the North Sea covers well over 1000 gridpoints; on a good day, observations from perhaps 10 locations in this area will be available. Over the Atlantic, the problem is worse: within the model area, there are no observations available regularly over the Atlantic.

For this reason, the Interactive Mesoscale Initialisation (IMI) (Wright and Golding 1990) was developed to try and make the best possible use of the limited data available. The philosophy behind the development of the IMI was that conventional upper air data, e.g. radiosondes, were at too coarse a horizontal resolution, approximately 300 km, to make a fine resolution traditional 3D (or 4D) analysis system worthwhile and that the large scale balance equations, e.g. geostrophy, may not be appropriate. Therefore, effort was concentrated on the use of surface synoptic observations, which approach the required resolution, and radar and satellite imagery to adjust the very short period forecast fields from the Mesoscale and Limited-Area Models.

The first stage of this adjustment process is to produce two dimensional analyses of observed variables (mean sea level pressure, 10 m wind, precipitation rate, total cloud cover, cloud base height, cloud amount on model levels, visibility, snow depth, screen temperature and dew point temperature) using a "hybrid" of the Mesoscale and Limited-Area Model forecasts or a field derived from the radar or satellite imagery (in the case of the precipitation rate and cloud cover) as a first guess. This analysis stage can be run automatically, but it has been designed for "interactive" use. It was originally felt that traditional quality control procedures could not be used with high resolution analyses as there may be "true" large differences between adjacent observations (due to land/sea boundaries, edges of cloud sheets, fronts, orographic height changes etc) or between observations and the first guess fields (due to forecast errors) that need to be retained in the final analysis. Therefore, the observations are not quality-controlled before use in the analyses and manual intervention is used to allow the forecaster to decide whether an observation should be rejected or reinforced by modifying the first guess or analysis field. The use of manual intervention was also to allow the forecaster to use indirect observations to modify analyses in data sparse areas, such as the North Sea and the Atlantic Ocean, to include mesoscale features such as polar lows, sharp troughs, temperature gradients etc; for example the radar or satellite imagery could be used to adjust the mean sea level pressure analysis.

However, there is now increasing pressure to produce a fully automatic system, which can provide analyses, both for use in the production of initial conditions for the Mesoscale Model, and for provision to outstations for use in their own right. Therefore, it is timely to review the performance of the 2D analysis scheme to see whether it can be tuned or developed further to give automatic analyses that do not require manual adjustment.

It has been found that sparseness of observations over the sea areas can result in bulls eyes in the automatic analyses where the observations are very different from the background (first guess) fields. If the observations are correct, it is evident that the radius of influence of the observations needs to be increased to spread the impact of the observations over a wider area and produce smoother analyses. However, on occasions these are erroneous observations and the scheme needs to be extended to include automatic quality control of observations.

It is also felt that the analysis of cloud cover on model levels needs to be improved. The density of cloud cover and cloud base observations is less than that of other variables, partly due to the introduction of automatic weather stations, but also because of the variation of cloud base (actual and reported) between stations, which means that there are only a few observations at any given level; if the radius of influence of the individual cloud observations is too small, this can result in a patchy cloud analysis, rather that a continuous cloud deck.

The aim of this project was to develop a program that would allow the sensitivity of the analysis scheme to various tunable parameters to be tested outside the IMI. This paper reports on the results of those sensitivity studies for mean sea level pressure; section 2 describes the analysis scheme, section 3 reports on the various analysis experiments and section 4 summarises the conclusions and suggests aspects of the analysis scheme which require further investigation.

2 The analysis scheme

The analysis scheme uses a recursive filter spread the information from the observations (Purser and McQuigg 1982A, Hayden and Purser 1986). This section briefly outlines the analysis scheme and is based on the more detailed description given in the Mesoscale Model documentation (Purser and McQuigg 1982B); at more than one point, the documentation is in conflict with what the operational code actually does, in these cases, the description follows the operational code.

There are a number of options in the analysis scheme, which allow it to be adjusted to take account of the characteristics of the different variables. One option in the analysis is whether to analyse the value of the observation itself, or the difference between the observation and the first guess field interpolated to the observation point. For the first case, the variable IANL is set to zero, and for the second, IANL=1. Generally, the observation itself is used if the analysed field is expected to be reasonably smooth, as for the visibility field. If the field is expected to change sharply (e.g. temperature, at fronts, and at fixed topographic boundaries, such as coast lines), then the differences are analysed. This prevents sharp gradients from being smoothed out in the "smearing" process. (The basic operation of the analysis scheme can be divided into two parts. The observations are added into the hybrid background field, and then the resulting field is smoothed by smearing out the information. Together, these two processes constitute one "scan" through the data.)

A number of scans is performed, with each scan beginning with some initialisation. Each gridpoint is assigned both an initial value stored in the array ANLWK, and a background weight, stored in the array WBKGWK. The weights are modified by the observation density around points. For the analysis of observations-minus-background (O-B), the values are initially set to zero. For the analysis of the variable itself (O), each initial gridpoint value in ANLWK is the product of the value from the first guess field, and the background weight at that point.

Each observation is then assigned a weight, using the procedure described below. The analysed quantity (either O or O-B) is multiplied by this weight, and the product divided among the four nearest gridpoints, using bilinear interpolation, with the largest fraction going to the closest point. Each fraction is added to the existing value of ANLWK at the gridpoint. In a similar way, the observation weight is itself divided among the four gridpoints, with the resulting fractions being added to the existing gridpoint weights in WBKGWK.

The process described above is repeated for each observation. Once this has been done, we desire that the change produced by each observation be smeared out to influence the surrounding area and create a smooth field. In the mesoscale model analysis scheme, this is done using recursive numerical filters: in essence, this method spreads each change out over a Gaussian distribution centred on the observation producing the change. (In actual fact, the filter only provides an approximation to this distribution. For a fuller description of the working of the filter, see Purser and McQuigg 1982B.) In the model, both the field of weighted observations, ANLWK, and the field of gridpoint weights, WBKGWK, are smoothed in the same way, ensuring that consistency between the fields is maintained, and allowing one field to be divided into the other.

The standard deviation of the Gaussian, which is the characteristic smoothing radius, is determined by the data themselves. This radius is calculated, at each gridpoint, as:

$$\mathrm{RANGE}\ (i,j) \ = \ \frac{\mathrm{RF}}{\sqrt{\mathrm{W}(i,j)}} \qquad (1)$$

although it is then constrained to lie between the current values of RMIN and RMAX. RF reflects the shape of the Gaussian (the larger the value the flatter the Gaussian), and is an empirical factor which is set once, and remains unchanged throughout the analysis. W(i,j) is the gridpoint weight. The reasoning behind the method is that for large weights (i.e. high observation density), a small radius of influence is desired, whereas for low gridpoint weights (i.e. sparse observations), the observations must be allowed to influence a wide area.

Since we do not wish to use a field of weights which has not yet been smoothed, the smoothing itself relies on gridpoint weights calculated for the previous smoothing operation. For the smoothing performed on the first scan, the initial field of uniform background weights is used.

The analysed values ANLWK are divided by the corresponding gridpoint weights at each point to give the analysis value (either O or O-B). If the analysis is of the differences between observations and background, one final operation is needed to complete a scan. The increments calculated during the scan are added back on to the first guess field, and the working array which held these increments is reset to zero at the start of the next scan.

Smoothing radius

In the calculation of smoothing radii, the radius at each gridpoint is constrained to lie between the current values of RMIN and RMAX. According to the model documentation (Purser and McQuigg 1982B), RMAX remains constant, while RMIN decreases in a geometric sequence, from its starting value, towards the limit RLIM. This behavior is controlled by RINC: the minimum radius allowed for the n^{th} scan ($n = 1,2,\ldots$) is:

$$RMIN = RLIM + RINC^{n-1}(RMAX-RLIM) \qquad (2)$$

However, in the operational code, although RMAX does indeed remain fixed, RMIN starts at, and remains fixed at, the value of RLIM; RINC, although defined, is ignored. This difference is the subject of one of the investigations described later.

Observation weights

If the analysis is performed with IANL=1 (analyse differences), each observation weight depends both on the difference between the observation (O) and the background field interpolated to that point (B), and on a tolerance factor, TOL. This tolerance is applied uniformly over all gridpoints, and is decreased between scans; it provides a measure of how far different the observation must be from the background field before being effectively rejected. The weight, W, is calculated as:

$$W = \frac{1}{1 + \left((O-B)/TOL\right)^4} \tag{3}$$

If |O-B| is large compared with the tolerance, the observation weight is correspondingly low (i.e. much less than 1).

In starting with a large tolerance, we allow for the possibility of the first guess being far from the truth, and hence far from the observations. After the first scan, the background field should be much closer to the observations, and we therefore reduce the tolerance. In this way, we hope to reduce the influence of observations which are inaccurate or plainly wrong. In one case examined in detail, ØØZ 8th December, one observation of mean sea level pressure of 998 mb is recorded as 1Ø98 mb. This sort of error must not be allowed to influence the analysis. Analyses run interactively should not have this problem, as the observation is drawn to the attention of the forecaster, and can be removed or corrected interactively. However, analyses run in batch must be able to deal with the problem, and assign negligible weights to such observations. The erroneous observation was not removed or corrected for the experiments discussed in this paper.

For analyses with IANL=Ø (analyse the actual value), the O-B in the denominator of equation 3 becomes O (the values of the observation). Since the tolerance factor, TOL, can no longer be used to quality control the observations, it is given a value of one million, with the result that all the observation weights become extremely close to 1. (For the 8th December case, this creates a major problem: the automatic analysis produces a very compact, very intense high pressure area around the observation, which would disrupt the forecast.) In fact, quality control can still be applied when using observation values, and this is discussed later.

3 Experiments performed

The initial experiments all used analyses of mean sea level pressure (pmsl) for midnight (ØØZ) on 8th December 199Ø. Most of the changes were to the parameters used in the ANAL2 / ANALYS / SMEAR subprograms, although other modifications, such as the use of different grid point weights over land and sea, were considered. The effect of varying the following parameters (some of which are explained in greater detail later) is investigated for the pmsl analysis; their operational values are given for reference (appendix A shows the values used operationally for other variables):

NSCAN	3	(number of scans through data)
NSMOO	2	(number of smoothing sweeps in smear process)
IANL	1	(analyse difference from first guess)
IEDGE	Ø	(use edge point values in smear)
ICHRAD	Ø	(fixed minimum smoothing radius)
RF	Ø·8	
RMAX	7	(gridlengths)
RLIM	1	(gridlengths)
RINC	Ø·5	
TOLMAX	4	(mb)
TOLMIN	Ø·1	(mb)
TOLINC	Ø·5	
WBKG	Ø·Ø4	

N.B. RLIM is known as RMIN in the operational code

The model documentation claims that the minimum smoothing radius used should decrease between scans, although this is not actually implemented in the operational code. To allow for this, the variable ICHRAD is introduced.

ICHRAD=Ø is equivalent to having the fixed minimum smoothing radius (RMIN) used operationally. ICHRAD=1 brings in the variable minimum smoothing radius, which with successive scans tends towards the limit RLIM. Although the variables RMIN (in the operational code) and RLIM (in the code as documented) have differing names, they are treated here as corresponding to one another.

In order to run individual analyses, the subprograms ANAL2, ANALYS, and SMEAR were extracted, and combined with a control program written separately. This allows values of all the above parameters to be read in from a dataset, without the need to recompile the program. Other input is taken from standard hybrid and observation datasets, and output is written to an analysis dataset, which is examined using the Mesoscale Graphics Facility (from which all diagrams in this report have been output). In the heading for each experiment described below, the variable given in brackets is the main subject of that experiment. In addition to the figures referred to here, the hybrid pmsl field, and the pressure observations for each of the two cases considered are included, for reference, as figures 34 to 37.

Expt. 1 (ICHRAD)

The first experiment is a comparison of the analyses produced with ICHRAD=Ø (as used operationally) and ICHRAD=1 (i.e. a variable minimum smoothing radius). The pressure contours from these analyses are shown together on figure 1. Although there is not much difference between the two, setting ICHRAD=1 does eliminate two kinks: one in the 1Ø18 mb contour north of Stornoway, and one in the 1ØØ2 mb contour off the North Wales coast. Both of these features are slightly dubious - certainly the one off Stornoway is affected by a suspect observation. Smoothing out this feature certainly seems desirable. For this reason, all subsequent analyses are run with ICHRAD=1.

Throughout the rest of this report, the term "standard" analysis refers to an analysis with ICHRAD=1, and all other parameters set to their operational values. If in any experiment, a value is not given for a parameter, then the "standard" value has been used. If an analysis is referred to as standard, but with a different value given for a particular parameter, then this new value is used in place of the standard value.

Expt. 2 (NSCAN)

A selection of values of NSCAN are tried with ICHRAD=1: 2, 3 (the standard) and 4 (see figure 2). Over the whole domain, the effect of increasing NSCAN is much the same: it pushes the contours closer to observations, but at the expense of losing some of the smoothness of the analysis. This problem is prevalent throughout the investigation - contours can either be smooth, or be brought close to the observations, but rarely are both achieved. This is particularly evident in the North Sea, where the sparsity of observations often means that it is desirable for observations to influence analysis over a wide area. However, "knobbles" are produced near observations (such as the one on the 998 mb contour between the Wash and the Netherlands. When RF is increased, in an attempt to smooth these features, the contours do not come as close to the observations.

In many locations, the modification produced by increasing NSCAN tends to be greater for the change from NSCAN=2 to NSCAN=3, than for the change from NSCAN=3 to NSCAN=4. Even in the limited number of places where increasing NSCAN from 3 to 4 had visible effect, this effect was not great. This may be a consequence of the additional scans being carried out with smaller and smaller influence radii (see equation 1). Increasing RINC as well as NSCAN might produce a greater impact. It was thought that values as high as 6 might be required for NSCAN to show any significant difference from the operational value of 3; these two values were adopted for subsequent experiments.

Expt. 3 (RMAX)

The smoothing radius which is used at any point (i,j) is given by:

$$\mathrm{RANGEW} = \begin{cases} \mathrm{RMIN} & \text{for } W(i,j) > (\mathrm{RF}/\mathrm{RMIN})^2 \\ \dfrac{\mathrm{RF}}{\sqrt{W(i,j)}} & \text{for } (\mathrm{RF}/\mathrm{RMIN})^2 \geq W(i,j) > (\mathrm{RF}/\mathrm{RMAX})^2 \\ \mathrm{RMAX} & \text{for } W(i,j) \leq (\mathrm{RF}/\mathrm{RMAX})^2 \end{cases} \quad (4)$$

In this expression, it can be seen that the maximum value RANGEW can take is RMAX itself. Thus, increasing RMAX alone will have little effect: it merely provides a cut off limit, and is not otherwise used in the calculation of RANGEW. Similarly, increasing RF alone will produce larger smoothing radii, but these will simply be restricted to the value of RMAX. Instead, it is sensible to increase RF and RMAX together.

Figures 3 and 4 show RF=Ø·8, RMAX=7 and RF=2, RMAX=17·5 respectively. In each case, runs are performed with NSCAN=3 and NSCAN=6. The choice of RMAX is not entirely arbitrary; since we wish to spread information over the whole of the North Sea, which, very roughly, has a width of 35 or 40 gridlengths, RMAX should take a value of about half of this width. The analysis RF=2·0 is visibly smoother, though some further change needs to be made to bring the contours closer to observations. (There are two possible methods of achieving this: increase the tolerances used for each observation (i.e increase TOLMAX/TOLMIN), indicating greater faith in the observations; or decrease the background grid point weight, WBKG.) Before leaving these figures, note that the effect of increasing NSCAN from 3 to 6 provides much less pronounced changes for the larger value of RF, as the change is smoothed out more.

Expt. 4 (WBKG)

The parameter WBKG, the background gridpoint weighting, is investigated as suggested above; Values of of 0·01 and 0·02 are considered, and compared with the default value of 0·04 (see figure 5). It can be seen that altering WBKG has little effect over the land (The changes to the gridpoint weights induced by the change in the background weight are swamped by the contributions from the observation weights). An exception is near Rennes, in the middle of the southern edge of the grid, where two observations of 1002 mb close together have a dramatic effect on the 1002 mb contour.

Over the Atlantic, where there are no observations, the pressure analysis remains virtually the same as the first guess, no matter which analysis parameters are altered (choosing to analyse the absolute pressure rather than the pressure difference between the observations and the first guess field *does* have an effect here, and this is discussed later). Over the North Sea, where there are a limited number of observations (perhaps ten or a dozen), the effect is much more dramatic. Particularly striking are the widened range of influence of the 998 mb observation off East Anglia, and the “lumpiness” introduced into the 1006 and 1008 mb contours. However, the use of a decreased background weight does result in contours which match the observations very well, but at the expense of smoothness. By increasing RF, even the WBKG=0·01 analysis can be made reasonable (smoother). If further changes, such as an increase in TOLMAX, are introduced, then the choice of WBKG=0·01 produces a rather extreme analysis.

The particular difficulty with these analyses is that the low pressure area centred on the east coast of England should extend further north, with the pressure contours running much more north-south than they do in the first guess. The sort of sweeping change which is required to correct this deficiency is very difficult to achieve with so few observations. Another problem in this case is that the observations of 1007 mb and 1009 mb (actually 1006·5 and 1008·6 mb) lying near the 1008 mb contour in the middle of the North Sea (see figure 35) seem to be at odds with one another (possibly the 1006·5 mb value is at fault, being rather too low), and this does not aid the task of constructing a satisfactory analysis. A quality control procedure, such as a 'buddy check', might ease this problem.

Expt. 5 (TOLMAX)

The tolerance TOL is a measure of how great the difference between the observations and the first guess can be, if the observations are still to have an impact in the analysis. Thus, increasing TOLMAX should result in the observations having more influence on the analysis. For the initial scan, the tolerance is set to TOLMAX, and after each scan, it is decreased in a geometric sequence towards the limit TOLMIN. The rate of this decrease is determined by TOLINC: the tolerance used for the n^{th} scan ($n = 1,2,\ldots$) is given by:

$$\text{TOL} = \text{TOLMIN} + \text{TOLINC}^{n-1}(\text{TOLMAX}-\text{TOLMIN}) \qquad (5)$$

Increasing TOLMAX does indeed have broadly similar effects to decreasing WBKG. However, when we look closely, some differences are evident; decreasing WBKG spreads the influence of the observations over a wider area, whereas increasing TOLMAX increases the magnitude of this influence within a confined area. (A good example of this is on the 1002 mb contour on figure 6. A pair of spikes is created to the east of Edinburgh, when TOLMAX is increased from 4 mb to 8 or 12 mb. Each spike points towards a 1002 mb observation.)

Certainly, increasing TOLMAX can not serve as a substitute for decreasing WBKG; the latter has an effect over a wider area, and in a larger number of locations. However, increasing TOLMAX could usefully enhance the changes near observations, although again, greater smoothing (i.e. increasing RF) would be required.

The parameters considered so far (ICHRAD, NSCAN, RF, RMAX, WBKG, and TOLMAX), together with IANL (which is discussed later), are those which have greatest effect on the analysis. The remainder, RMIN/RLIM, RINC, TOLMIN, TOLINC and IEDGE have lesser impact, and so will only be considered briefly below.

Expt. 6 (RLIM)

Two experiments are performed with varying values of RLIM. The first using the values:

RF=Ø·8

RMAX=7

RLIM∈{1,3,5}

The second using:

RF=2·Ø

RMAX=17·5

RLIM∈{1,7}

Increasing RLIM, in the first experiment (figure 7) makes a small difference in some places, smoothing out sharp changes in the direction of the contours. This difference is even less apparent in the second experiment (figure 8), although the change in RLIM is greater (1 to 7). Indeed, the differences resulting from a change in the value of RF (comparing figure 7 and 8) are far more significant than those resulting from the changes in RMIN.

Expt. 7 (RINC)

The effect of changing RINC is also fairly small. Figure 9 shows the analyses with RINC=Ø·3, Ø·5 and Ø·7. The changes produced by varying RINC are very localised and quite small, although reducing its value does pull the contours towards observations.

Expt. 8 (TOLINC)

Figure 10 shows analyses using values of TOLINC of 0.3, 0.5 and 0.7. Increasing TOLINC, decreases the tolerance less between each scan, and has the same effect as increasing TOLMAX; it allows the observations to influence the analysis more (this is particularly evident for the the 1ØØ2 mb and 1ØØ8 mb contours). Changing TOLINC has a greater impact than changing RINC, especially over the North Sea. However, it would be desirable to have a smoother analysis.

Expt. 9 (TOLMIN)

Figure 11, shows analyses using values of TOLMIN of 1, 2 and 4. With TOLMAX=4, increasing TOLMIN from 1 to 4 only has a small effect over the Norwegian coast, the North Sea and northern England. However, the default value is Ø·1, and increasing TOLMIN from Ø·1 to 1 (cf. figure 1 earlier) has a more pronounced impact in the vicinity of the observations over the North Sea. The effect is much the same as increasing TOLINC from Ø·5 to Ø·7: the two sets of contours are very closely aligned. This is not surprising, as the values of the tolerance generated by both these options are very similar. However, with TOLMAX=8, any value of TOLMIN from 1 to 4 (figure 12), gives an analysis which is almost identical to that for TOLMAX=TOLMIN=4. This suggests that the observations are being fitted for every scan. Whether the observations are fitted for all the scans, or just the first few scans, dependents on the initial tolerance (TOLMAX) and the rate at which the tolerance falls off (TOLINC and TOLMIN). With TOLMAX=8, the rate of values of the tolerance are sufficient to fit the observations whatever the value of TOLMIN, but for TOLMAX=4 or less, TOLMIN must be also be 4 to ensure maximum fit to the observations. This suggests that the maximum possible influence is being obtained from the observations with TOLMIN=1 and TOLMAX=8, and that any further increases in either of these parameters, or indeed TOLINC, will have a negligible effect. Of course, this would not be the case if there was an observation present with a value slightly further away from the first guess field.

Expt. 10 (NSMOO)

The parameter NSMOO is the number of double smoothing sweeps made in the "smearing" process, after each scan through the data. The effect of changing NSMOO from 2 to 3 is investigated with various values of other parameters. The cases considered are the standard one, WBKG=Ø·Ø2, WBKG=Ø·Ø1, and TOLMAX=8 (figures 13, 14, 15, and 16 respectively). The last three are chosen because they are all less smooth than the standard analysis, so increasing NSMOO might be advantageous. However, in all cases, the change produced is minimal, with the greatest effect being in the WBKG=Ø·Ø1 case (figure 14). Figure 13, shows the standard set of options with three different values of NSMOO: 1, 2, and 3 (the heaviest contours are for NSMOO=3). In many places, the contours for NSMOO=2 lie indistinguishably close to NSMOO=3, although the contours for NSMOO=1 diverge. As for NSCAN, it would appear that each increase in NSMOO brings a diminishing return (the only significant difference between NSMOO=2 and NSMOO=3 occurs for the 1006 mb contour at the Norwegian coast, when WBKG=0.01). The additional smoothing obtained here appears to be at the expense of fitting the observation. This is not particularly desirable, especially since, by increasing RF, it is possible to smooth the analysis and spread information at the same time.

