TECHNICAL MEMORANDUM

149

Data assimilation and anomalous lows

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1. INTRODUCTION

Very occasionally an intense vortex develops at the top model level, taking the form of an 'anomalous low' in which the circulation is anticyclonic (Fig 1). This is a form of gradient wind balance in which the sum of the pressure gradient and Coriolis forces is balanced by centrifugal acceleration. This has occurred, so far, on at least three occasions: July 1988, west of Australia; June 1986, east of Madagascar; and August 1983 over South America.

Once initially established, the vortex can increase in strength during the assimilation cycles, until wind speeds increase to such a level that the model becomes unstable. In July 1988 the solution adopted was to filter the initialised analysis at the top model level until only a few waves remained (Simmons, personal communication).

It is difficult to envisage how such a circulation could arise naturally. During the initial stage of development, air parcels accelerating in response to an imposed pressure distribution will be deflected by the Coriolis force in such a way as to establish cyclonic circulation around a low, or anticyclonic circulation around a high. However, once (artificially) introduced into the model, these vortices can prove remarkably stable. The 1983 vortex was happily advected along at the top model level for several days in the forecast, reaching southwest of Australia by day ten with little change of amplitude (Simmons and Jarraud, 1984). Simmons and Jarraud (1984) show also that the feature can cause problems in the forecast, in their case, triggering instabilities in the vicinity of the polar night jet.

The purpose of this study was to investigate how such an anomalous (and probably erroneous) feature can be formed and developed during the assimilation, and to devise a solution.

2. THE PROBLEM

In the case of anticyclonic flow (clockwise in the northern hemisphere, anticlockwise in the southern hemisphere) the Coriolis and centrifugal forces are opposed to one another. Normally the centrifugal force is a relatively small term, and a near balance exists between Coriolis and pressure gradient forces.