In addition to controlling the number of double smoothing sweeps, increasing NSMOO decreases the smoothing radius, in the operational code; this was left unchanged for the experiments discussed in this paper. This reduction of the smoothing radius may reduce the impact of using a greater number of smoothing sweeps.

IANL & IEDGE

The final two options which are examined are IANL and IEDGE. IANL is set either to Ø, to analyse the observation variable itself, or to 1 to analyse the difference between the variable and the first guess field. In the operational code, the tolerance has no real meaning for IANL=Ø, and is always set to one million (large enough to be considered infinite), which means that all observations are given a weight of 1, and thus no quality control is applied. For the 8^{th} December case, one observation is incorrectly reported (it is 1ØØ mb out), and so with no quality control, this has a catastrophic effect on the analysis (see figure 17). The next set of experiments avoid this problem by considering a different case: Ø3Z 23rd July 1991, which contains no gross errors in the observations.

Expt. 11 (IEDGE)

It is useful to consider IEDGE before looking at the IANL in detail. IEDGE is either set to Ø, to use the edge values in the smoothing process, or to 1, to exclude the edge values from the smoothing process. It should be noted, that although the edge values may be used in the smoothing process, they are not updated, and retain the same value for each scan. Four different pairs of analyses are considered: the standard analysis, WBKG=Ø·Ø2, TOLMAX=8 and NSCAN=6; each with IEDGE=0 and 1 (shown in figures 18 to 21, with the IEDGE=Ø analysis in the lighter contours). Figures 18 and 19 in particular show the benefit of using IEDGE=1: a number of features which show up as little closed contours with IEDGE=Ø are eliminated with IEDGE=1, and hence show up only as light contours. Aside from these obvious changes, the only other significant change is near the south east corner of the grid where the main section of the 1Ø16 mb contour is smoothed out.

Expt. 12 (IANL)

A comparison of analyses with IANL=Ø and IANL=1 is made, using three sets of options: the standard analysis, WBKG=0.02 and NSCAN=6 (the same as those considered in exp. 11), but all with IEDGE=1. The experiment using a different value of TOLMAX is not appropriate, because the tolerance is fixed with IANL=1. These analyses are shown in figures 22,23 and 24 (the analyses with IANL=Ø are in the heavier contours). It is evident that in each of the figures a lot of detail is lost, particularly over the land, when IANL is changed from Ø to 1. In some cases, this might be advantageous, removing spurious features which are present in the first guess field. However, a lot of the detail in the first guess pressure field which is generated by the orography (e.g. over Scotland), and might be correct, is also lost. In all cases the analyses appear very smooth indeed, and it may be that the smoothing parameters need to be adjusted, but for the options used here the failings in the analysis outweigh any benefits.

Expt. 13 (Quality control)

It is evident that with the possibility of gross errors in the observations, some form of quality control is needed within the analysis scheme. The system of tolerances provides this when analysing observation differences from the first guess (IANL=1), but there is no such provision when analysing the variable itself (IANL=Ø). However, there is no reason why it is not possible to use the difference between the observation and the background as a measure of quality (i.e. use the tolerance scheme), although the variable itself is being analysed. If this approach is introduced into the analysis scheme, and it gives each observation a weight, calculated, as before, by:

$$W = \frac{1}{1 + \left((O-B)/TOL\right)^4}$$

The new quality controlled (QC) version, with this tolerance system added, is compared with the non-controlled (NQC) analyses for three cases: the standard analysis, WBKG=Ø·Ø2, and NSCAN=6, all with IANL=Ø and IEDGE=1 (shown in figures 25 to 27). As there are no gross errors in the observations for the 23^{rd}July case, there are only a few differences between the QC and NQC analyses in each case. For the first two pairs of runs, the differences are fairly small; the most noticeable two being associated with two observations: one over Wales and one over Scotland, and both showing up in the 1Ø1Ø mb contour. In both cases, introducing the quality control reduces the amount by which the contour deviates towards the observations. Careful study of the observations shows that in each case, the deviation is produced by an isolated low observation. The deviation to the west of Wales is definitely not present in the first guess, and is probable undesirable. Here, the quality control is definitely preferable.

In the third pair of analyses, with NSCAN=6, the effect of a quality control is more evident, although it is less clear whether or not the change is an improvement. There are a number of features introduced by the larger number of scans (such as the troughing over southwest Ireland) which are removed by the quality control. Some of these may be undesirable, but others may be beneficial. For example, although the trough to the southwest of Ireland is probably not a real feature, the 1ØØØ mb contour does need to comes further southeastwards, to agree with the observations. Whether additional smoothing can achieve this is questionable, as it might remove much of the detail introduced by the observations over the land.

Thus, introducing the quality control brings mixed blessings: while allowing inaccurate observations to be rejected, it can prevent correct observations from having the necessary large effect on an inaccurate first guess field. Nevertheless, to guard against gross errors such as the 1ØØ mb error in the observation on 8^{th} December, some type of quality control is essential: the difference between the QC and NQC versions in the 8th December case is immediately apparent when comparing figures 28 and 17.

For the pressure field itself, this discussion may be somewhat academic: by analysing the observations themselves rather than the differences between observations and background, too much detail from the first guess is lost. It may be possible to retain more detail by selecting different values for the other parameters (e.g. by increasing WBKG, or decreasing RF).

Expt. 14 (IEDGE)

Previously, the effect of IEDGE was examined for some runs with IANL=1. Another set of tests was performed with IANL=Ø, with the quality control introduced. As for previous experiments, four pairs of analyses were performed: the standard analysis, WBKG=Ø·Ø2, TOLMAX=8 and NSCAN=6 (figures 29 to 32, in which the darker contours represent IEDGE=1). As would be expected, the effect of the change of IEDGE is greatest near the edge of the grid, where the contours tend to be smoothed out, as they "jerk" towards the edge of the grid. This is evident particularly on the southern ends of the 1Ø12 mb and 1Ø14 mb contours, where rather unnatural looking features are eliminated. The change of IEDGE from Ø to 1, which excludes the use of the edge points in the analysis, seems to produce a more realistic analysis at the edges of the grid. However, this may not be the best way of dealing with the edges values.

Currently, at the end of each scan, the edge points themselves are never actually updated; they are originally set equal to the Limited Area Model (LAM) values and are left untouched to retain consistency with the LAM, which supplies boundary conditions to the Mesoscale Model. It may be better to allow all gridpoints to be updated in the analysis, and then attempt to blend in the information from the LAM at the edges of the model grid, as a totally separate step.

Expt. 15 (WBKG)

Since the observation density varies dramatically from the land to the sea, it almost seems that separate analyses are required for the land and the sea. This could be attempted, but would leave the problem of blending the two to produce a sensible analysis over the coast. The only parameter which ca be varied for every gridpoint, and therefore for land and sea is the background gridpoint weighting (WBKG). This can be implemented by reading in the orographic information from the first guess dataset (sea points are assigned a height of -1).

This is carried out for the 8th December case. The background weighting over the sea is given the name WBKSEA, and that over the land, WBKLAN. Values of Ø·Ø4, Ø·Ø2, and Ø·Ø1 are tried for WBKSEA, whereas WBKLAN is left unchanged at Ø·Ø4 (figure 33). Comparing figures 5 and 33 shows that, in general, the effect of changing the background weight is over the land, WBKLAN, is very small; most of the significant variations result from changes to the background weight over the sea, WBKSEA; pairs of contours produced with the same value of WBK and WBKSEA in figures 5 and 33 respectively almost match. However, there are marked differences over northern France and Norway, which are probably a result of the lower data density in these areas.

As stated in Expt. 4, a reduction in the background weights provides a closer fit to the observations, which is desirable if combined with increased smoothing. However, it is difficult to assess whether the effects over land are desirable or not; they may well be, as the changes occur in data sparse areas where the observations are not properly fitted.

4 Conclusions and suggestions for further work

The changes to analysis parameters which seem to provide the greatest benefit to the analysis will be summarised. The inclusion of a variable minimum smoothing radius, RMIN, (changing from ICHRAD=Ø to ICHRAD=1 in these experiments) removes one discrepancy between the documentation and the model, although the effect on the analysis appeared to be very small. Decreasing the background gridpoint weighting, WBKG, brings contours closer to the observations (this effect can also be achieved by increasing the maximum tolerance, TOLMAX, or the tolerance increment, TOLINC, but as these are really quality control options, and therefore can have other less desirable effects, it is probably better to adjust WBKG); further investigations would be needed to determine whether the background weight should be reduced everywhere or just over the sea. Increasing the "flatness" of the Gaussian parameter, RF, and the maximum smoothing radius, RMAX, provides a smoother analysis (Purser and McQuigg, 1982A/B, used a much larger value of RF than is considered here). If WBKG is decreased, additional smoothing (i.e. the increase in RF and/or RMAX) is probably required. Possible new values for these parameters are WBKG=Ø·Ø1, RF=2·Ø, and RMAX=17·5.

It is probably worth changing the analysis to not use the edge values (IEDGE=1), not because the edge values should not be included in the analysis, but because they are not updated, and thus their use can generate strange effects at the boundaries. However, in the long run, it would be better to allow the values at all the gridpoints to be used and adjusted in the analysis, and then blend the analysis with the boundary conditions at the edges of the model domain.

Analysing the model variable itself (IANL=1), rather than the observation increments (IANL=0), does not appear very promising for the pressure analysis, with the values of the other parameters which are used here. It results in an overly smooth analysis, and removes more of the potentially useful orographically-generated detail which is present in the first guess field (assuming this detail is correct feature rather than just one generated by the extrapolation to mean sea level; this needs further investigation). However, it may be that the advantages of a smoother analysis outweigh these problems, but it would be preferable to use the incremental form of the analysis scheme (IANL=1) if a sufficiently smooth analysis could be achieved over the sea areas.

Additionally, some changes probably need to be made to the analysis method itself. The treatment of the edge, discussed previously, is one example. As an immediate action, the use of the tolerance system should be extended to cover analyses of the variable itself (IANL=Ø), which at the moment are vulnerable to gross errors (the IANL=1 option is currently used with some variables other than pressure in the mesoscale analysis scheme). However, in the long run it would be preferable to introduce a more sophisticated method of quality control. Discrepancies between two or more observations in close proximity can often cause problems over the sea. Some kind of buddy check might prove useful in this situation.

Finally, it is worth noting that many of the changes made to the tunable parameters have been fairly small, so although they have supplied some useful ideas for changes to the analysis scheme, it is probably worth investigating the effects of more drastic changes. Most of the results in this paper are similar to those obtained by the current scheme; larger changes might yield greater impacts. A further consideration is the use of 10 m wind observations (especially over the sea) in the analysis of mean sea level pressure, making use of geostrophic effects; this is carried out in many other data assimilation schemes.

Acknowledgements

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References

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APPENDIX A

The use of the analysis scheme in the IMI

The subroutine 'ANALYS' is called a number of times to provide the required analyses of several variables in the model. The routine performs two main steps. Firstly, data from the observation points are used to modify the first-guess field, and secondly, the modified field is smoothed (using the subroutine 'SMEAR'). In some cases, the observations themselves are used in the modification, while in others, either the logarithm of the observations, or the difference between the observations and the background field is used.

Various parameters used by 'ANALYS' are set initially by 'ANAL1'; these may vary depending on which variable is being analysed. For example, some analyses include the edge points while others exclude them; different analyses use different sets of values for the 'tolerance' assigned to observations. The tables below summarise those variables which are actually analysed, and those for which there is an option in 'ANAL2' to allow them to be analysed. In each case, the parameters used are also shown.

Variables which are analysed

Variable	IANL	ILOG	IEDGE	RMIN	RMAX	RF	TOLMIN	TOLMAX	TOLINC
Visibility	var	log	inc	0	4	0.5	10^6	10^6	0.7
Pressure	diff	var	inc	1	7	0.8	0.1	4.0	0.5
Temperature	diff	var	inc	1	7	0.8	1.0	5.0	0.5
Cloud cover	var	var	inc	0	4	0.5	8.0	8.0	0.7
Cloud base height	var	log	inc	0	4	0.5	10^6	10^6	0.7
Dew point	diff	var	inc	1	7	0.8	1.0	5.0	0.5
Precipitation rate	var	var	inc	0	4	0.5	10^6	10^6	0.7
Accumulated pptn.	var	log[1]	inc	0	2	0.5	2.0	4.0	0.7
U component of wind[2]	diff	var	exc	1	7	0.8	2.0	10.0	0.6
V component of wind[2]	diff	var	exc	1	7	0.8	2.0	10.0	0.6

Other variables which can be analysed

Variable	IANL	ILOG	IEDGE	RMIN	RMAX	RF	TOLMIN	TOLMAX	TOLINC
Cloud top height	var	log	inc	0	4	0.5	10^6	10^6	0.7
Relative humidity	diff	var	inc	1	7	0.8	10.0	90.0	0.5
Convective intensity	diff	var	inc	0	4	0.5	4.0	8.0	0.7

(For explanation of table, see over)

```
IANL=1 (diff) - analyse difference between observation and background field
    =2 (var)  - analyse variable itself
ILOG=1 (log)  - analyse logarithm of variable
    =0 (var)  - analyse variable itself
IEDGE=0 (inc) - include edge points
     =1 (exc) - exclude edge points
RMIN, RMAX    - minimum and maximum radii of smoothing in gridlengths
RF            - 'pointedness' of Gaussian
TOLMIN,TOLMAX - minimum and maximum tolerance values over several scans
TOLINC        - measure of change of tolerance between scans
```

Other variables are set in 'ANAL1' along with those listed above, and then left unchanged. These are:

```
NSCAN=3  - number of scans over grid
NSMOO=2  - number of smoothing sweeps within each scan
RINC=0.5 - (supposedly) measure of change of radius of smoothing between
           scans. (Not used at present)
```

Notes

1. In actual fact, the variable which is analysed is log(2-ap), where ap=accumulated precipitation. This is to allow for large negative values of the variable (representing lying snow). Taking logarithms prevents excessive spreading of depths of snow.

2. The U and V components of the background field wind are actually offset by half a grid length in the X and Y directions respectively.

List of figures

The figures are described in detail where they are referred to in the text; below, only those analysis parameters which have been changed are summarised.

Figure	Expt.	Description	Day
1	1	ICHRAD=Ø,1	Ø8.12.9Ø
2	2	NSCAN=2,3,4	"
3	3	RF=Ø·8; RMAX=7; NSCAN=3,6	"
4	3	RF=2·Ø; RMAX=17·5; NSCAN=3,6	"
5	4	WBKG=Ø·Ø4,Ø·Ø2,Ø·Ø1	"
6	5	TOLMAX=4,8,12	"
7	6	RLIM=1,3,5; RF=Ø·8; RMAX=7	"
8	6	RLIM=1,7; RF=2·Ø; RMAX=17·5	"
9	7	RINC=Ø·3,Ø·5,Ø·7	"
1Ø	8	TOLINC=Ø·3,Ø·5,Ø·7	"
11	9	TOLMIN=1,2,4	"
12	9	TOLMIN=1,2,4; TOLMAX=8	"
13	1Ø	NSMOO=1,2,3;	"
14	1Ø	NSMOO=2,3; WBKG=Ø·Ø2	"
15	1Ø	NSMOO=2,3; WBKG=Ø·Ø1	"
16	1Ø	NSMOO=2,3; TOLMAX=8	"
17	-	IANL=Ø; IEDGE=1 (no quality control)	"
18	11	IEDGE=Ø,1	23.Ø7.91
19	11	IEDGE=Ø,1; WBKG=Ø·Ø2	"
2Ø	11	IEDGE=Ø,1; TOLMAX=8	"
21	11	IEDGE=Ø,1; NSCAN=6	"
22	12	IANL=Ø,1; IEDGE=1	"
23	12	IANL=Ø,1; IEDGE=1; WBKG=Ø·Ø2	"
24	12	IANL=Ø,1; IEDGE=1; NSCAN=6	"
25	13	Quality control test; IANL=Ø; IEDGE=1	"
26	13	Quality control test; IANL=Ø; IEDGE=1; WBKG=Ø·Ø2	"
27	13	Quality control test; IANL=Ø; IEDGE=1; NSCAN=6	"
28	13	Quality control; IANL=Ø; IEDGE=1	Ø8.12.9Ø
29	14	Quality control; IANL=Ø; IEDGE=Ø,1	23.Ø7.91
3Ø	14	Quality control; IANL=Ø; IEDGE=Ø,1; WBKG=Ø·Ø2	"
31	14	Quality control; IANL=Ø; IEDGE=Ø,1; TOLMAX=8	"
32	14	Quality control; IANL=Ø; IEDGE=Ø,1; NSCAN=6	"

33	15	WBKSEA=Ø·Ø4,Ø·Ø2,Ø·Ø1	Ø8.12.9Ø
34	ref	Hybrid	Ø8.12.9Ø
35	ref	Observations	"
36	ref	Hybrid	23.Ø7.91
37	ref	Observations	"