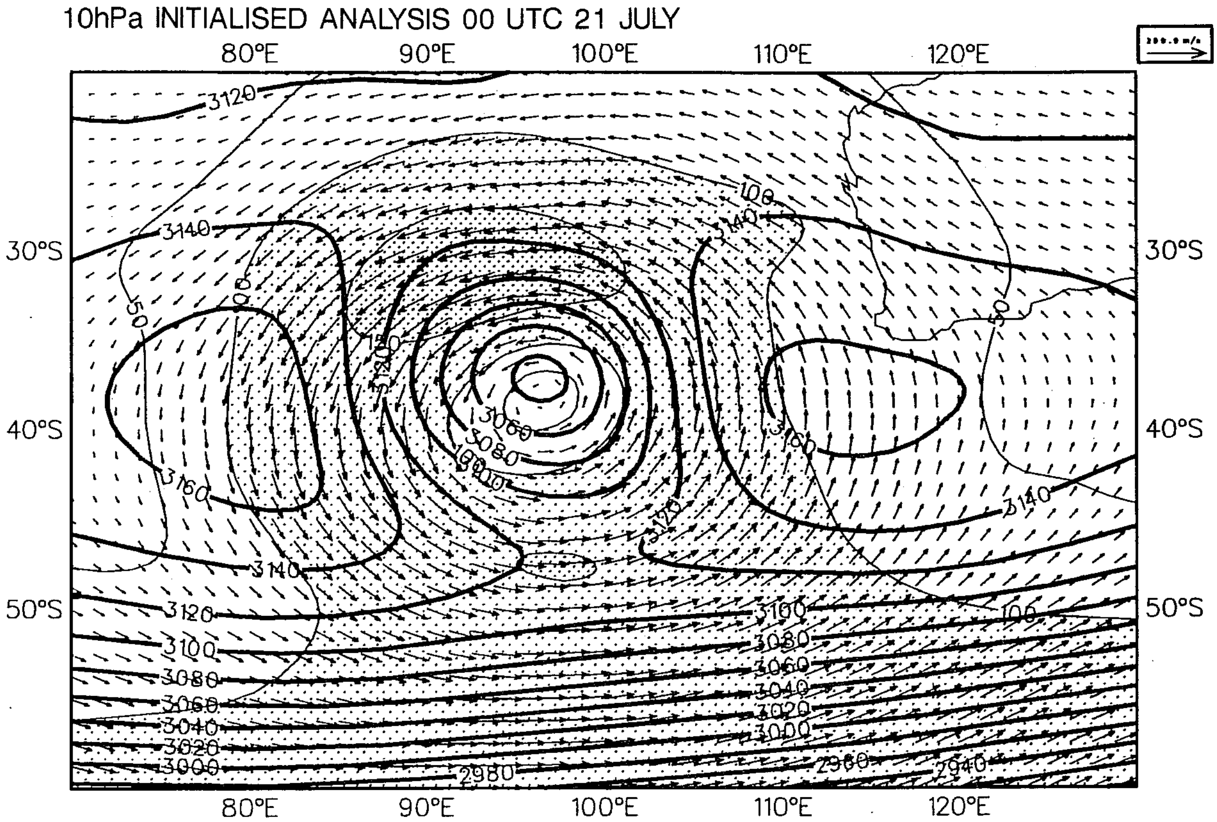

Fig. 1 10 hPa initialised analysis of height and wind for 0 UTC 21st July 1988. Wind vectors are drawn as arrows, with length proportional to wind speed. Isotacs are drawn as light solid lines with a contour interval of 50 m/s; values above 100 m/s are shaded. Height field drawn as thick solid lines, contour interval 20 dam.

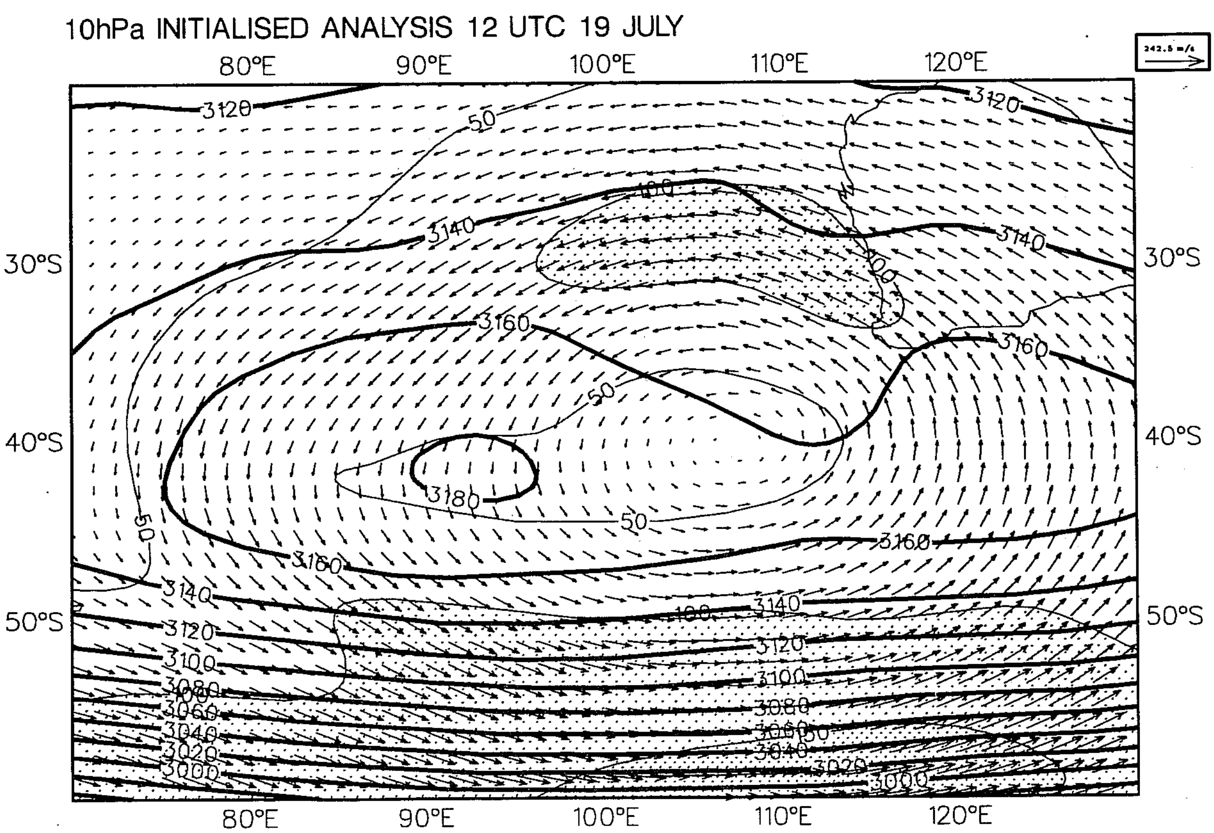

Fig. 2 The 10 hPa initialised analysis for 12 UTC 19th July 1988. Plotting convention as for Fig. 1.

In regions of high wind speed and significant flow curvature, and providing the horizontal scale is not too small, a primary balance can be established between the Coriolis and centrifugal forces. In the southern hemisphere this can take the form of anticyclonic circulation around a high (a 'regular' high), or even anticyclonic circulation around a low (an 'anomalous' low), or the pressure field may be flat (inertial balance).

The most plentiful observations at the top of the model in the southern hemisphere are temperature (mass) observations. Suppose such a gradient wind balance exists in the first guess, and the accompanying pressure gradients are weak, then mass observations indicating a slight pressure maximum in such a region will change the flow type to that of a 'regular' high. The analysis increment takes the form of a weak (geostrophic) high, tending to intensify the anticyclonic flow. The feature is almost sub-tropical, the vertical scale is short, but the horizontal scale is also short; in practice the wind field dominates in the initialisation. The wind increment is accepted by the initialisation and balance re-established in the presence of the enhanced anticyclonic flow by forming an 'anomalous' low - effectively discarding, or even reversing the mass increment.

Once established the anomalous low will be maintained in the forecast and will appear in the first guess for the subsequent analysis. If any mass observations are available an attempt will be made to remove this erroneous low by adding geostrophic increments to the first guess. The mass increment will fill the low, but the associated wind increment will increase the anticyclonic winds still further. The initialisation will ignore the mass information and adjust to the wind field - further deepening the low. This process will, presumably, continue at each cycle data is available until the winds increase to such an extent that the six hour forecast becomes unstable and 'blows up'.

3. AN EXAMPLE

Fig 2 shows the initialised mass and wind analysis at 10 hPa on 12 UTC on 19 July 1988, the day before problems become apparent. There are large regions with winds of over 50 m/s, and a significant area of over 100 m/s. Near geostrophic balance exists where the flow is relatively weak e.g. west of 80°E, or where the curvature is weak e.g. 105°E, 28°S.

Fig. 3 The 10 hPa first guess field for 0 UTC 21st July 1988. Plotting convention as for Fig. 1.

Fig. 4 The first guess for 10 hPa 0 UTC 21st July 1988 minus the, uninitialised, analysis for the same time (this is minus the change made by the analysis to the first guess). Wind difference vectors are drawn as arrows, with length proportional to wind speed. Isotacs are drawn as light solid lines with a contour interval of 20 m/s; differences greater than 40 m/s are shaded. The height field differences are drawn as thick solid lines for positive values and thick dashed lines for negative values; contour interval 5 dam.

Fig. 5 The 10 hPa uninitialised analysis for 0 UTC 21st July 1988. Plotting convention as for Fig. 1.

Fig. 6 The uninitialised analysis for 10 hPa 0 UTC 21st July 1988 minus the initialised analysis for the same time (this is minus the change made by the initialisation to the analysis). Plotting convention as for Fig. 4.

Fig. 1 10 hPa initialised analysis of height and wind for 0 UTC 21st July 1988. Wind vectors are drawn as arrows, with length proportional to wind speed. Isotacs are drawn as light solid lines with a contour interval of 50 m/s; values above 100 m/s are shaded. Height field drawn as thick solid lines, contour interval 20 dam.

Fig. 7 The 10 hPa first guess field for 6 UTC 21st July 1988 (this is the six hour forecast from the initialised analysis shown in Fig. 6). Plotting convention as for Fig. 1.