ICHRAD= 0,1

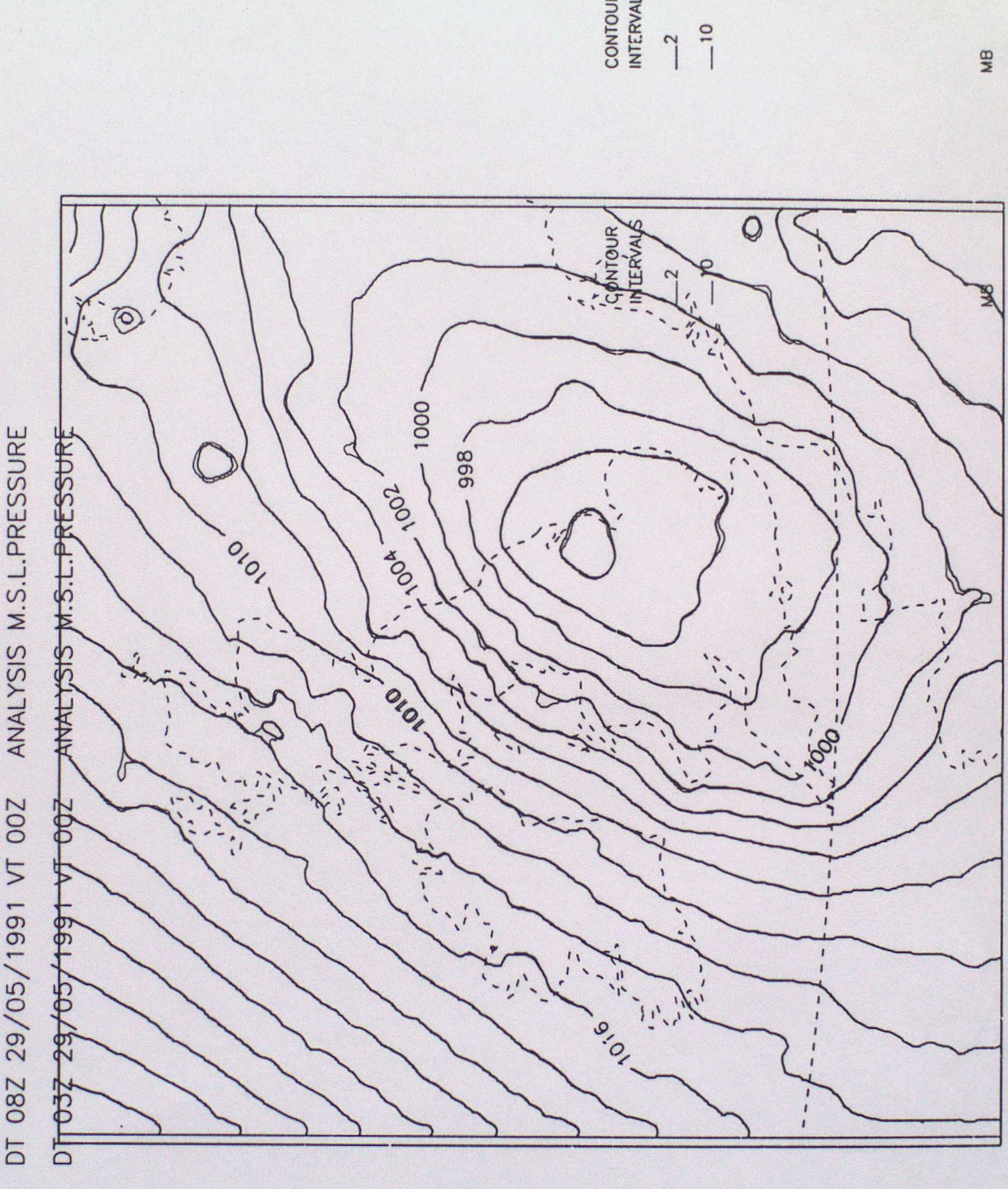

FIGURE 1 : ICHRAD = 0,1

2 2

NSCAN=2,3,4

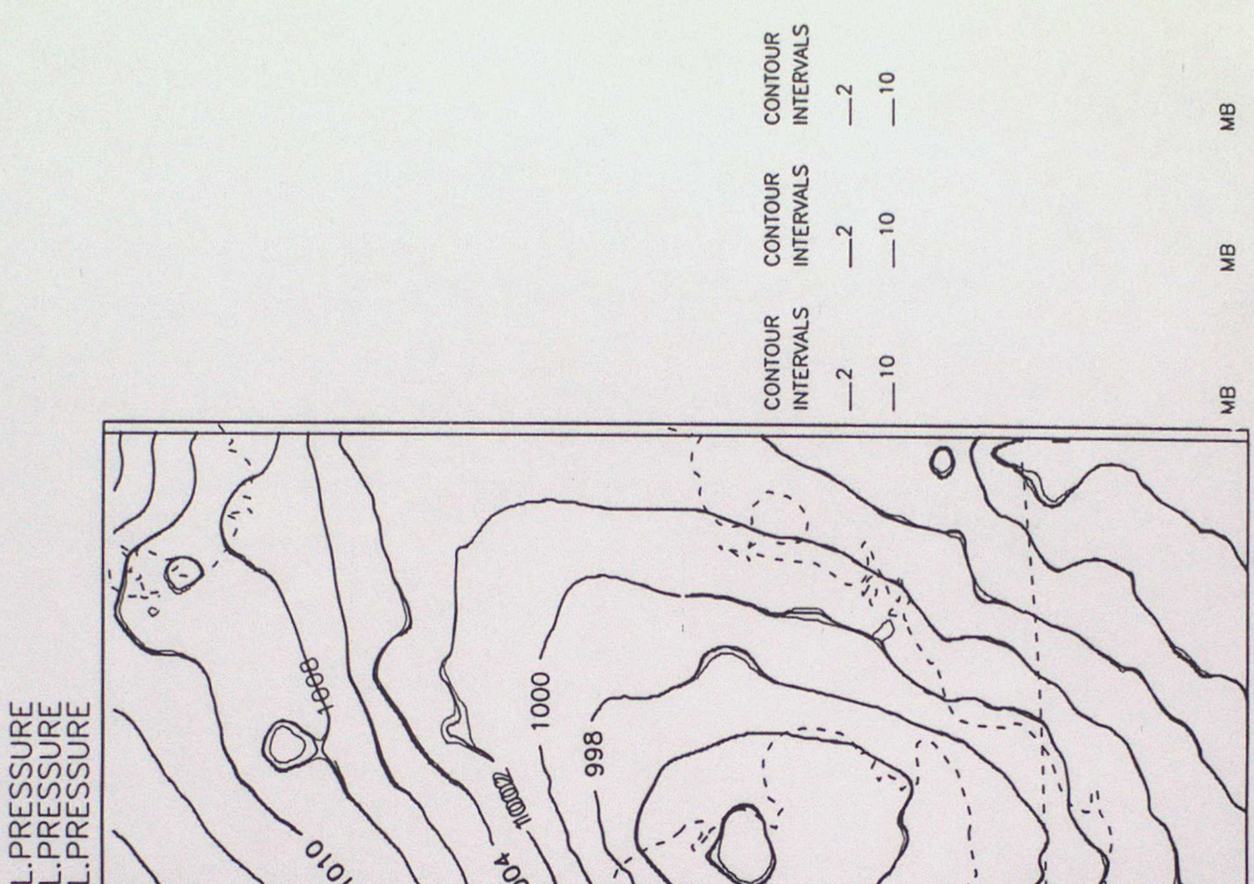

FIGURE 2 : NSCAN= 2,3,4

3 3

RF = 0·8; RMAX = 7
NSCAN = 3, 6

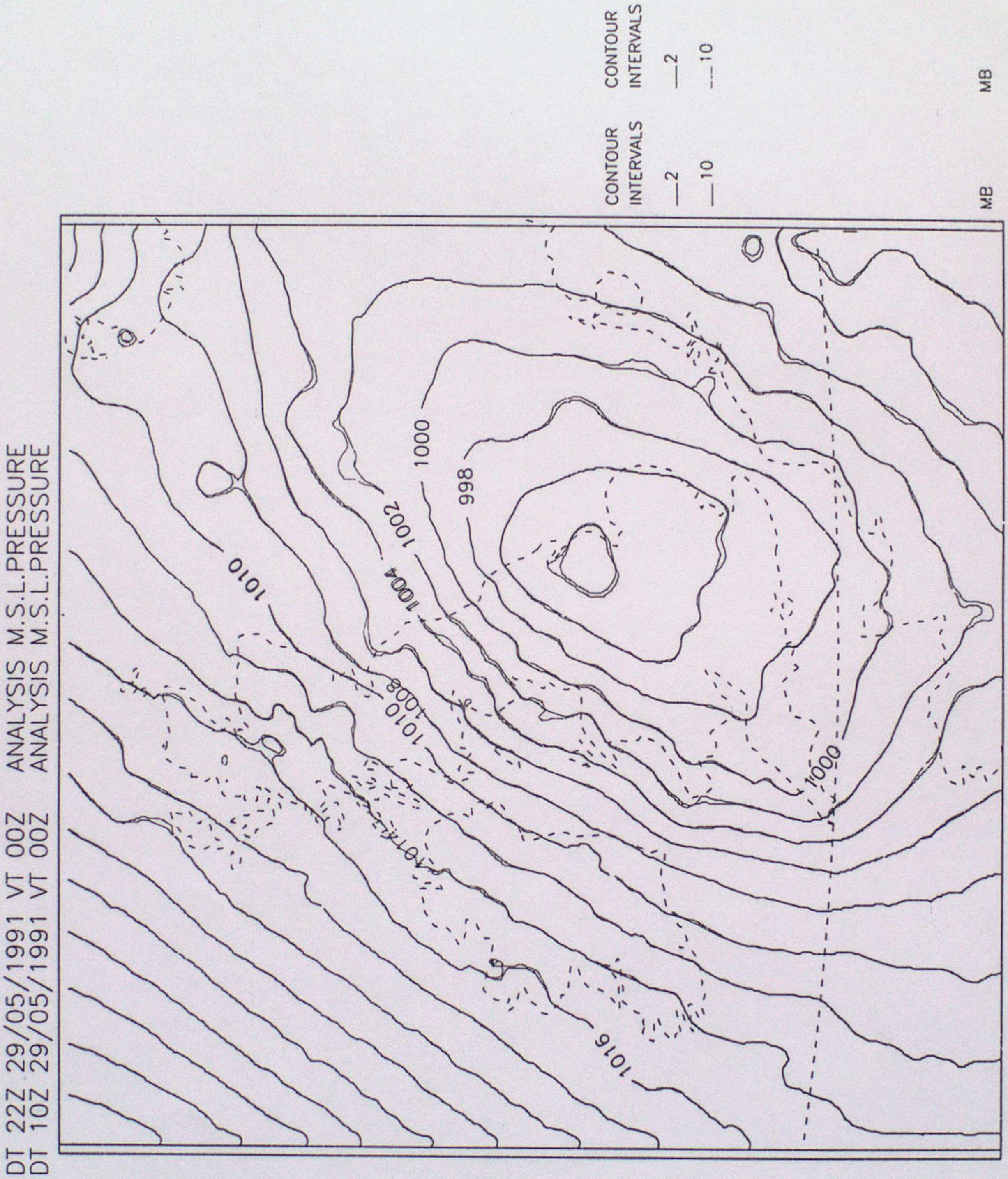

FIGURE 3: RF = 0·8 ; RMAX = 7 ; NSCAN = 3, 6

4 4

RF=2·0; RMAX=17·5
NSCAN=3,6

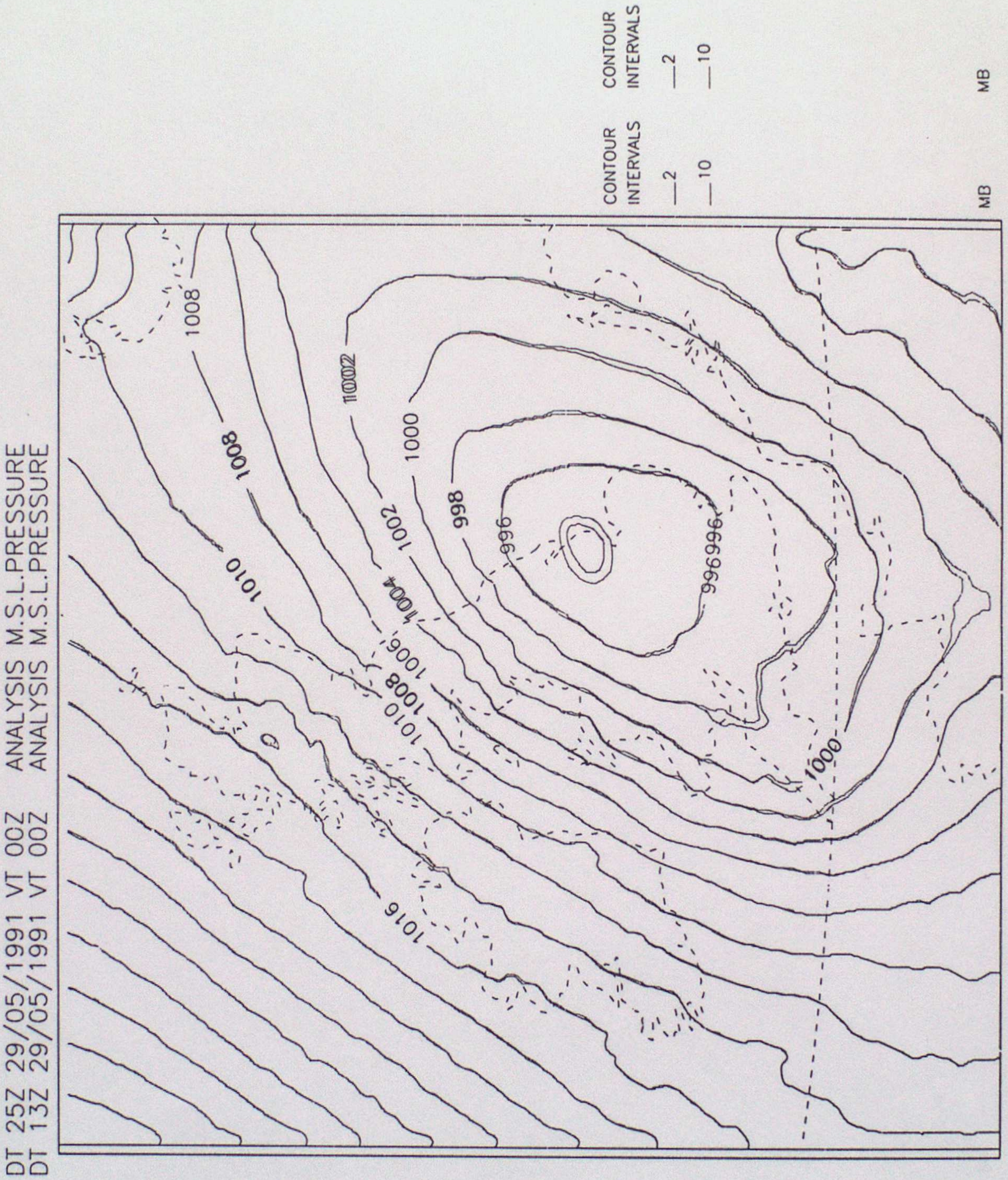

FIGURE 4: RF=2.Ø ; RMAX=17.5 ; NSCAN=3,6

5 5

WBKG = 0.04, 0.02, 0.01

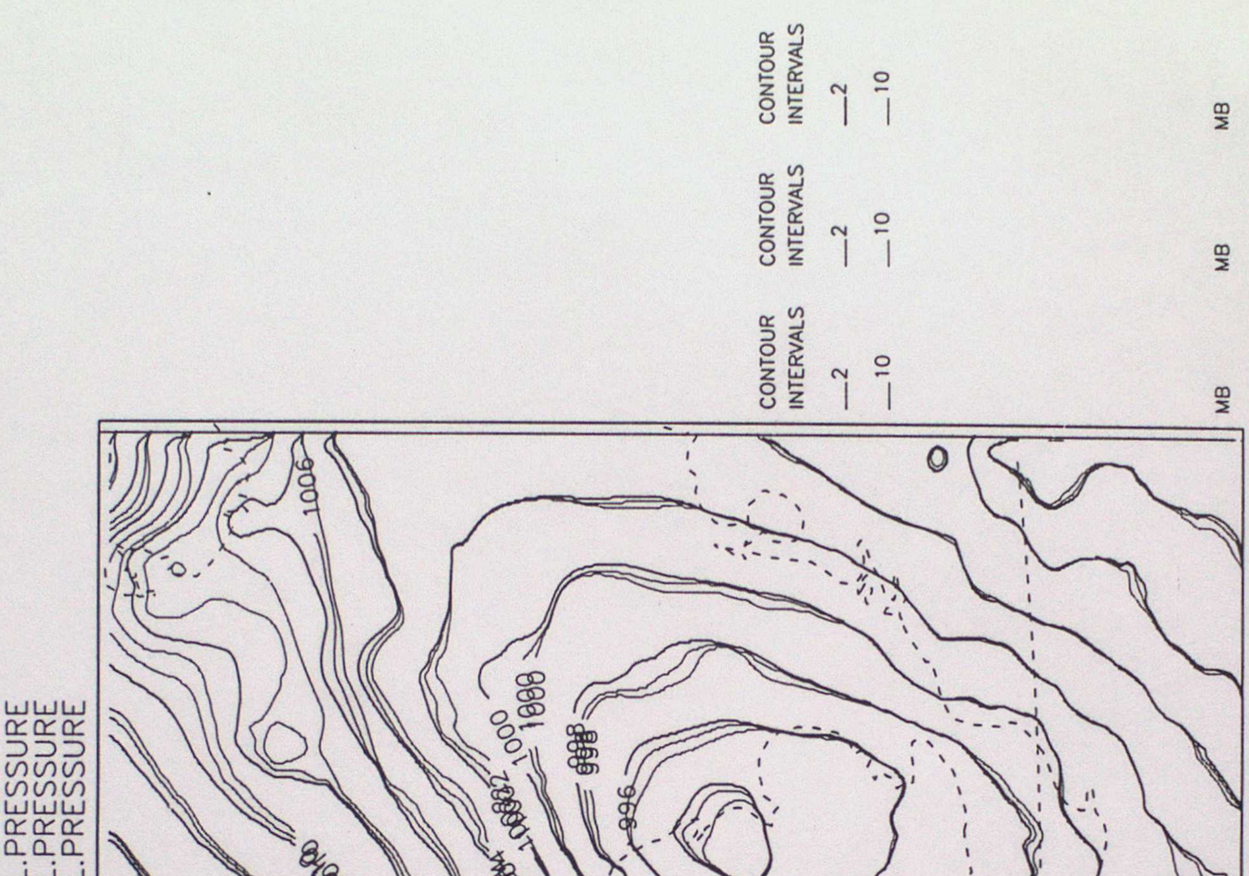

FIGURE 5: WBKG = 0.04, 0.02, 0.01

6 6