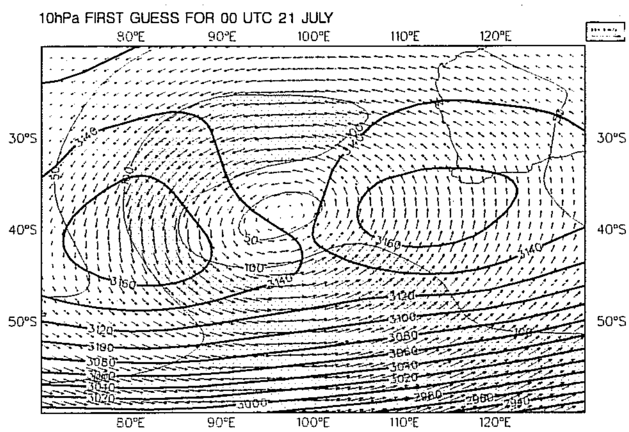

Fig. 3

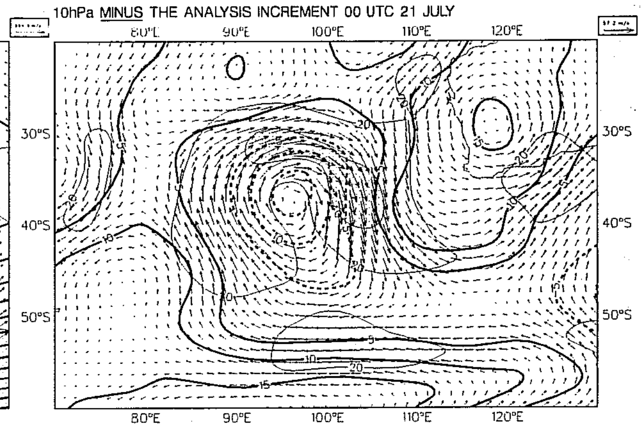

Fig. 4

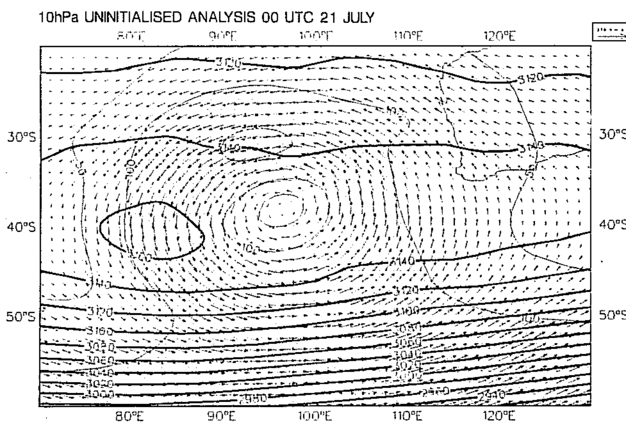

Fig. 5

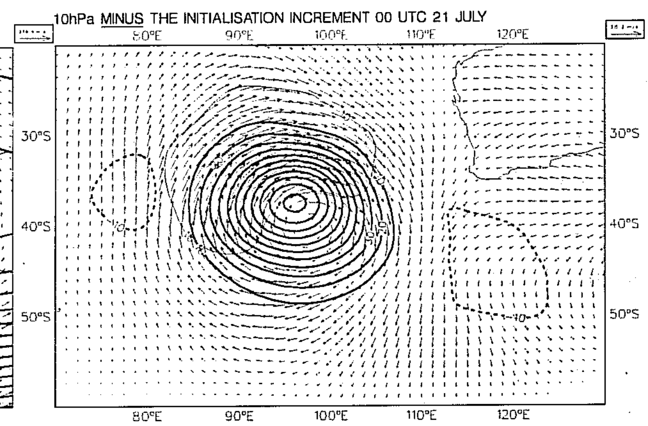

Fig. 6

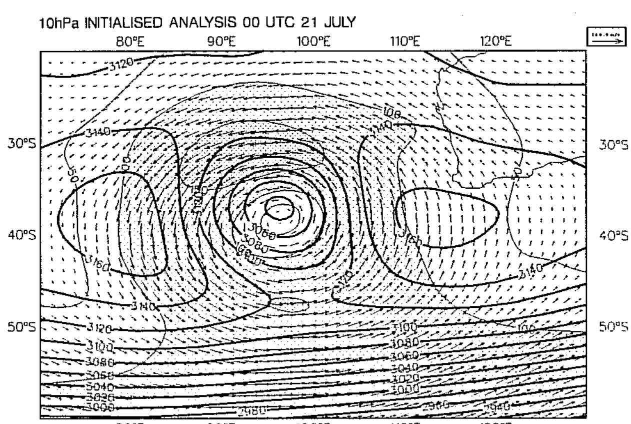

Fig. 1

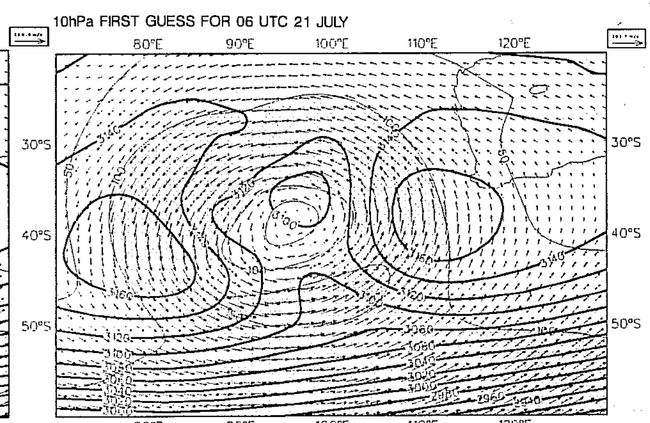

Fig. 7

Over large parts of the domain a more general gradient wind balance is evident. In regions of strong wind, and where the pressure gradient is weak (e.g. 120°E, 35°S), the flow appears to be in inertial balance.

Fundamental assumptions of the current analysis scheme are that the first guess field is in 'normal' gradient wind balance; that the data represent fields that are in 'normal' gradient wind balance; and that the forecast errors, which are the difference between these two, are in near geostrophic balance. This assumption cannot easily be modified within the current framework. It is clear that such an assumption is invalid in strongly ageostrophic flows.

Such balances are, however, acceptable to, and maintained by, the initialisation and forecast model. Fig 3 shows the first guess for 0 UTC on 21 July 1988. If data are available, the analysis will seek to 'correct' the first guess by adding geostrophically balanced increments. Fig 4 shows first guess minus uninitialised analysis, which is minus the analysis increment in the usual parlance. The analysis (Fig 5) shows increased anticyclonic flow and the pressure gradients have been almost wiped out. Initialisation adjusts the height field to the wind field, the increments (Fig 6 shows uninitialised analysis minus initialised analysis, which is minus the initialisation increment in the usual sense) not only remove the analysis change to the height field but also considerably deepen the low in the pressure field. The wind increment is relatively small and is such as to further increase the anticyclonic circulation. The initialised analysis is shown in Fig 1. The vortex is maintained by the forecast and presented to the subsequent analysis in the form of the first guess (Fig 7, cf Fig 1).

Wind speed drops sufficiently between 10 hPa and 30 hPa such that the winds at the second model level are in near geostrophic balance. At this level attempts by the analysis to remove the feature by adding geostrophic corrections to the first guess are successful. In this way the feature is confined by the assimilation to the top model level. A low is present at both 10 and 30 hPa, but with anticyclonic winds at 10 hPa and cyclonic winds at 30 hPa producing strong vertical wind shear (Fig 8, cf Fig 1). It is interesting to note that neither the initialisation nor the forecast model finds any difficulty with this arrangement.

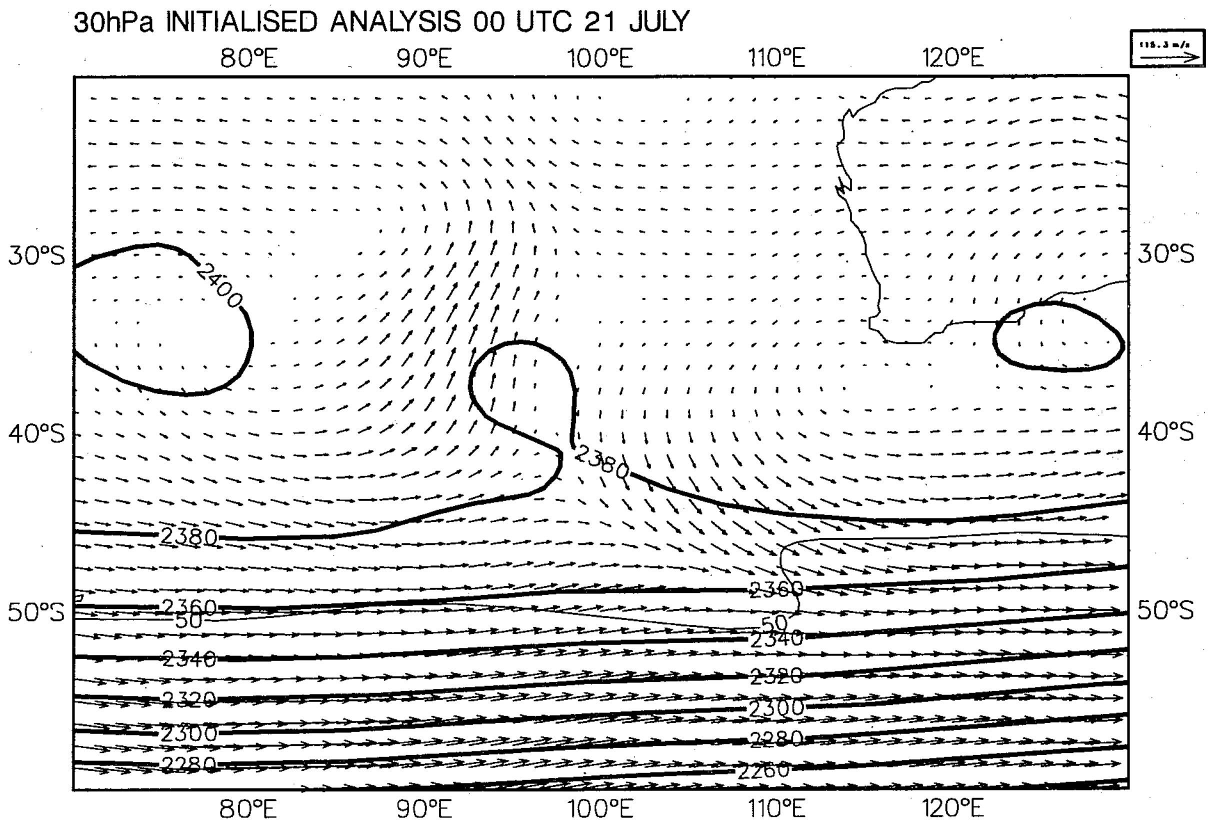

Fig. 8 The 30 hPa initialised analysis for 0 UTC 21st July 1988. Plotting convention as for Fig. 1.

Figs 9 through 11 show the evolution of the feature, in terms of the vertical component of absolute vorticity at 10 hPa, cycle by cycle, from 0 UTC on the 20 July 1988 through to 18 UTC on 22 July 1988. Units are 10^{-6} sec^{-1}. Top figures show the first guess, middle figures the uninitialised analysis; and bottom figures the initialised analysis. 0 UTC is on the left, and 18 UTC on the right. Things are fairly quiet until the 20th. At 0 UTC the analysis makes a change which is amplified by the initialisation, at this stage it is slightly weakened by the six hour forecast. Nothing much happens at 6 UTC (no data), and the first guess, uninitialised analysis and initialisation are much the same (clearly indicating that data is triggering the problem). At 12 UTC data is available, a larger change is made by the analysis, and a further intensification by the initialisation. Again at 18 UTC there was no data, and the feature is left unchanged. Similar dramatic amplification occurs at 0 UTC and 12 UTC on the 21st and 22nd.

The above scenario is one in which the vortex gradually develops through the process of data assimilation due to an intrinsic instability of the assimilation technique. This was the case for the 1988 and 1986 examples. The 1983 example (Simmons and Jarraud, 1984) can be attributed to the acceptance by the analysis of a single erroneous radiosonde, which immediately produced a strong perturbation at the top model level in the vicinity of the observation.

4. A SOLUTION

The instability in the assimilation occurs when the winds are strongly anti-cyclonic, in this case the vertical component of the absolute vorticity is close to zero (or even positive in the southern hemisphere). When the feature develops, the absolute vorticity is strongly positive (southern hemisphere), being several times larger than f. A convenient test for the likelihood of this instability occurring is for the absolute vorticity at the top model level to be of the 'wrong sign'.

The modification used is as follows. Within the analysis the vertical component of the absolute vorticity of the first guess at the top model level is calculated for each analysis box. If south of -15°S (or north of 15°N) and this quantity exceeds $.2*10^{-4}$ sec^{-1} (is lower than $-.2*10^{-4}$ sec^{-1}), then all the observations within that box at 50 hPa and higher are not used in the