TOLMAX=4, 8, 12

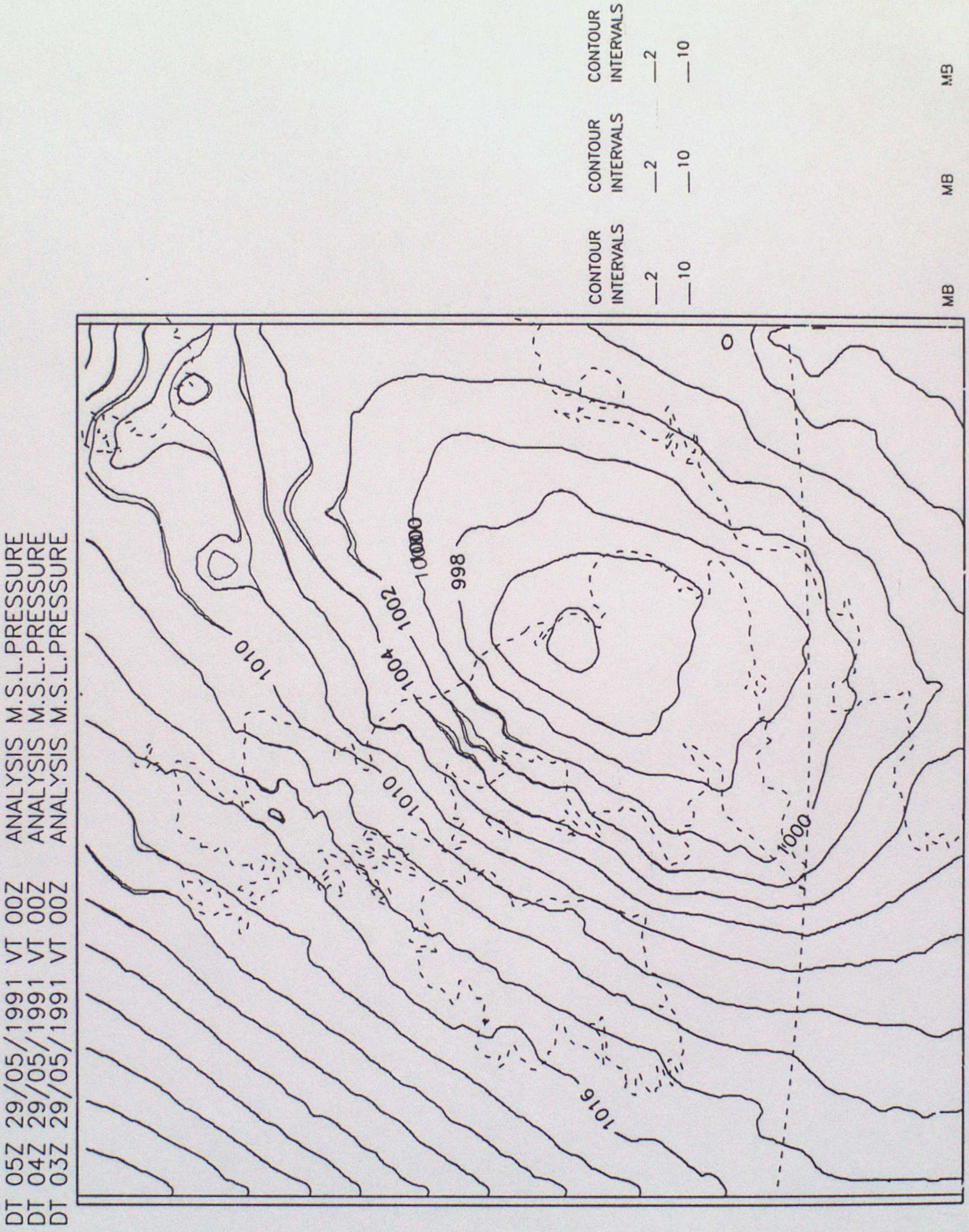

FIGURE 6: TOLMAX = 4, 8, 12

7

RLIM=1,3,5

RF= 0.8; RMAX=7

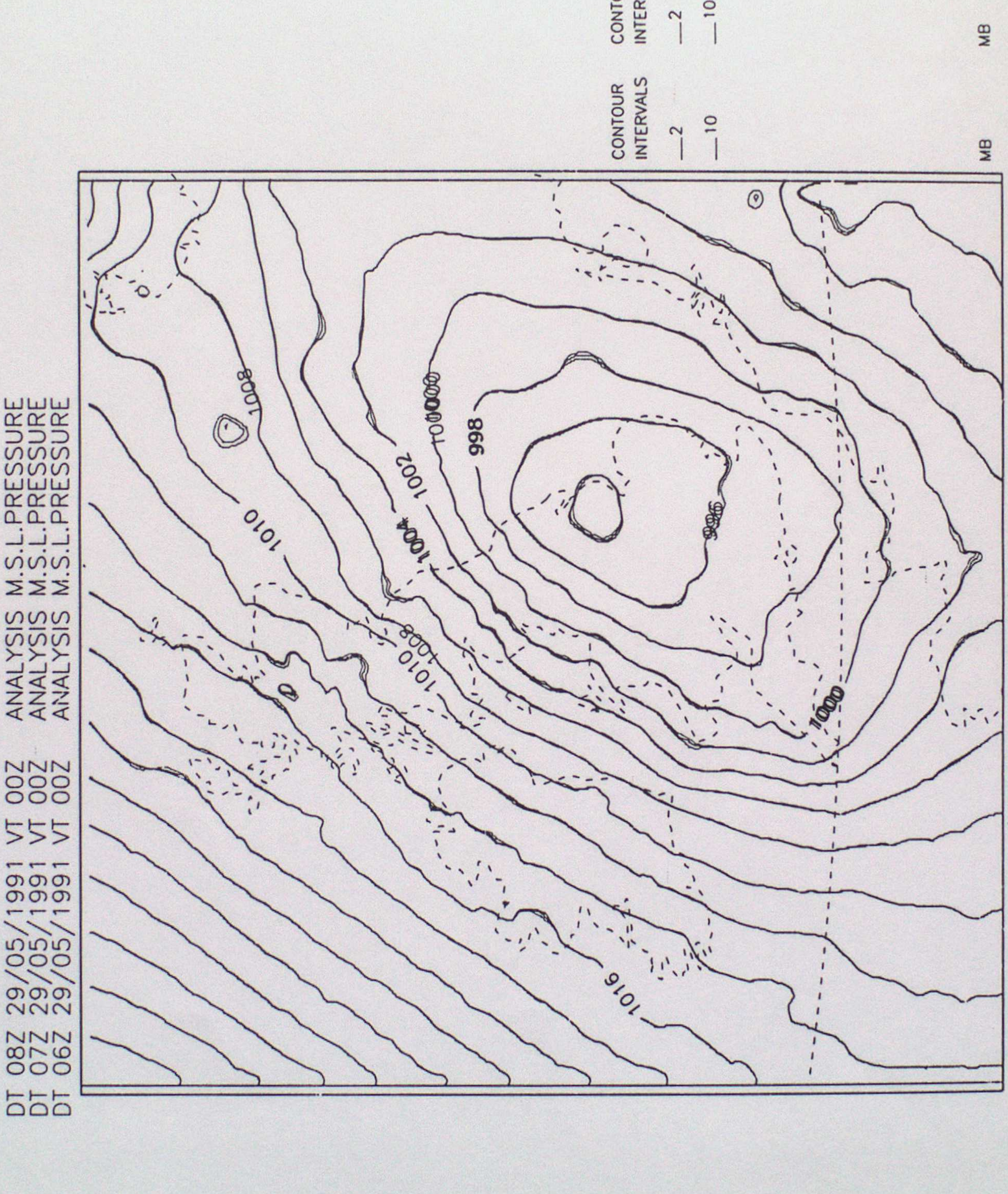

FIGURE 7: RLIM = 1,3,5 ; RF = 0.8 ; RMAX = 7

8 8

RLIM=1,7

RF=2.0; RMAX=17.5

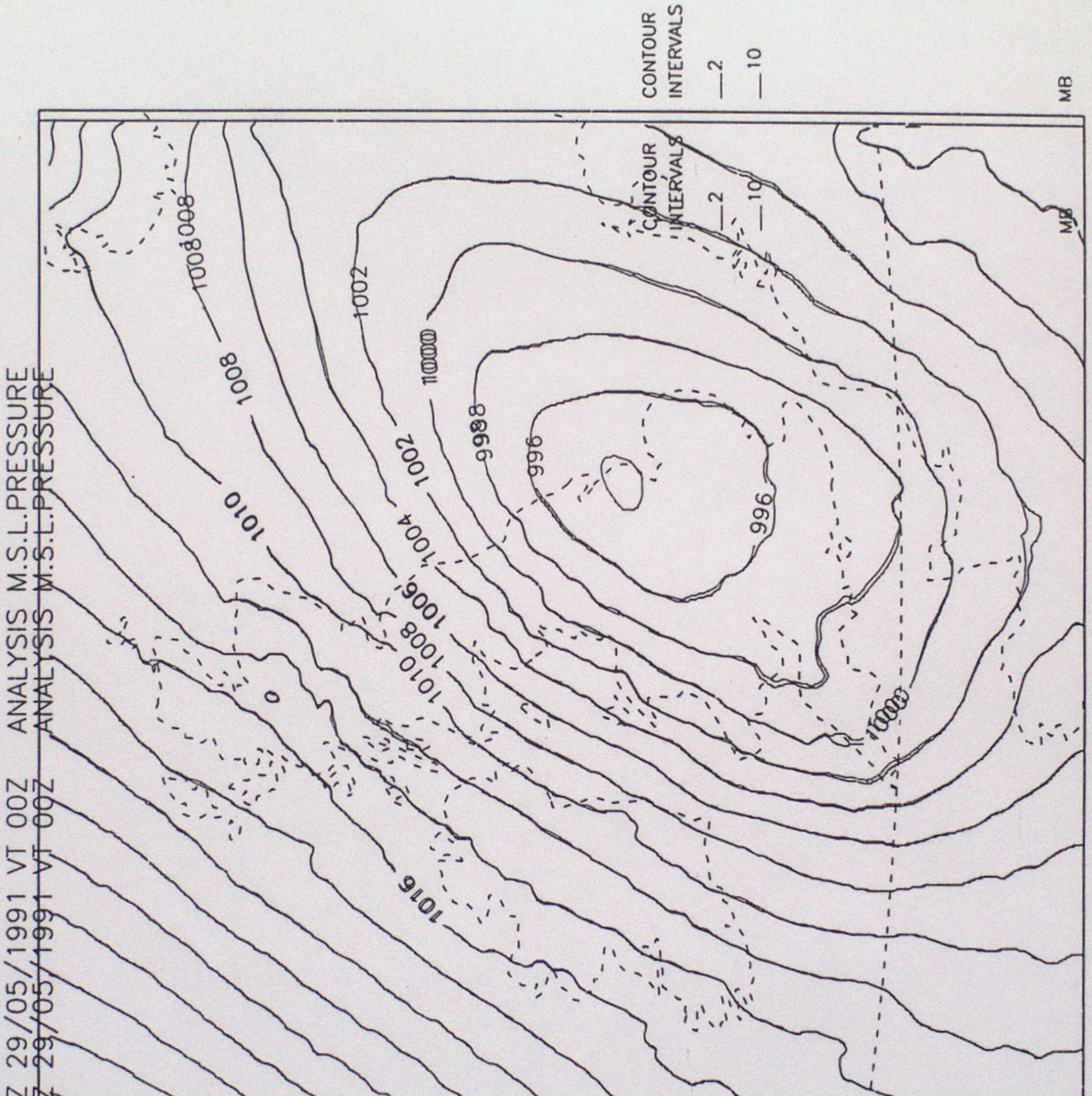

FIGURE 8: RLIM = 1, 7 ; RF = 2.Ø ; RMAX = 17.5

RINC = 0.3, 0.5, 0.7

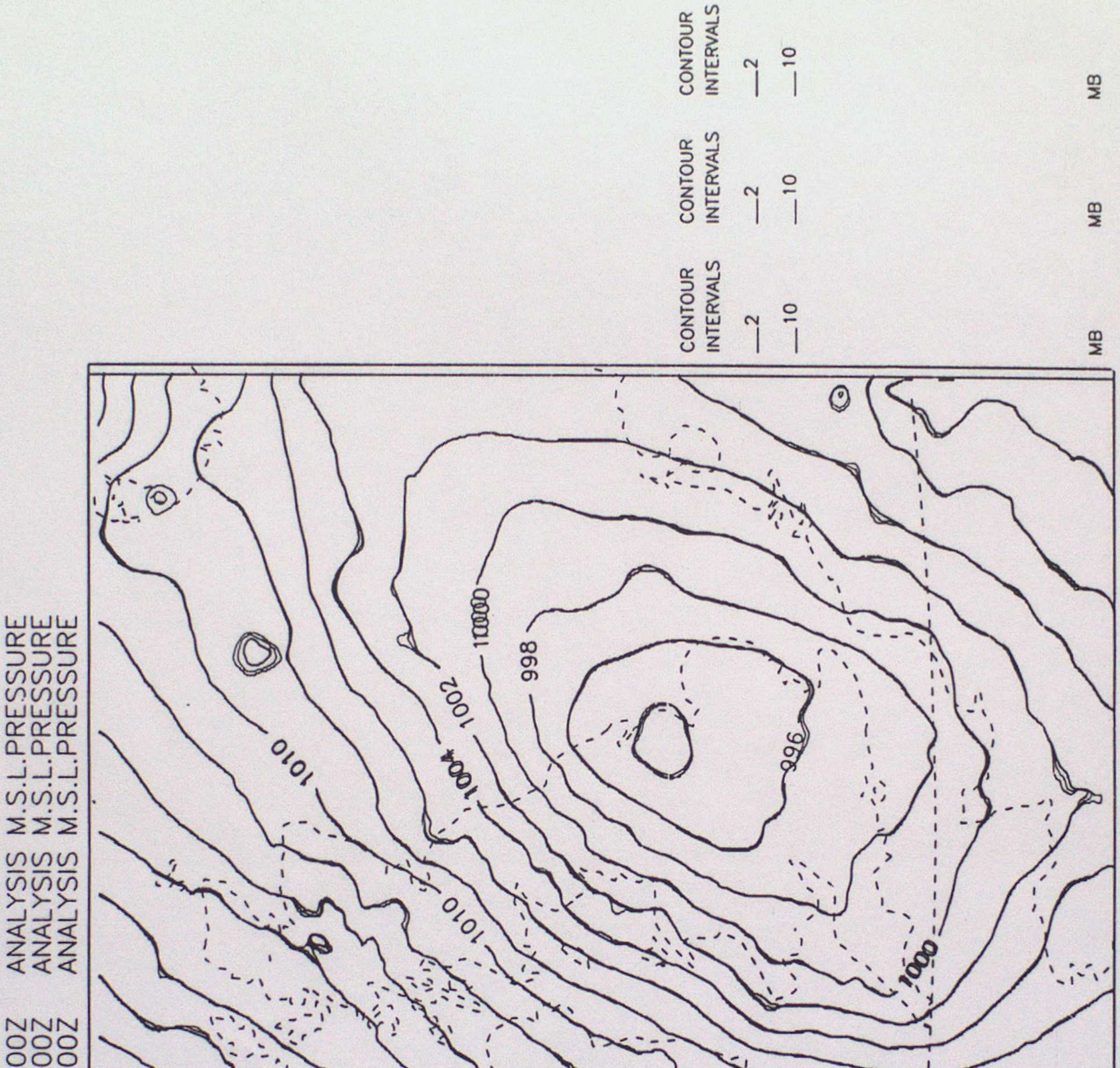

FIGURE 9 : RINC = 0.3, 0.5, 0.7

10

TOLINC=0.3,0.5,0.7

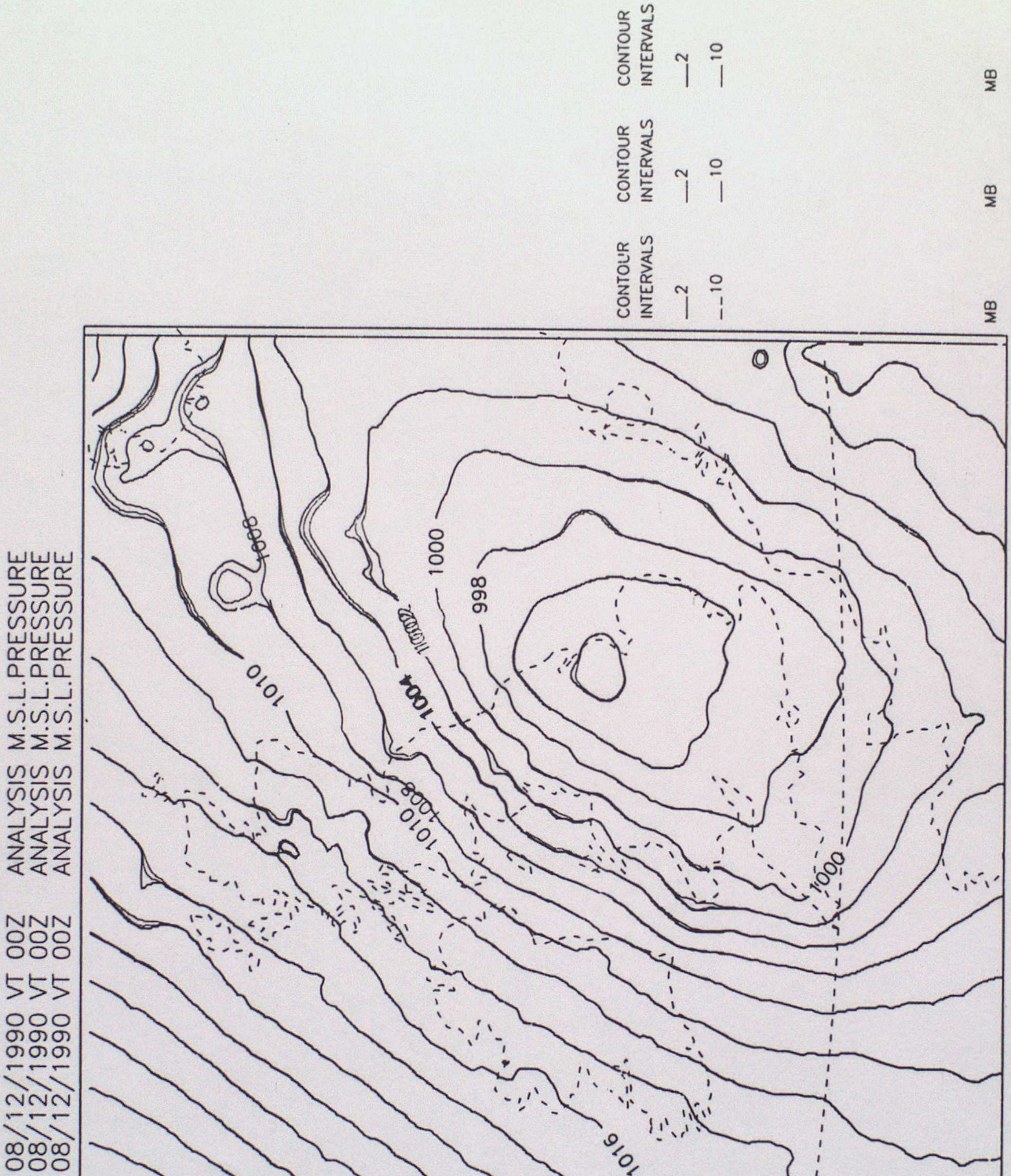

FIGURE 10: TOLINC = 0.3, 0.5, 0.7.

11

11

TOLMIN=1,2,4

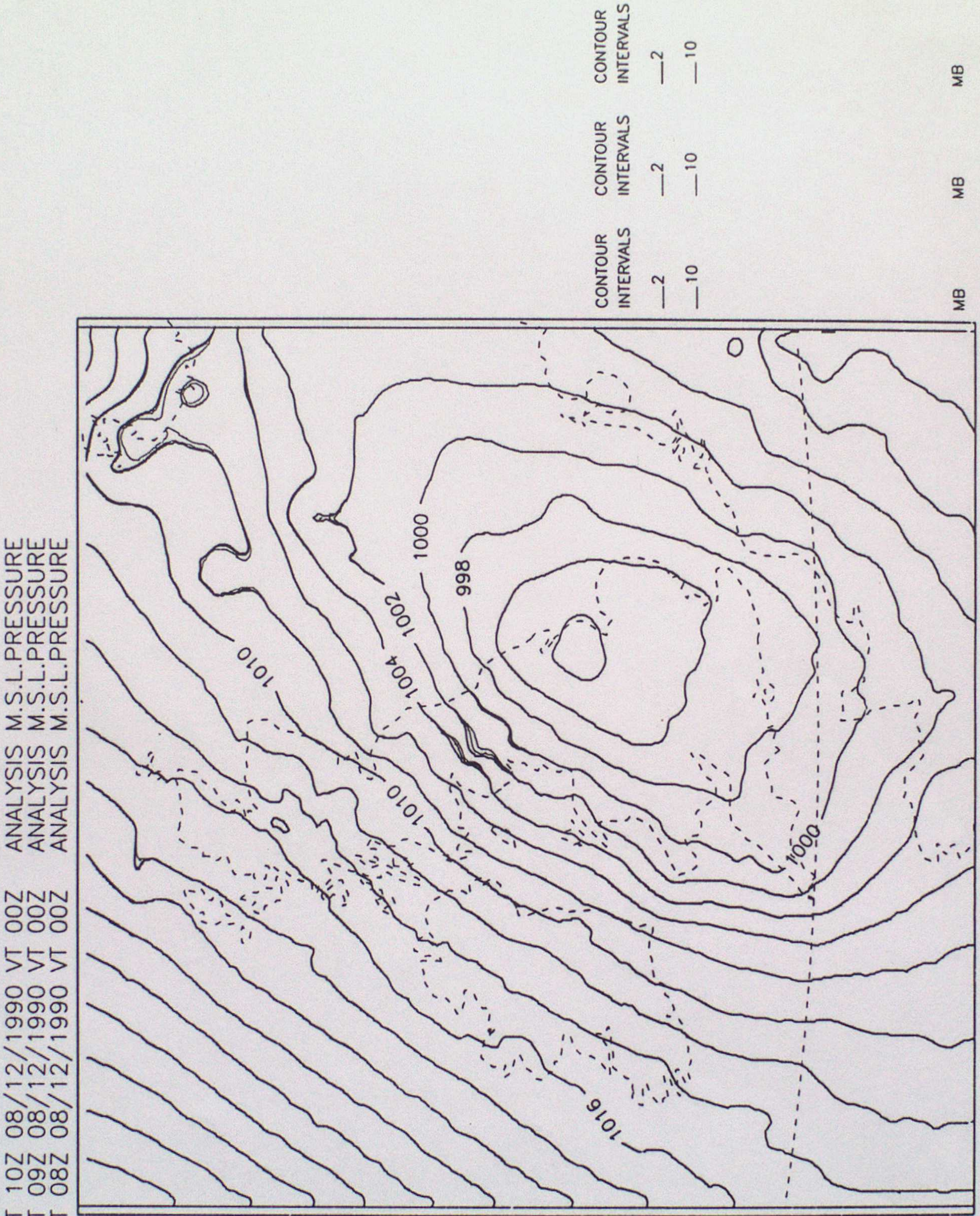

FIGURE 11 : TOLMIN= 1,2,4

12

12

TOLMIN=1,2,4
TOLMAX=8

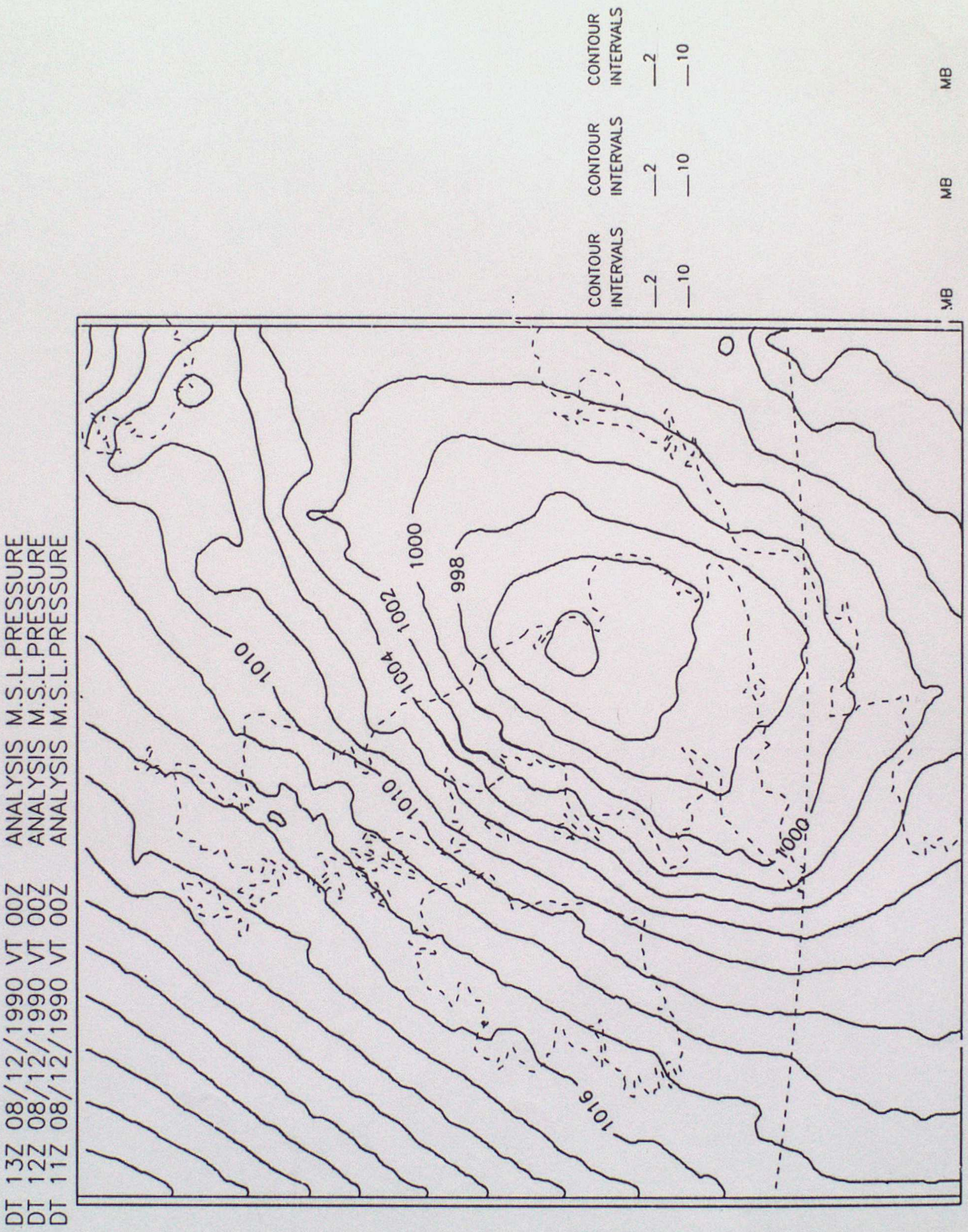

FIGURE 12: TOLMIN = 1, 2, 4 ; TOLMAX = 8

13 13

NSMOO = 1,2,3

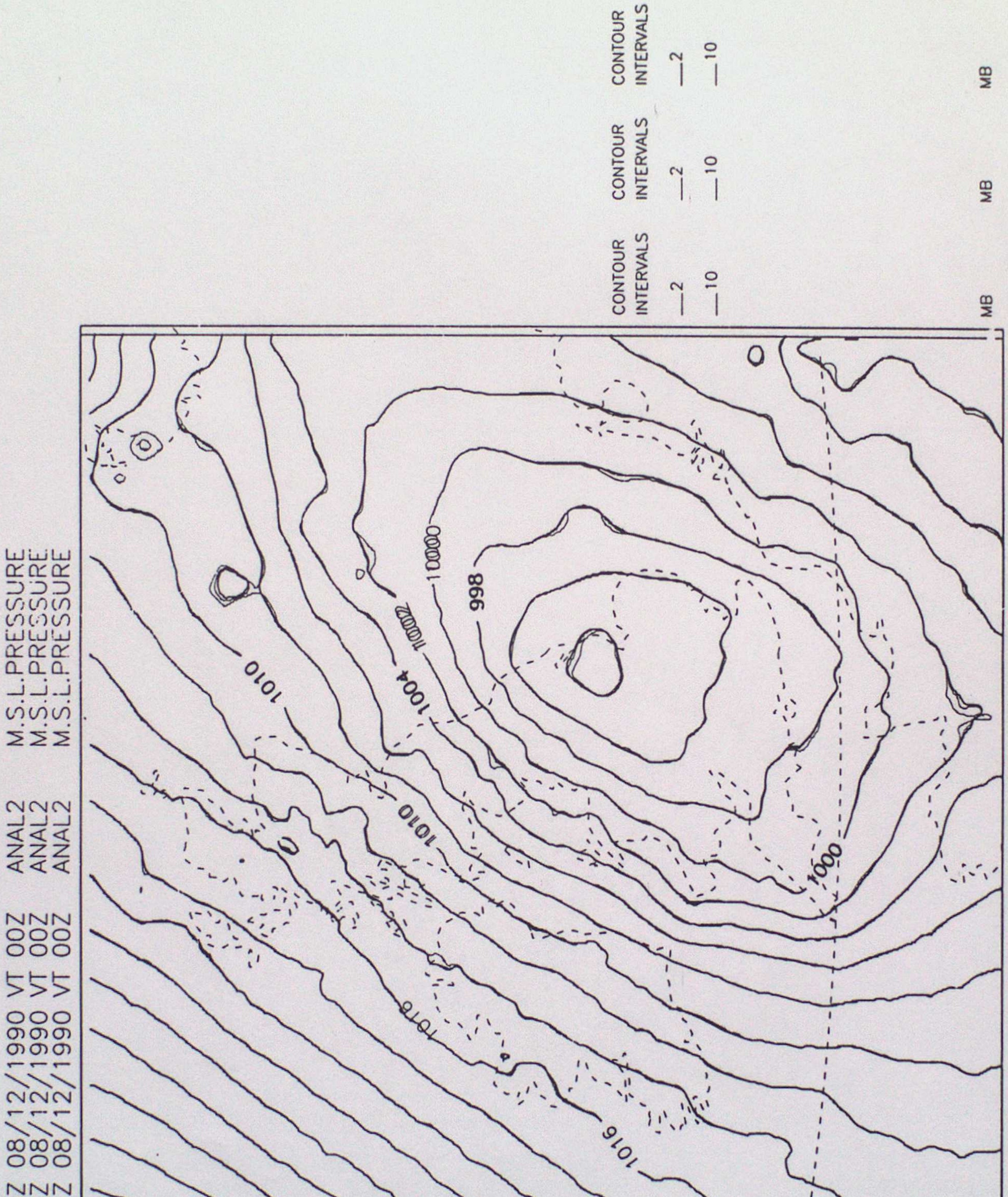

FIGURE 13: NSMOO = 1,2,3

14

14

NSMOO= 2,3

WBKG=0.02

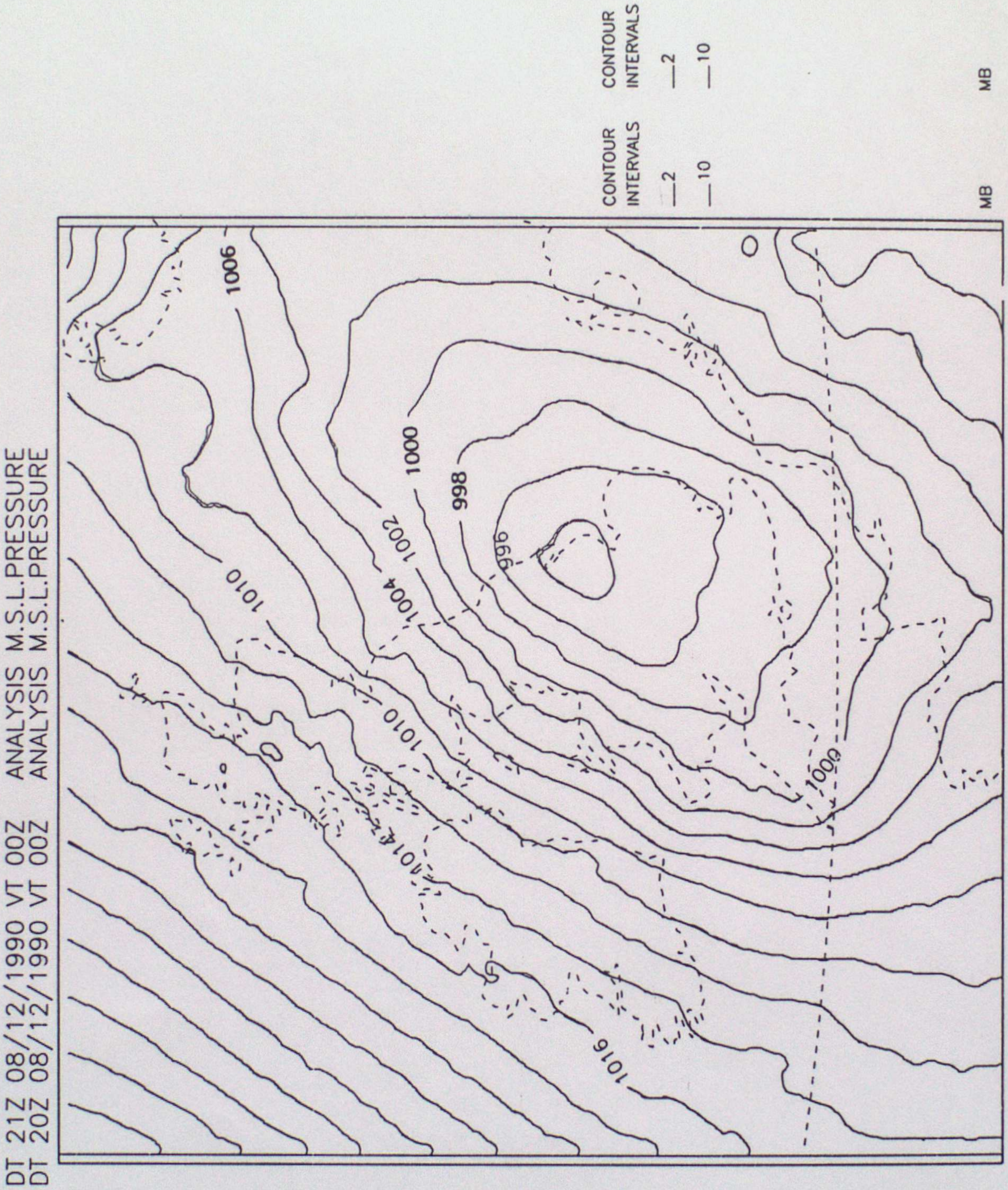

FIGURE 14: NSMOO = 2,3 ; WBKG = 0.02

15

15

NSMOO=2,3

WBKG = 0.01

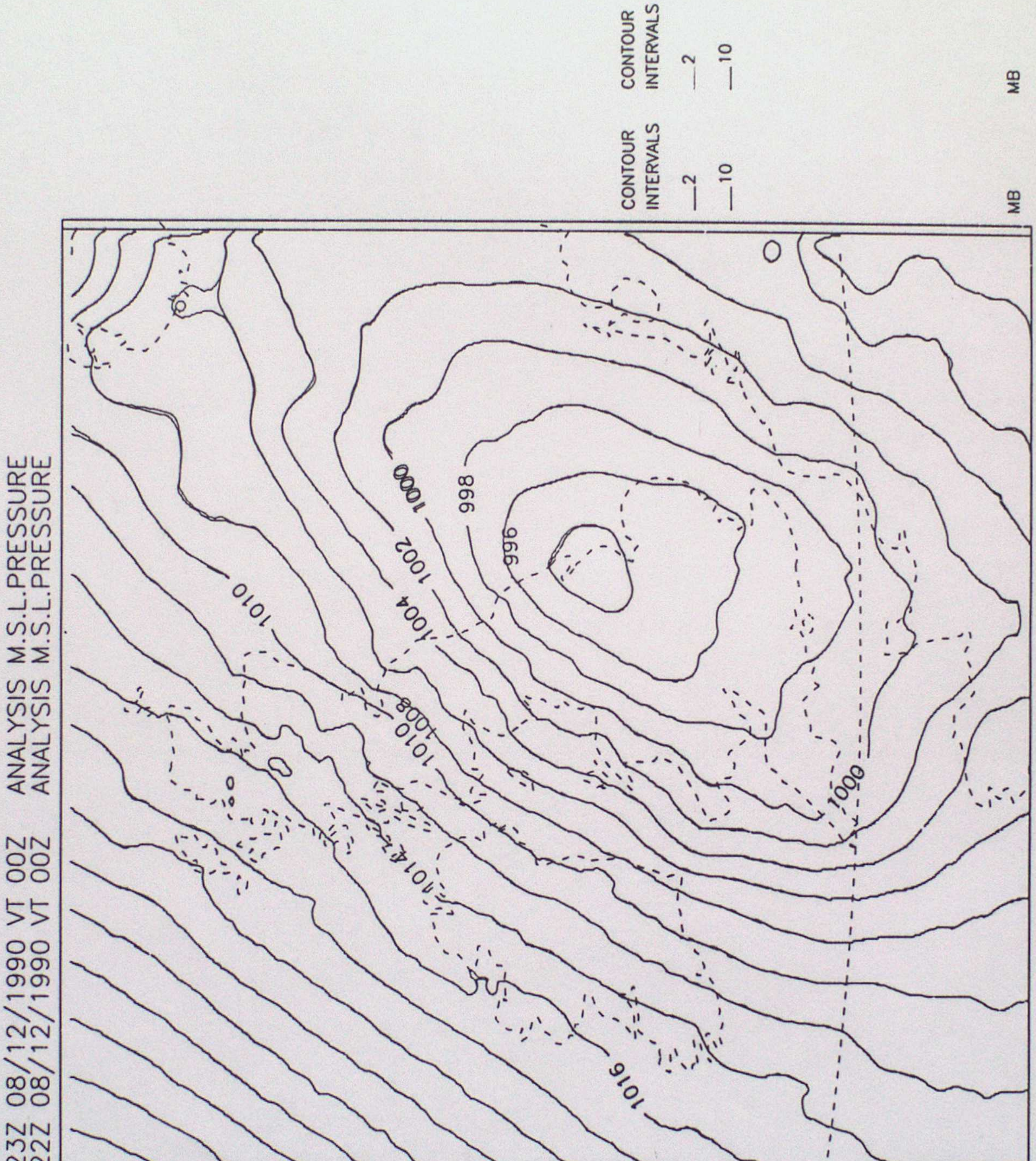

FIGURE 15: NSMOO= 2,3 ; WBKG = 0.01

NSMOO=2,3
TOLMAX=8

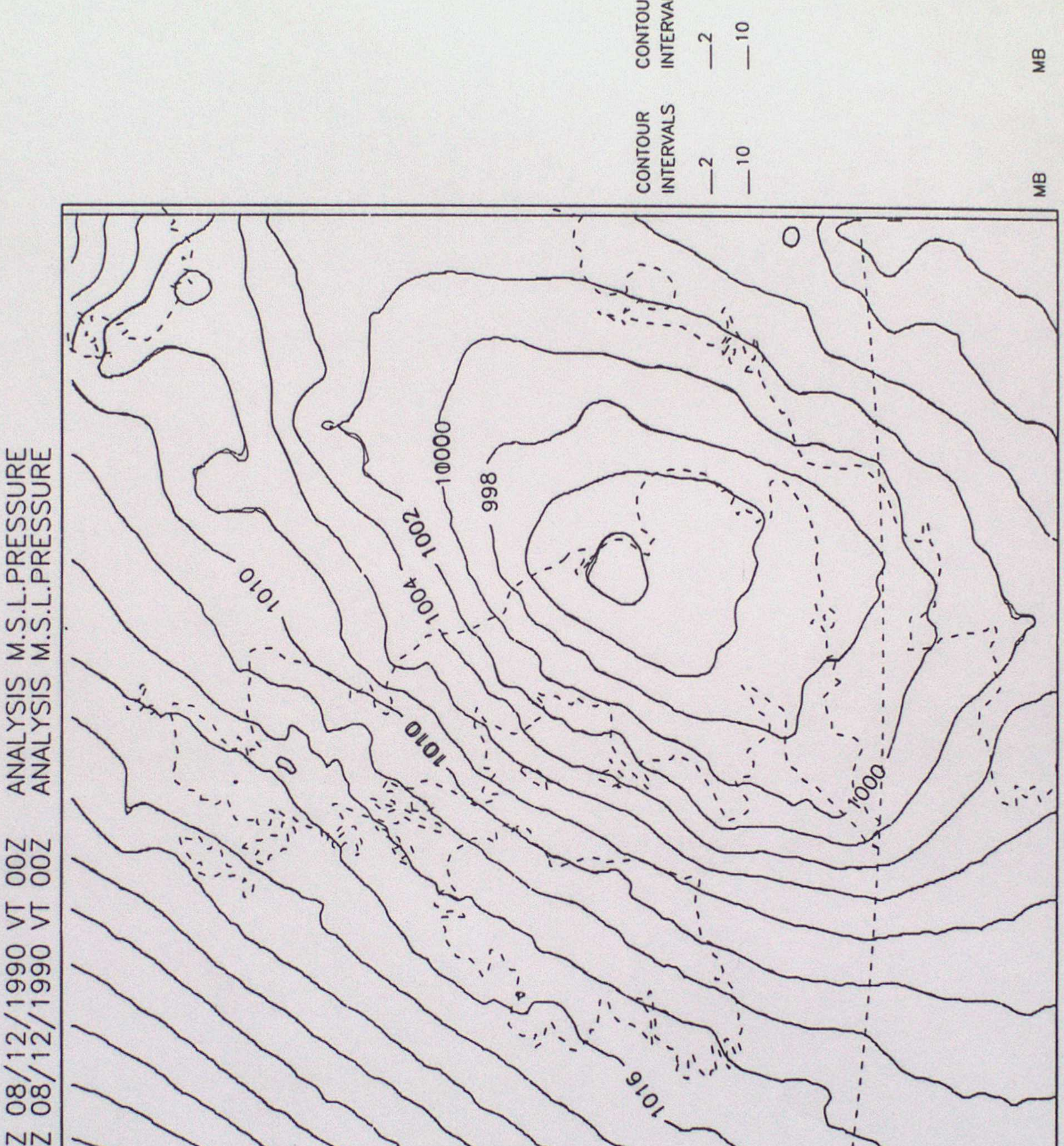

FIGURE 16 : NSMOO = 2, 3 ; TOLMAX = 8

17 17

IANL=0
IEDGE=1

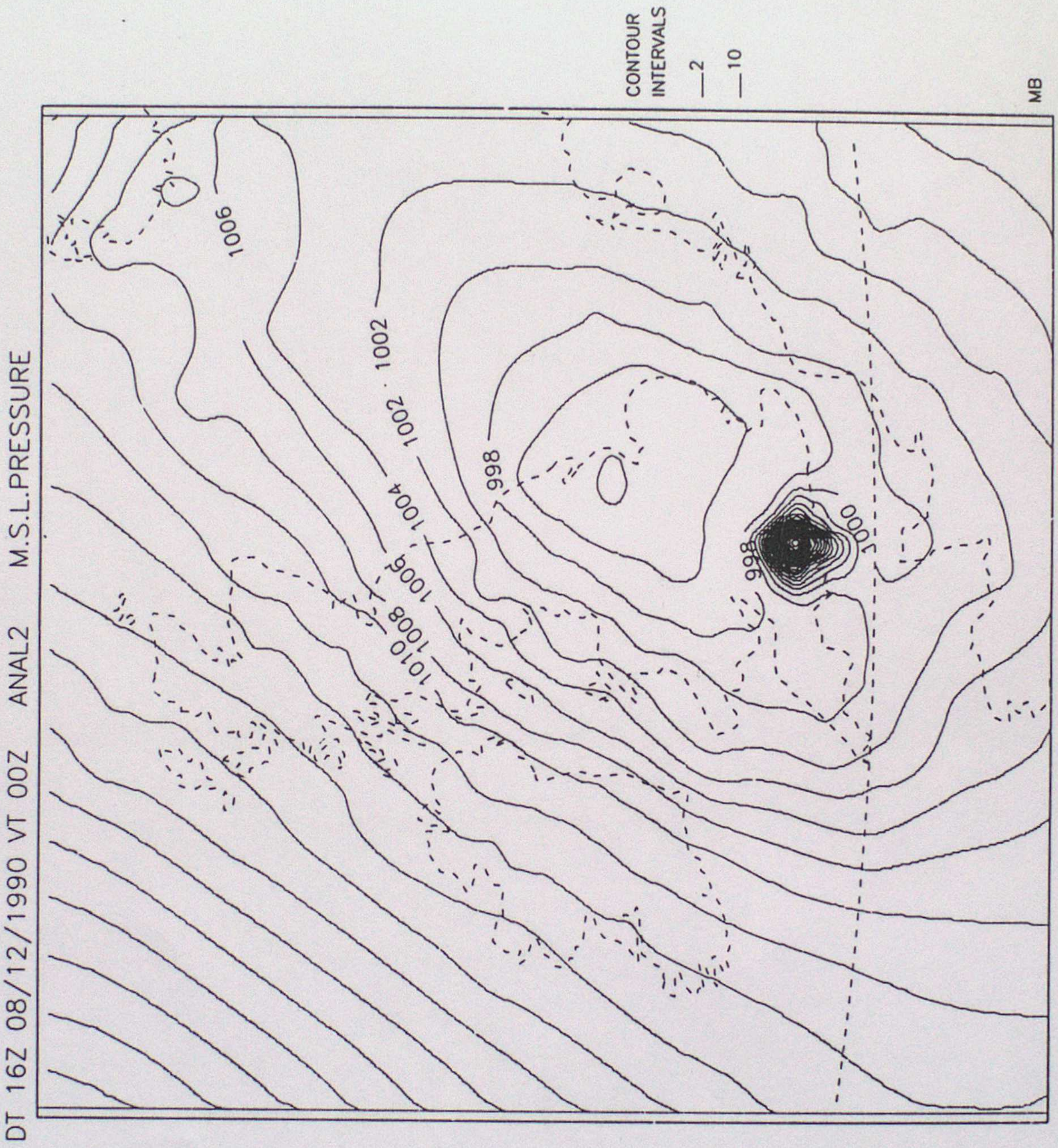

FIGURE 17: IANL = 0 ; IEDGE = 1

18

IEDGE = 0,1

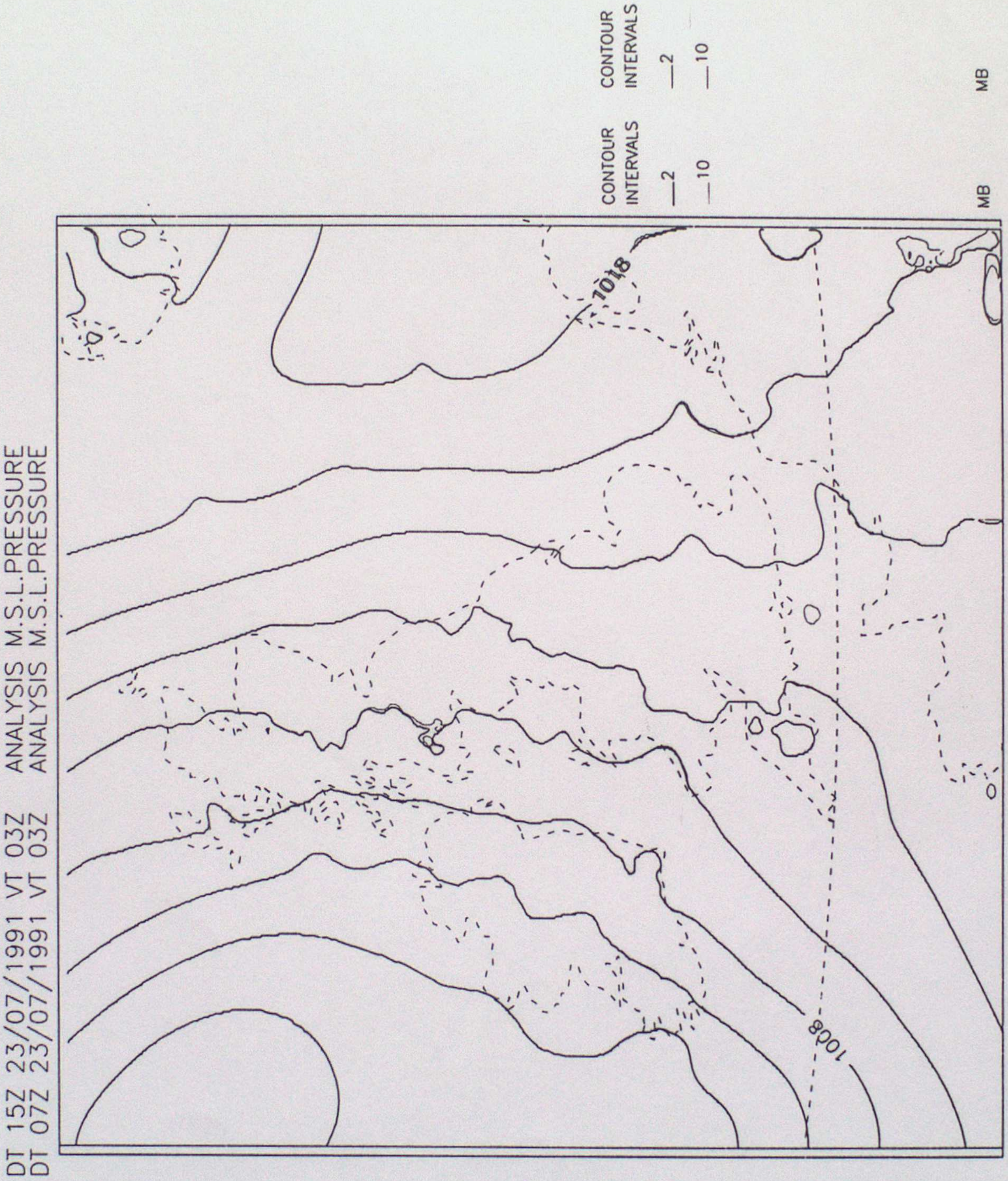

FIGURE 18: IEDGE = 0,1

19

IEDGE=0,1
WBKG=0.02

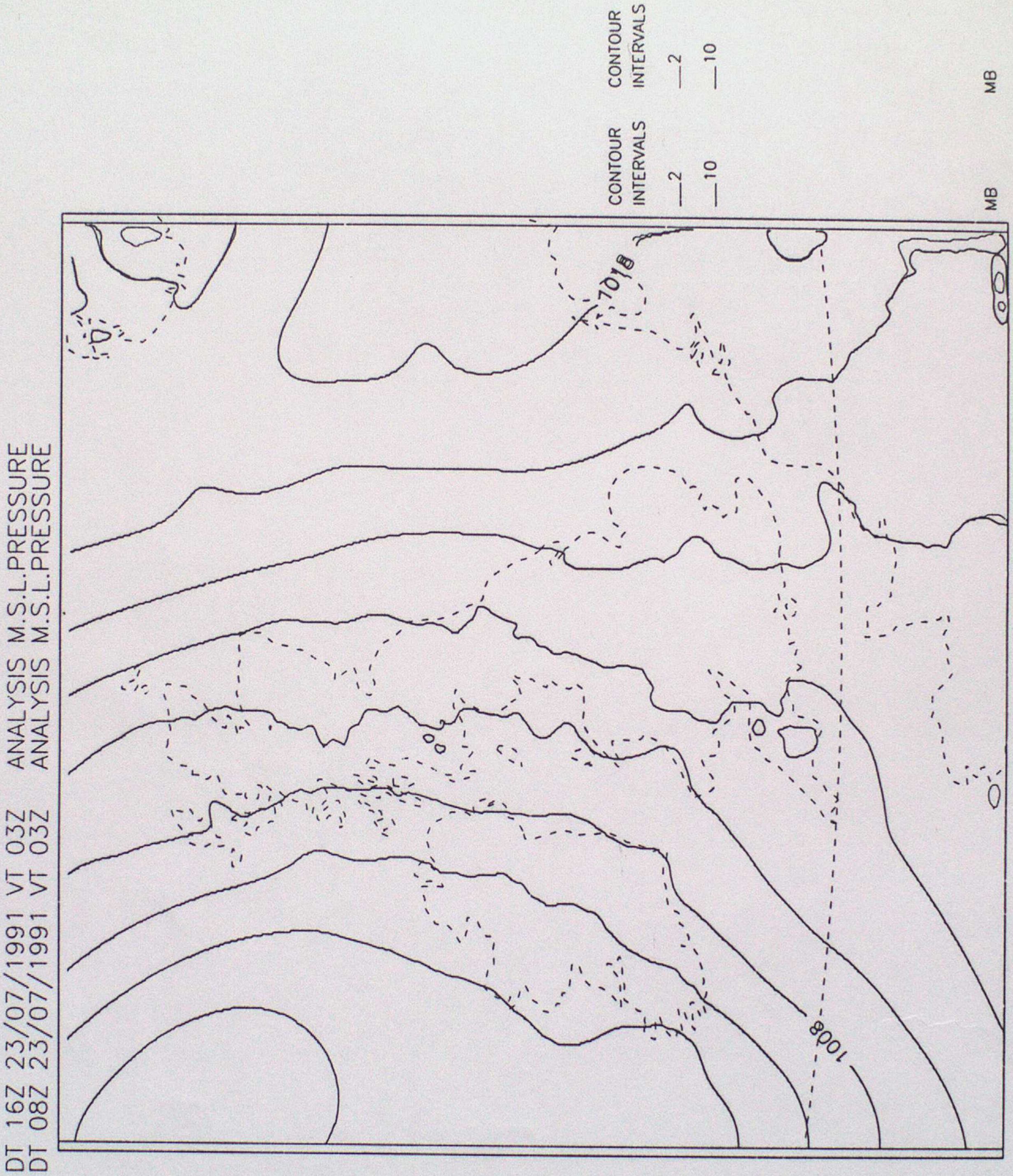

FIGURE 19: IEDGE = 0,1 ; WBKG = 0.02

IEDGE=0,1

TOLMAX=8

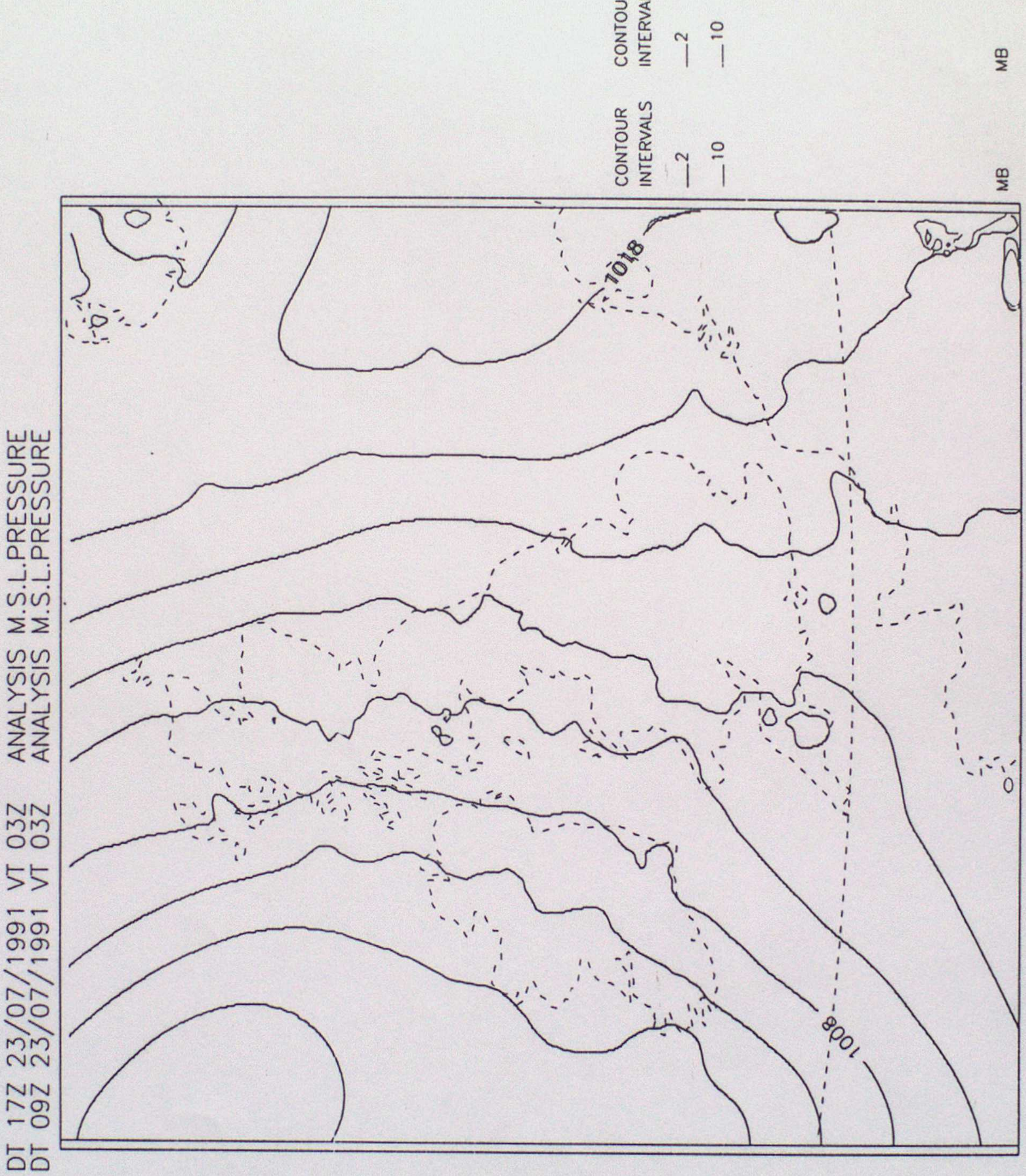

FIGURE 20: IEDGE = 0,1 ; TOLMAX = 8

21

IEDGE=0,1
NSCAN=6

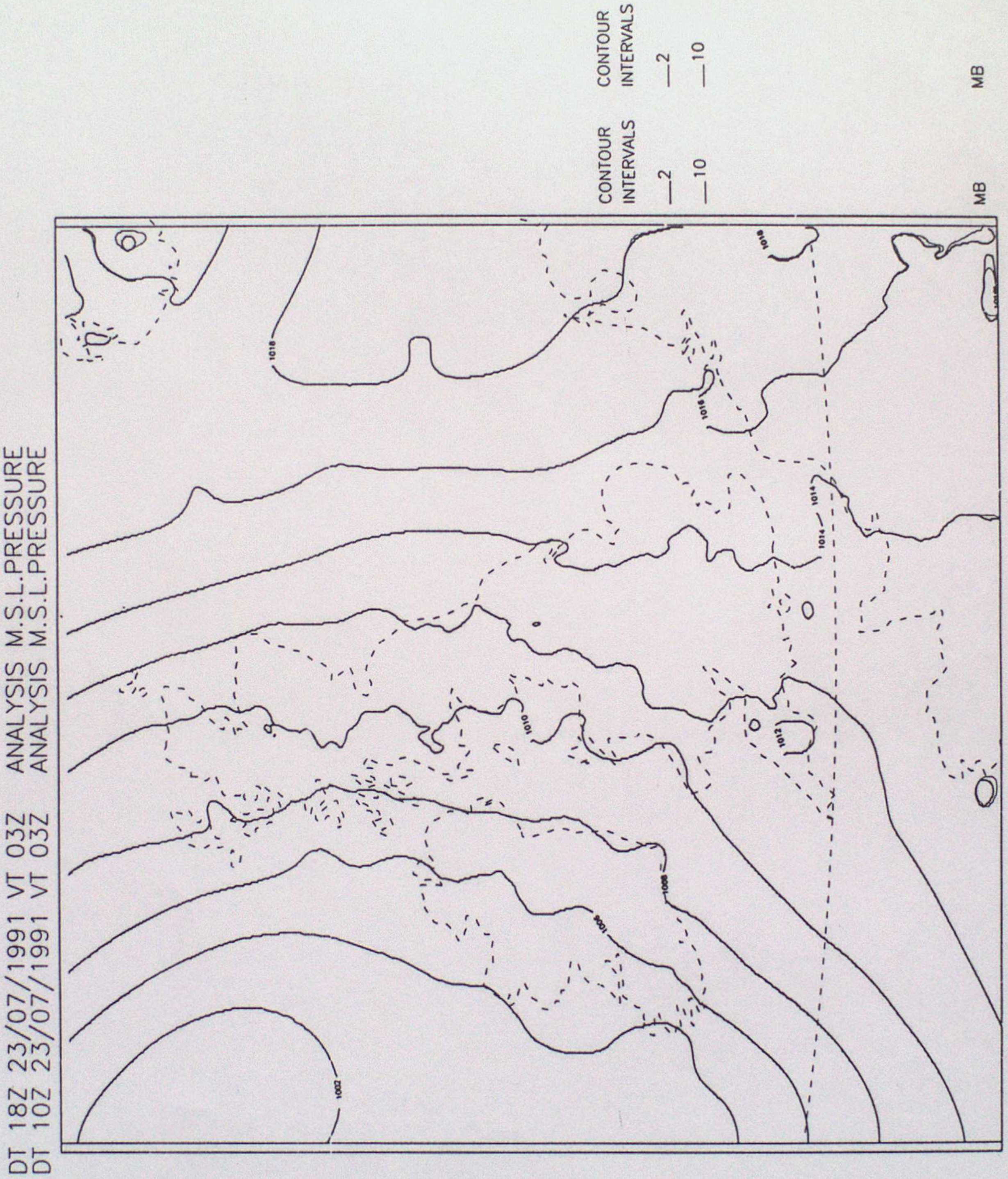

FIGURE 21: IEDGE = 0,1 ; NSCAN= 6

22

IANL = 0,1

IEDGE = 1

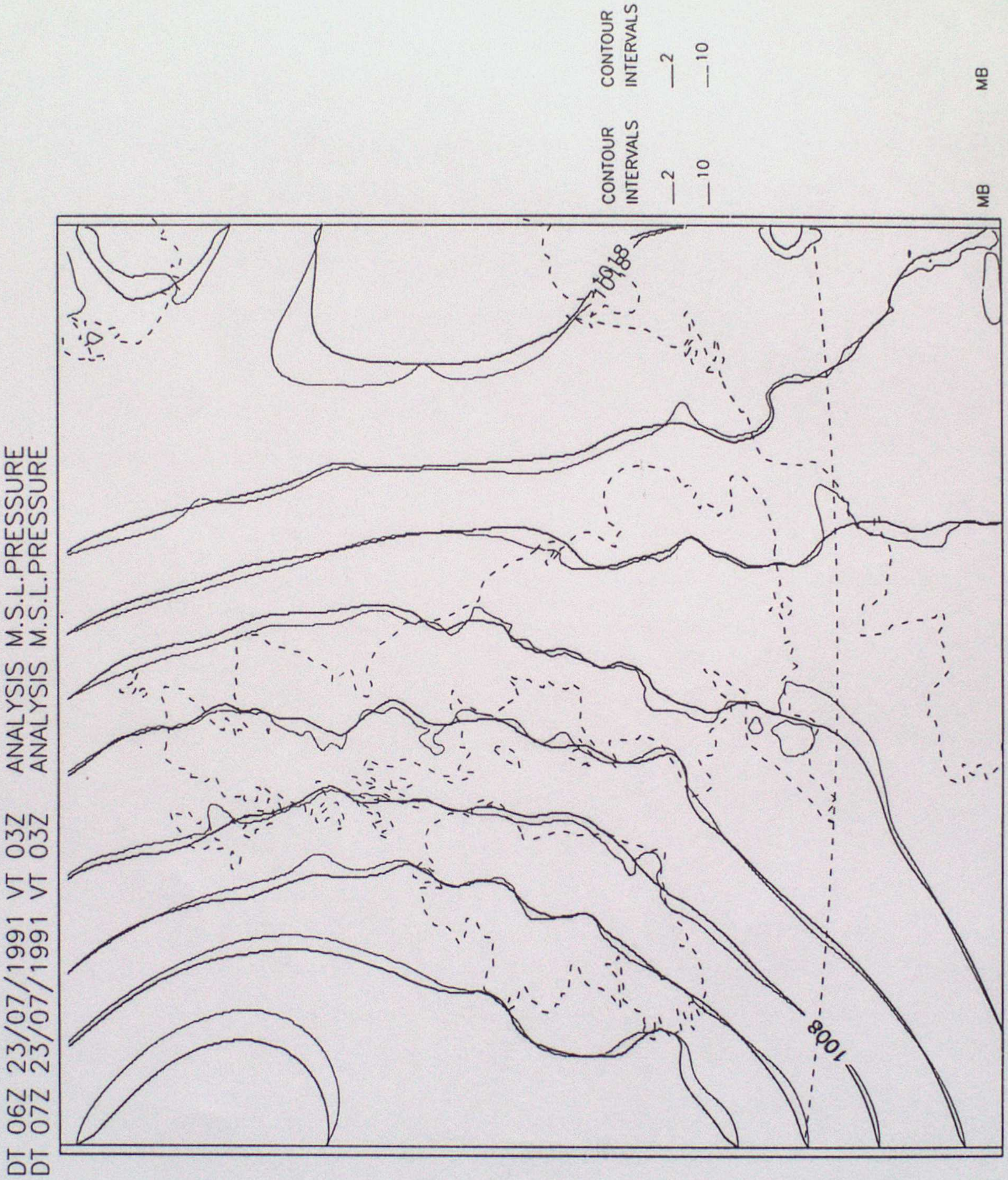

FIGURE 22: IANL = 0,1 ; IEDGE = 1

23

23

IANL=0,1
IEDGE=1
WBKG=0.02

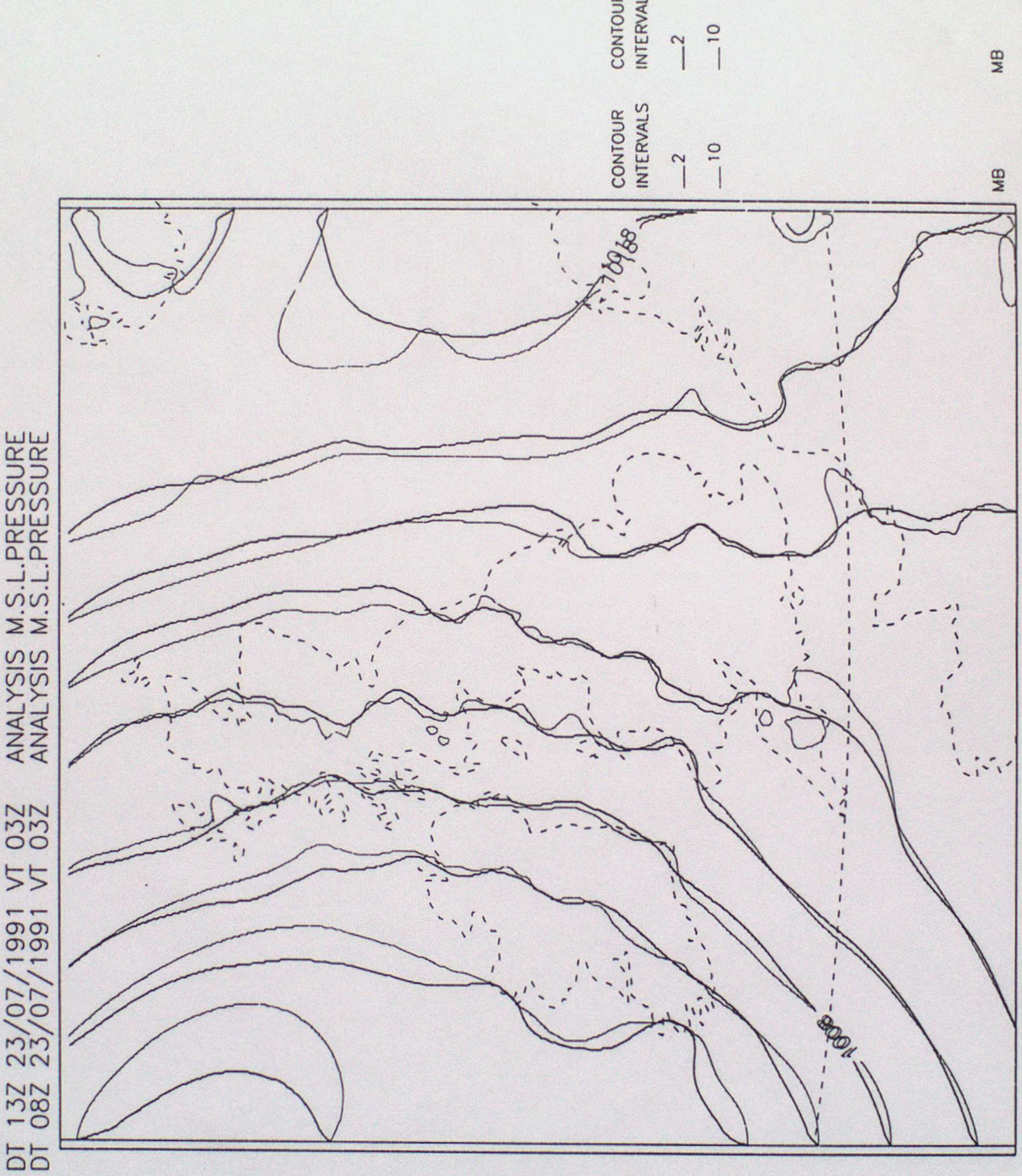

FIGURE 23: IANL = 0,1 ; IEDGE = 1 ; WBKG = 0.02

24

2A.

IANL=0,1
IEDGE=1
NSCAN=6

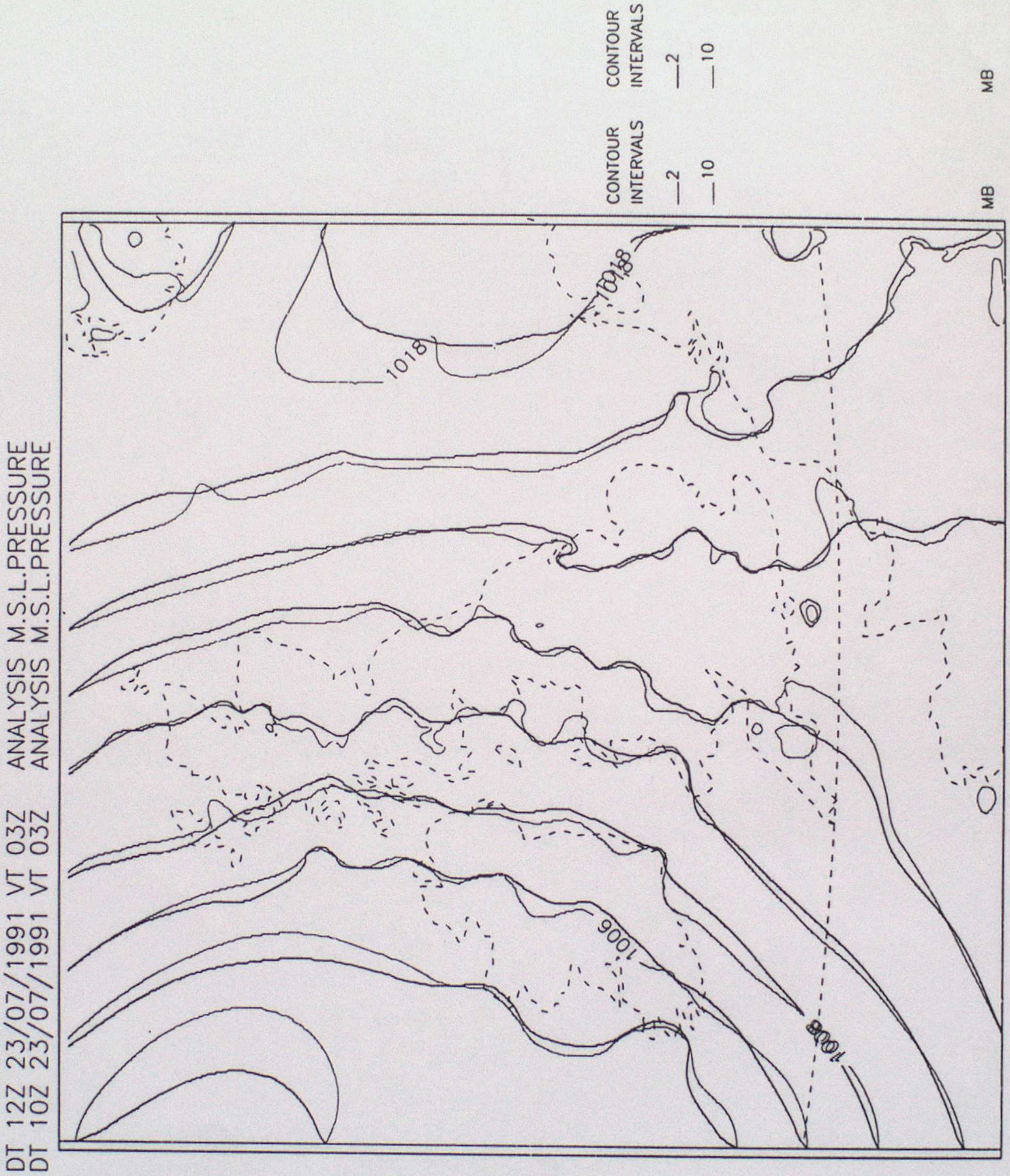

FIGURE 24: IANL=0,1 ; IEDGE=1; NSCAN=6

25

25

Quality control test

IANL=0

IEDGE=1

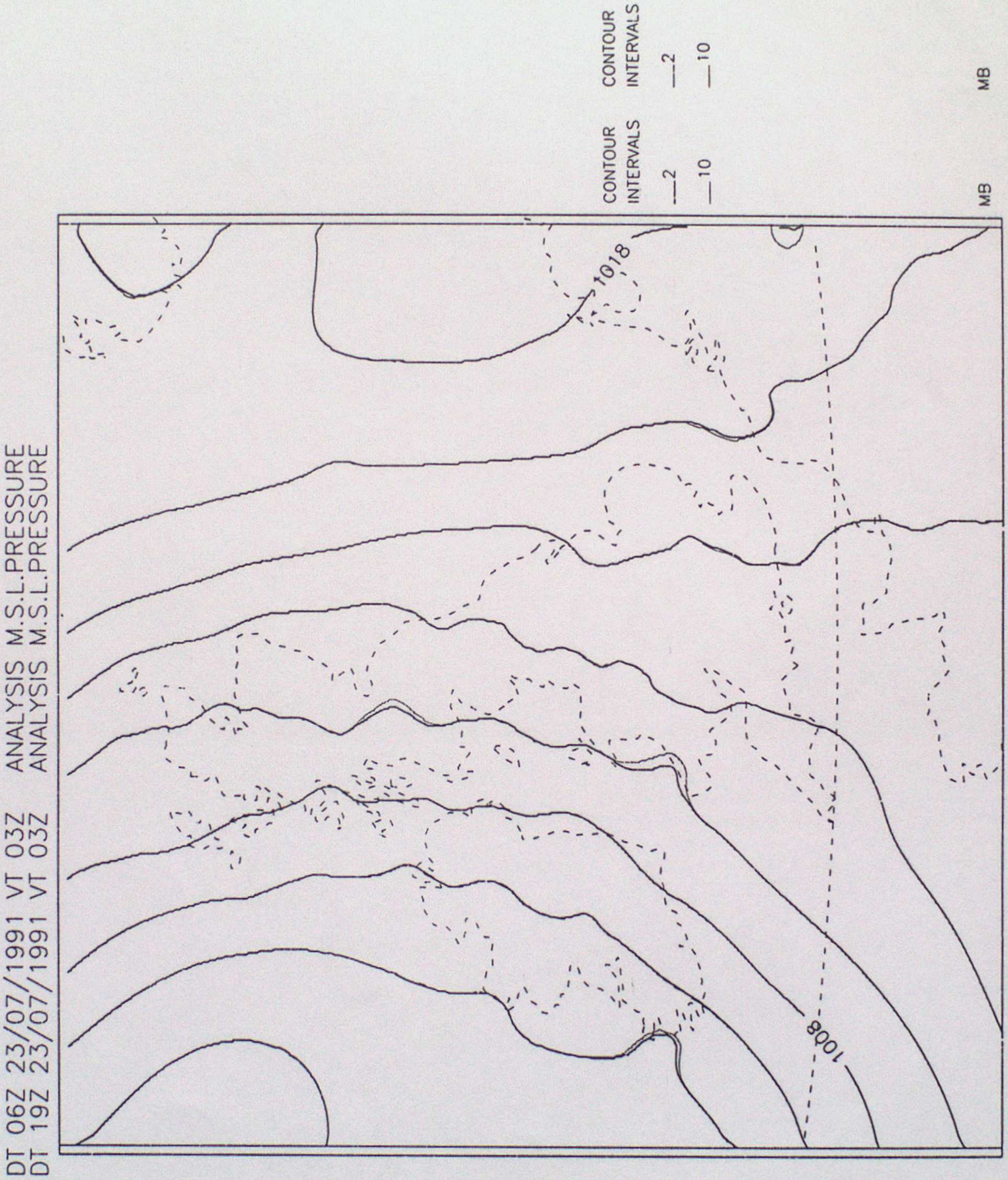

FIGURE 25: Quality control test ; IANL=0 ; IEDGE=1

26

Quality control test

IANL=0

IEDGE=1

WBKG=0.02

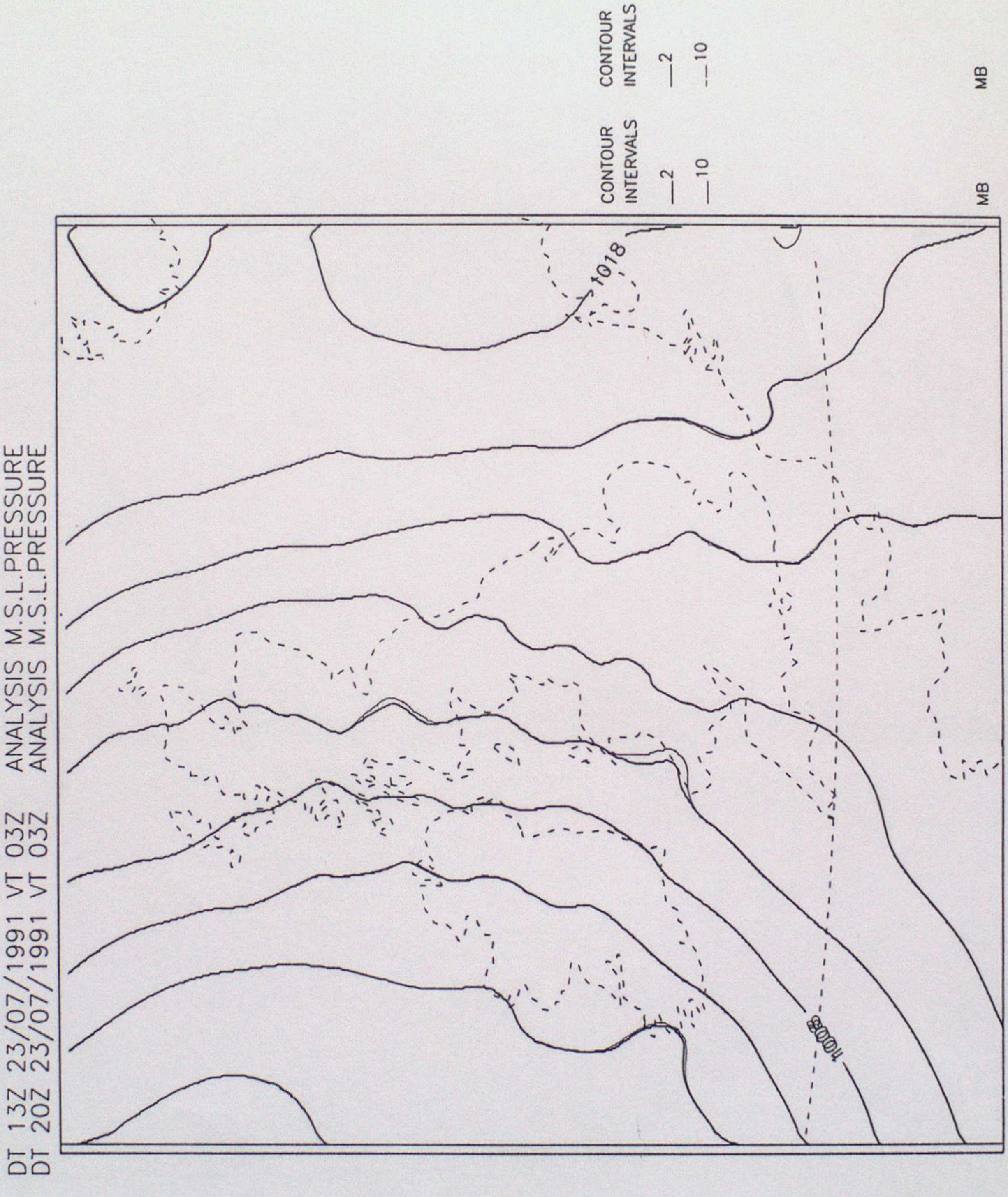

FIGURE 26: Quality Control test ; IANL=∅ ; IEDGE=1 ; WBKG=0.02

Quality control test
IANL=0
IEDGE=1
~~WBKG=0.0~~
NSCAN=6

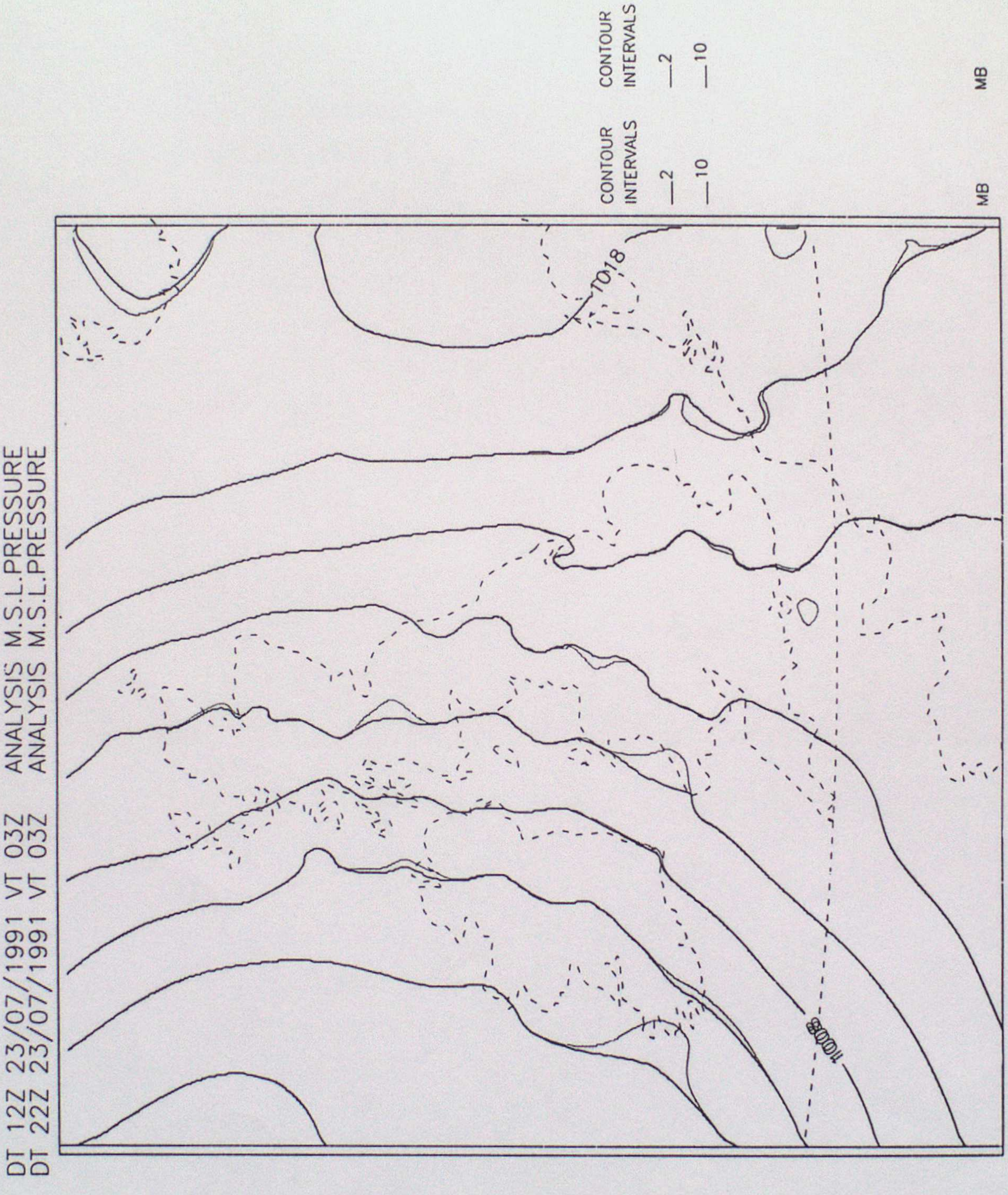

FIGURE 27: Quality Control test; IANL = Ø; IEDGE = 1; NSCAN = 6

28 28

Quality control
IANL=0
IEDGE=1

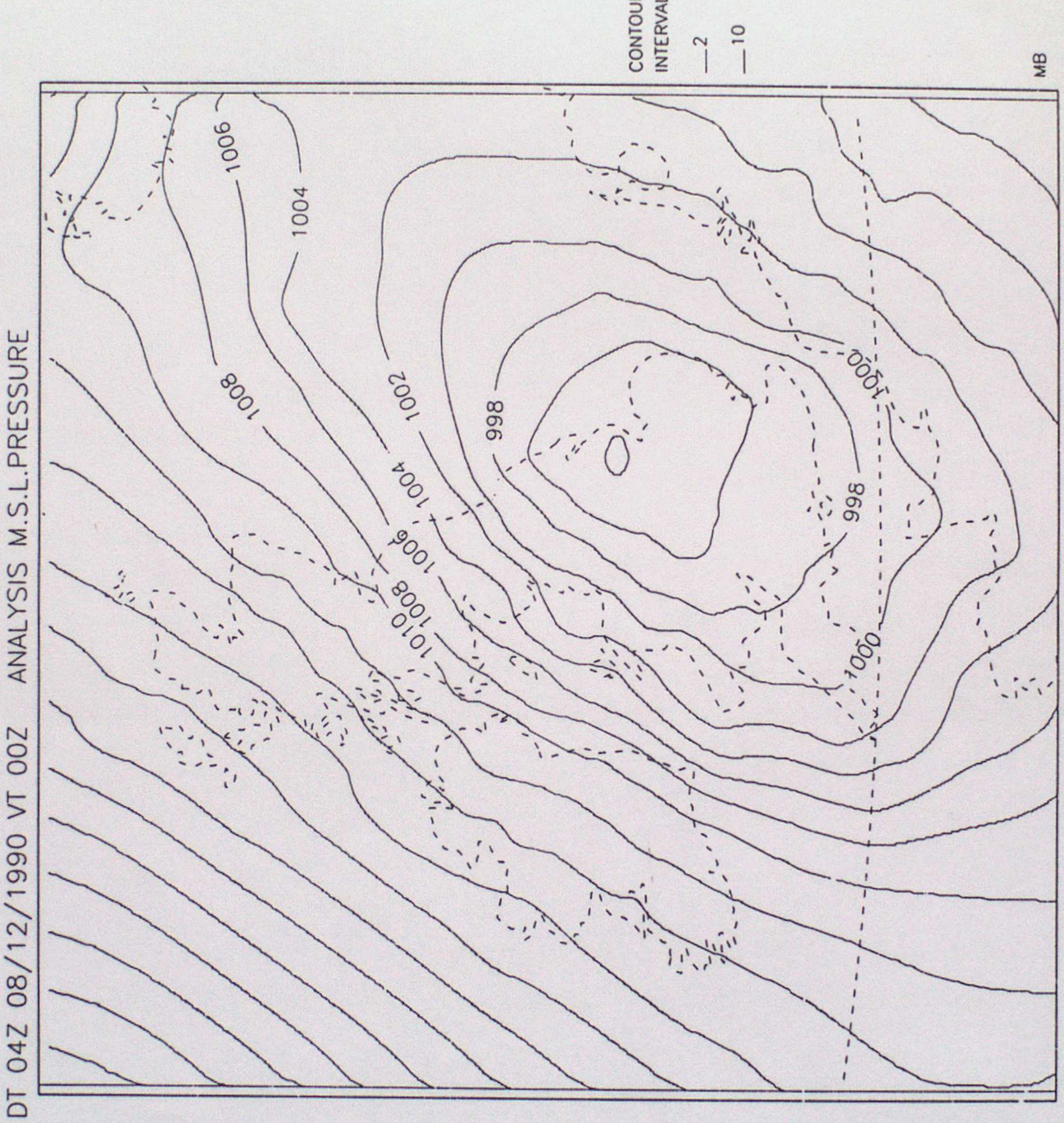

FIGURE 28: Quality Control ; IANL=0 ; IEDGE=1

29

29

Quality control

IANL=0

IEDGE=0,1

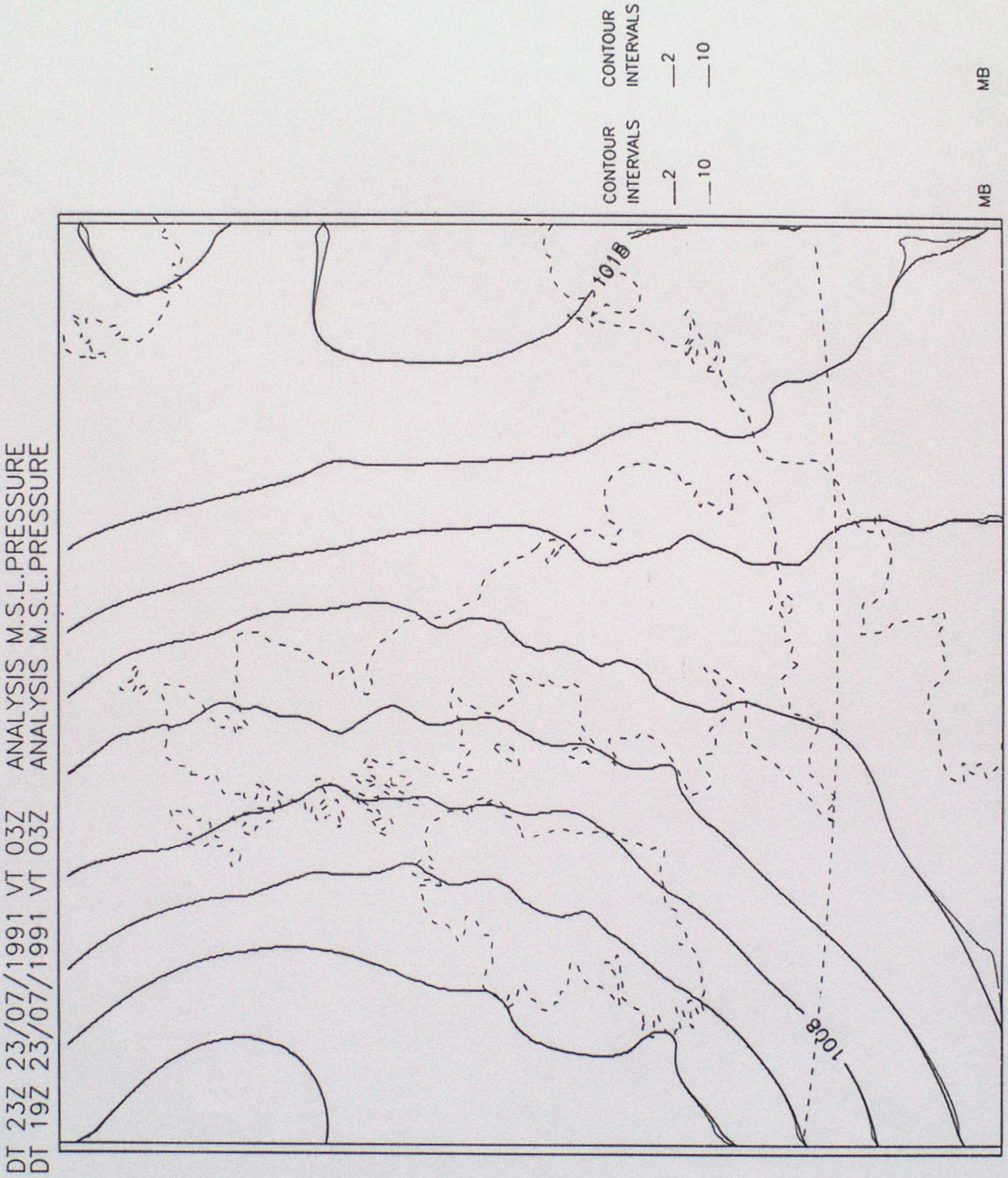

FIGURE 29: Quality Control ; IANL=0 ; IEDGE=0,1

30

30

Quality control
IANL=0
IEDGE=0,1
WBKG=0.02

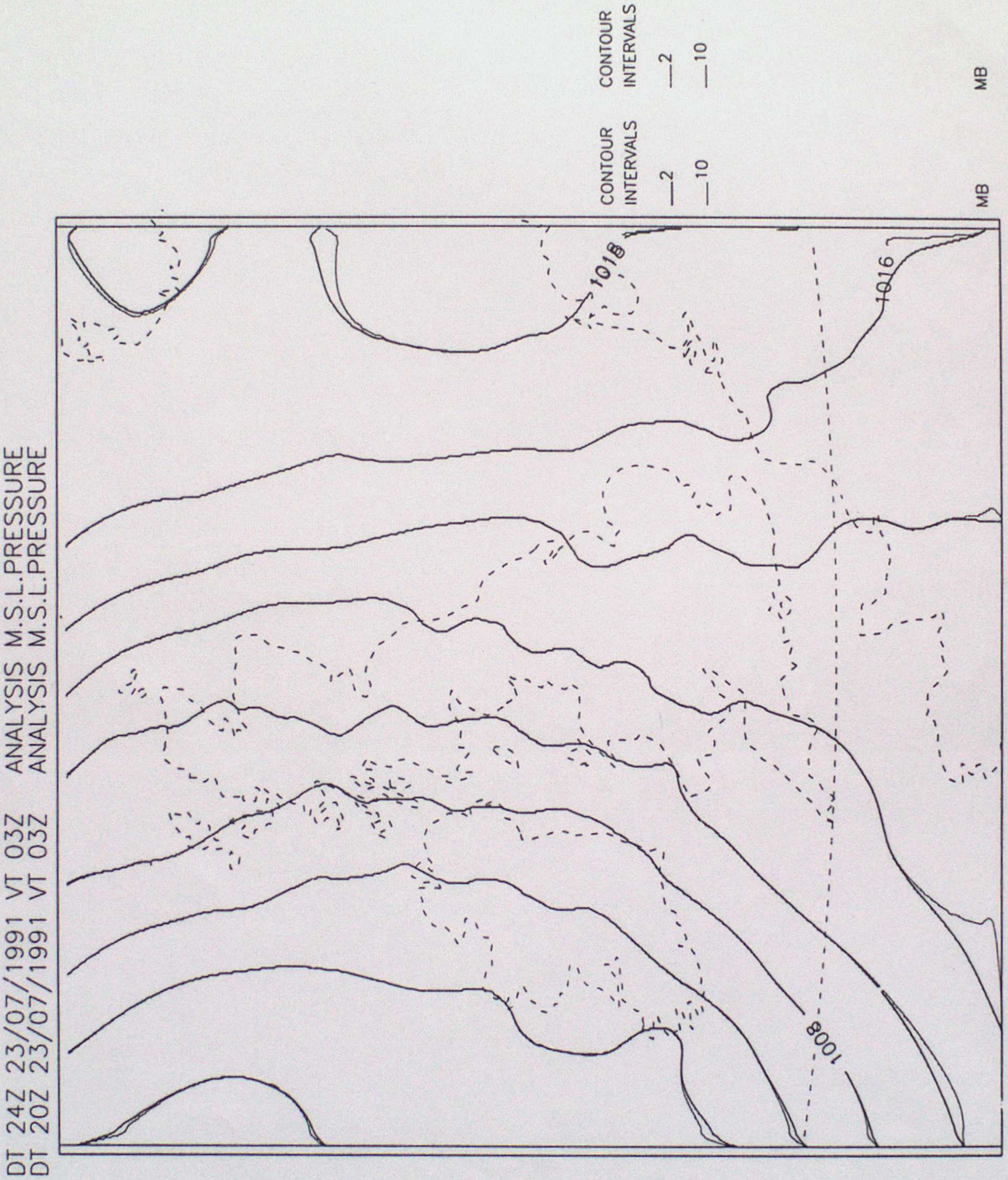

FIGURE 30: Quality Control ; IANL = Ø ; IEDGE = 0, 1 ;
WBKG = 0.02

31

Quality control
IANL=0
IEDGE=0,1
TOLMAX=8

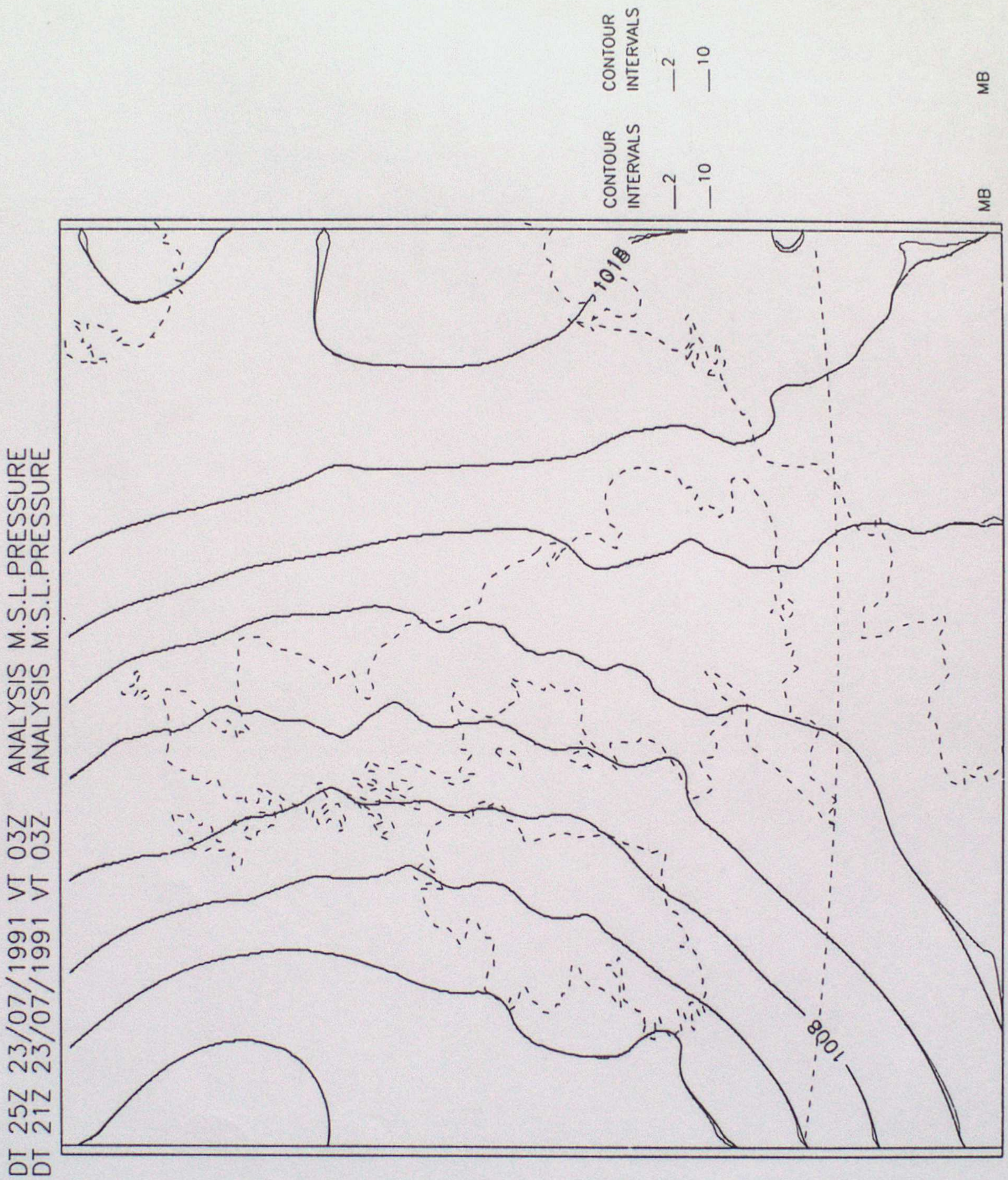

FIGURE 31 : Quality Control ; IANL = 0 ; IEDGE = 0,1 ; TOLMIN = 8

32 32

Quality control
IANL=0
IEDGE=0,1
NSCAN=6

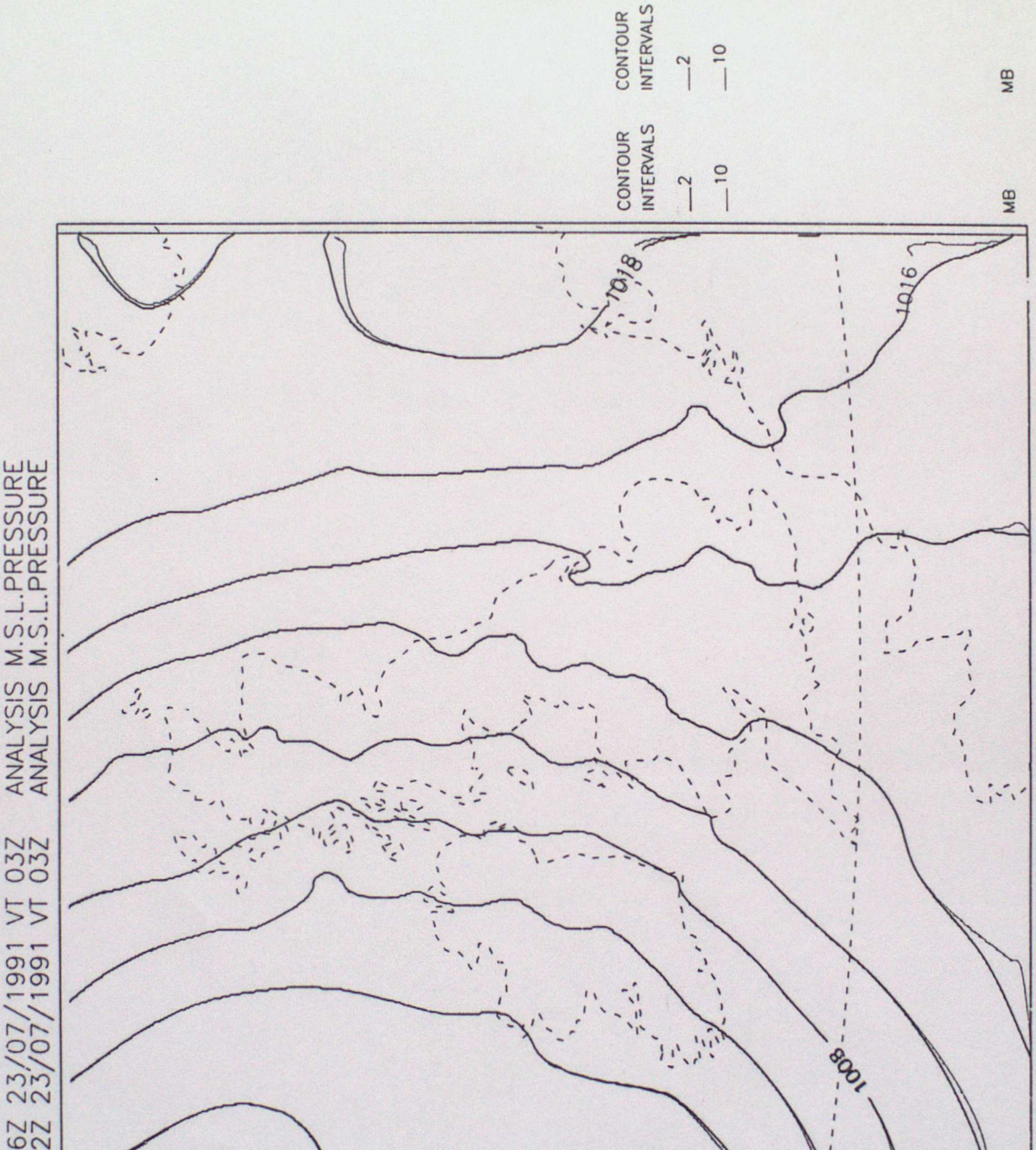

FIGURE 32: Quality Control; IANL = Ø; IEDGE = Ø,1; NSCAN = 6

WBKSEA= 0·04, 0·02, 0·01

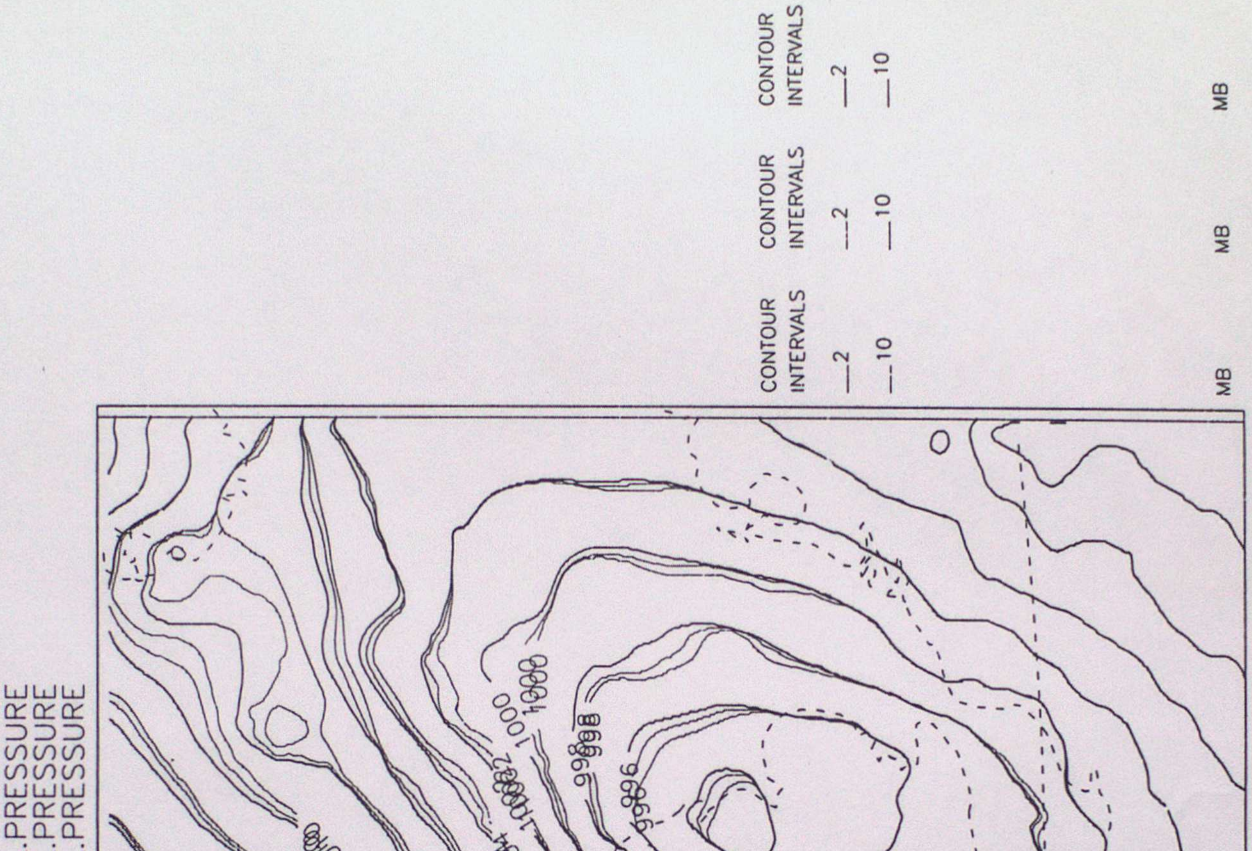

FIGURE 33: WBKSEA = 0.04, 0.02, 0.01

Hybrid

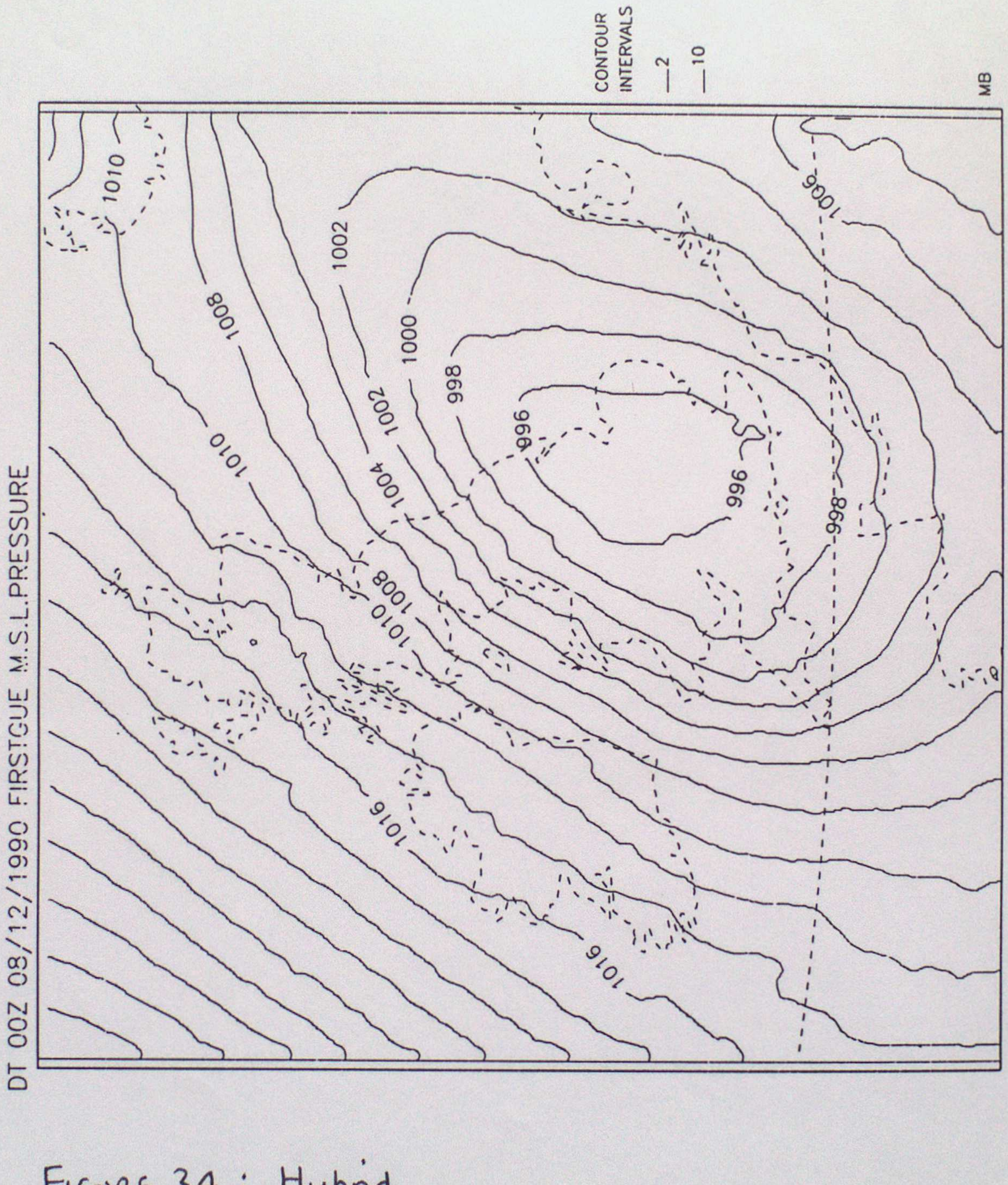

FIGURE 34 : Hybrid

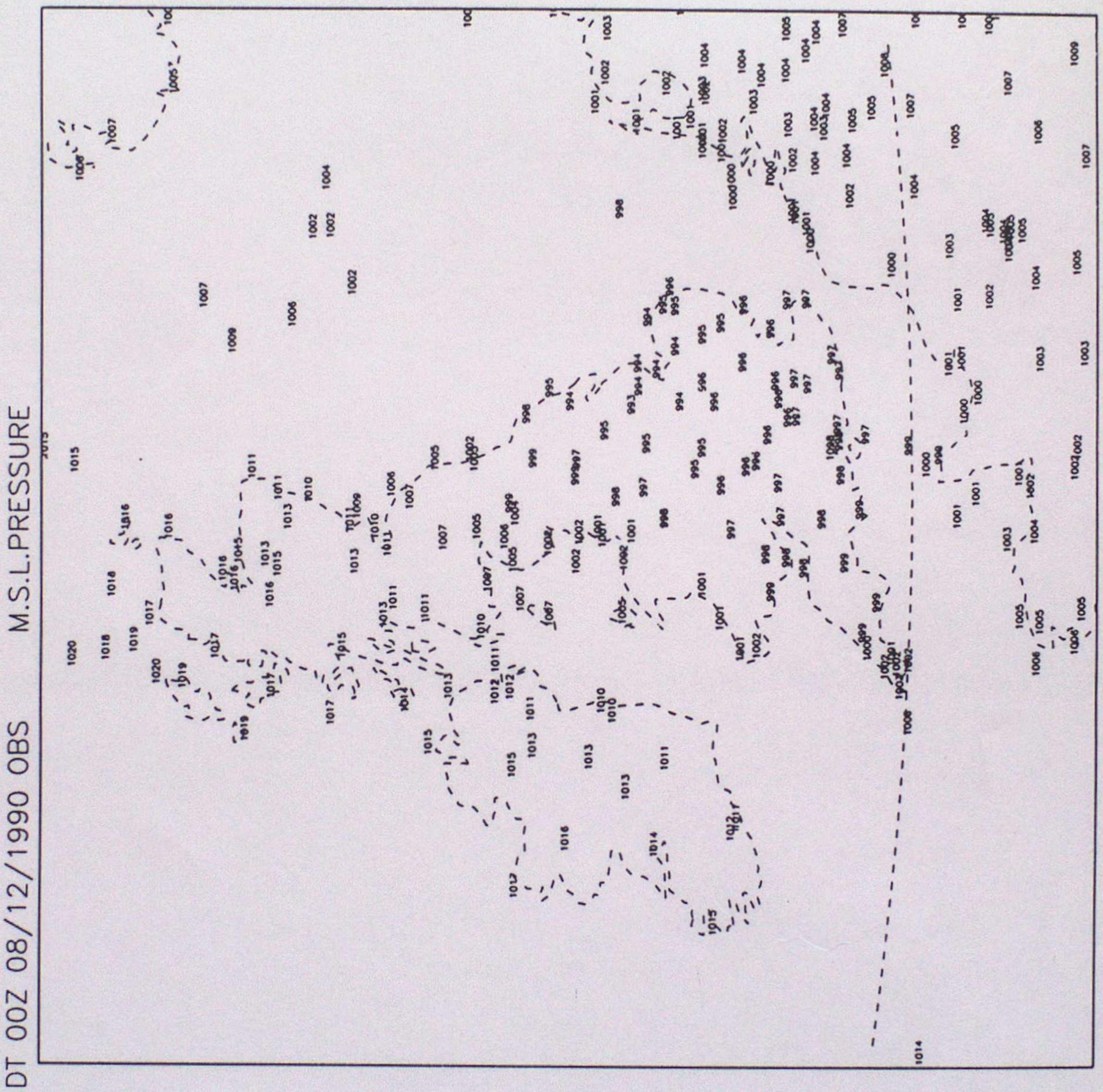

FIGURE 35: Observations

Hybrid

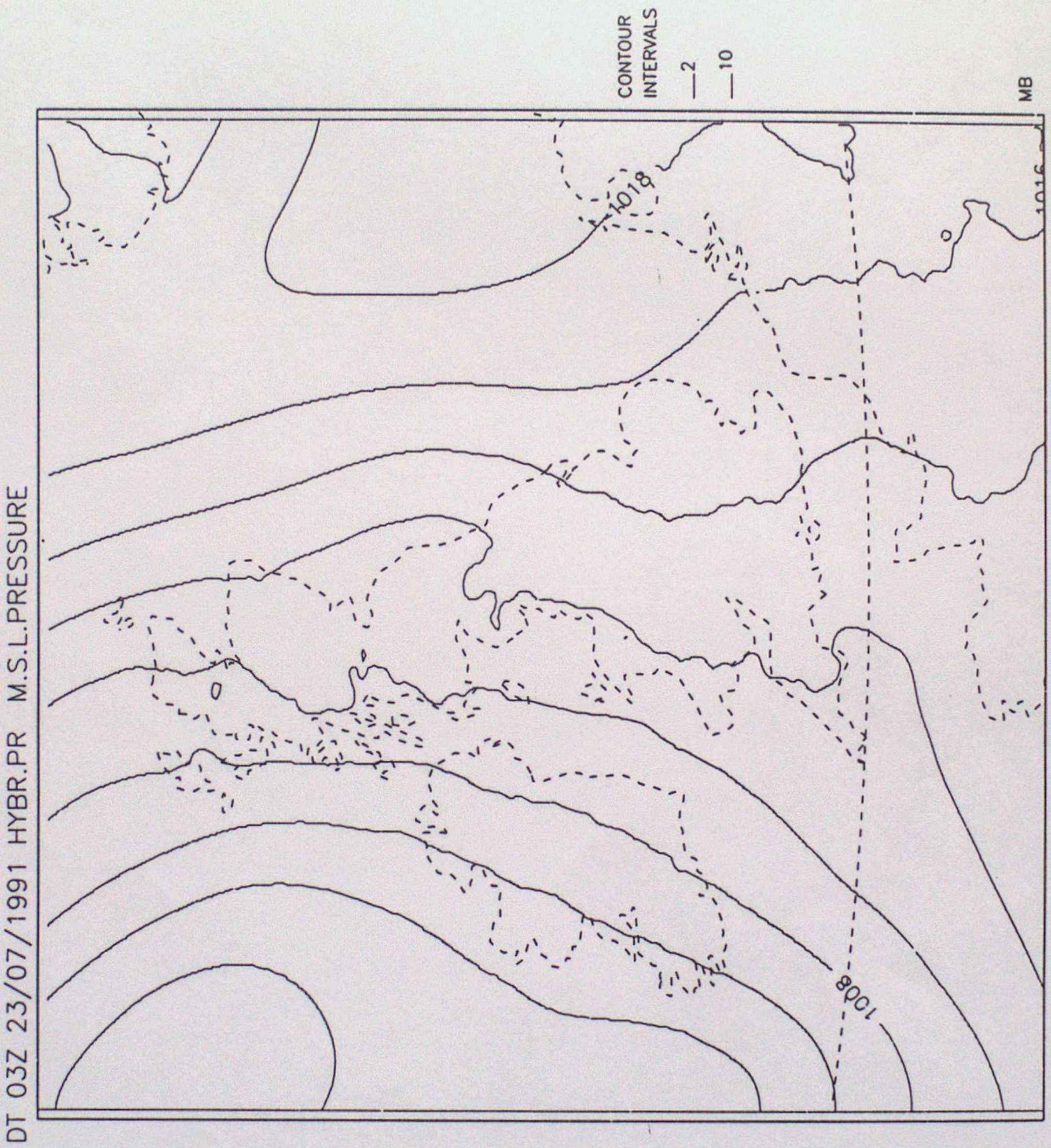

FIGURE 36: HYBRID

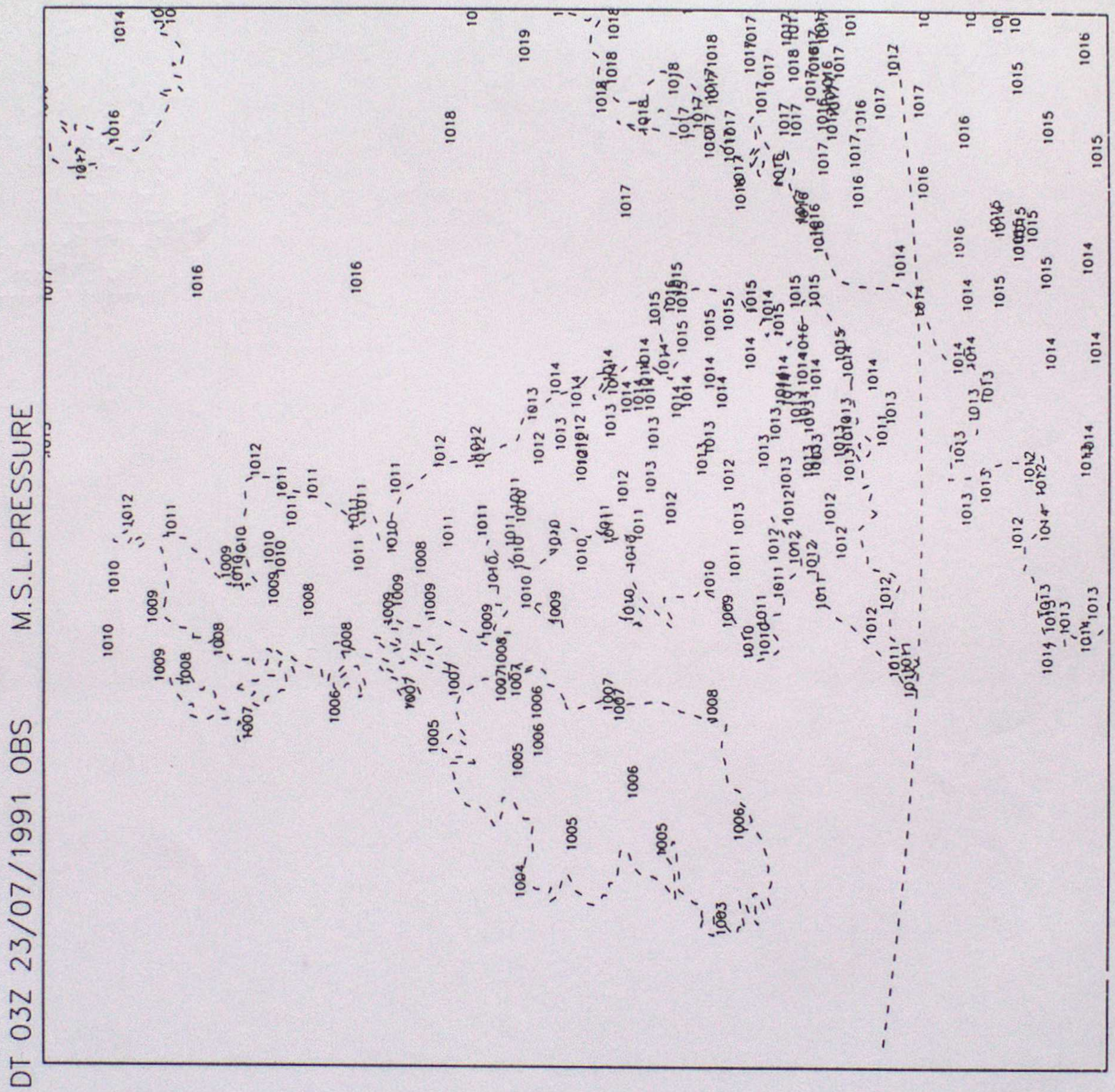

FIGURE 37: Observations.