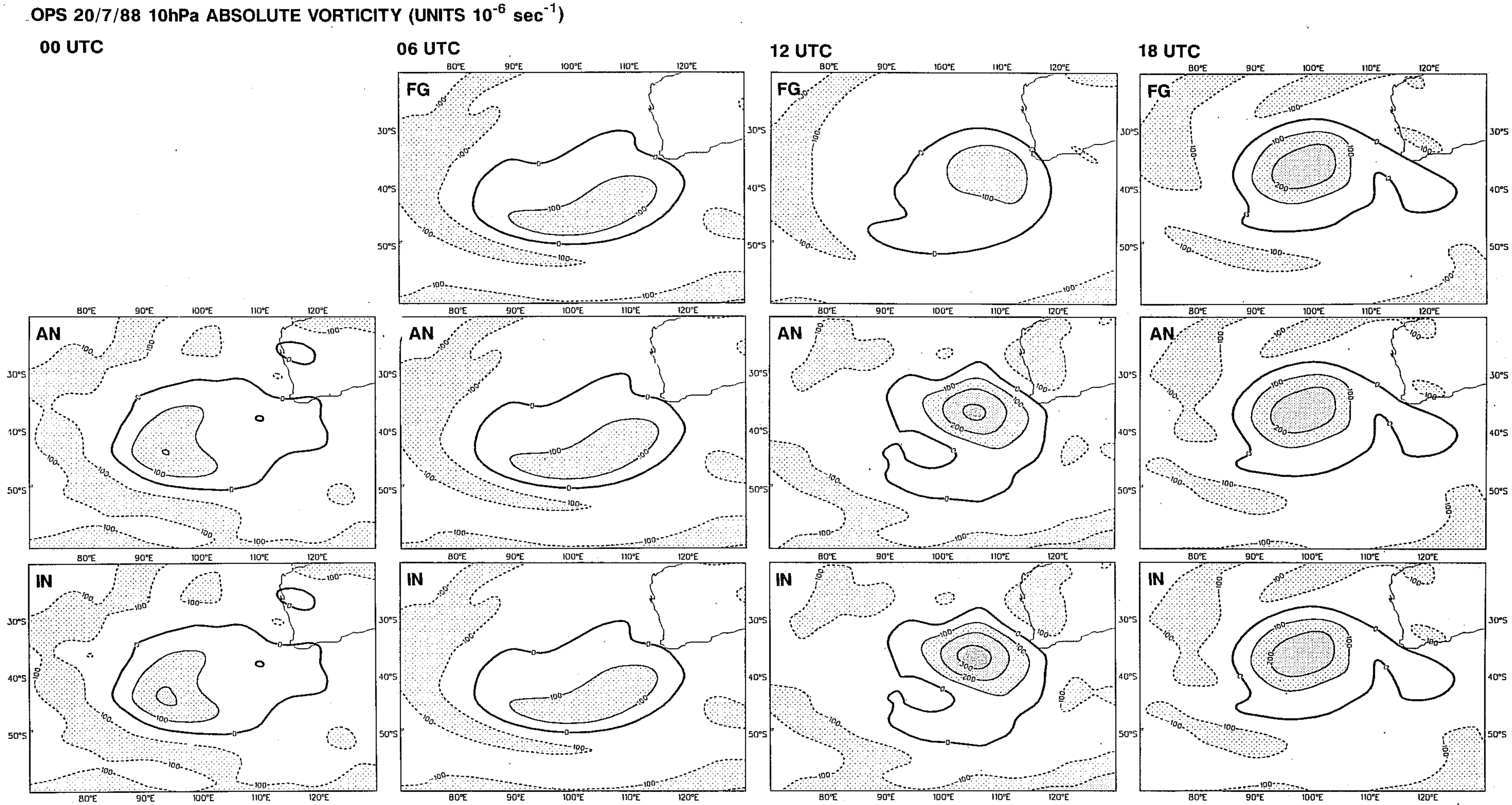

Fig. 9 The vertical component of absolute vorticity at 10 hPa on the 20th July 1988. The 1st (left) column shows values for 0-UTC; the 2nd column for 6 UTC; the 3rd column for 12 UTC; and the 4th (right) column for 18 UTC. The top row shows the first guess used for the analysis at these times (this is the six hour forecast from the initialised analysis of six hours earlier); the centre row shows the uninitialised analysis at these times; and the lower row the analyses after initialisation. Contour units are 10^{-6} s^{-1}, contour lines are drawn at intervals of $100*10^{-6}$ sec^{-1}; the zero contour is drawn as a heavy solid line; positive values as thin solid lines; and negative values as thin dashed lines. Values of over 10^{-4} sec^{-1}, or less than -10^{-4} sec^{-1}, are shaded.

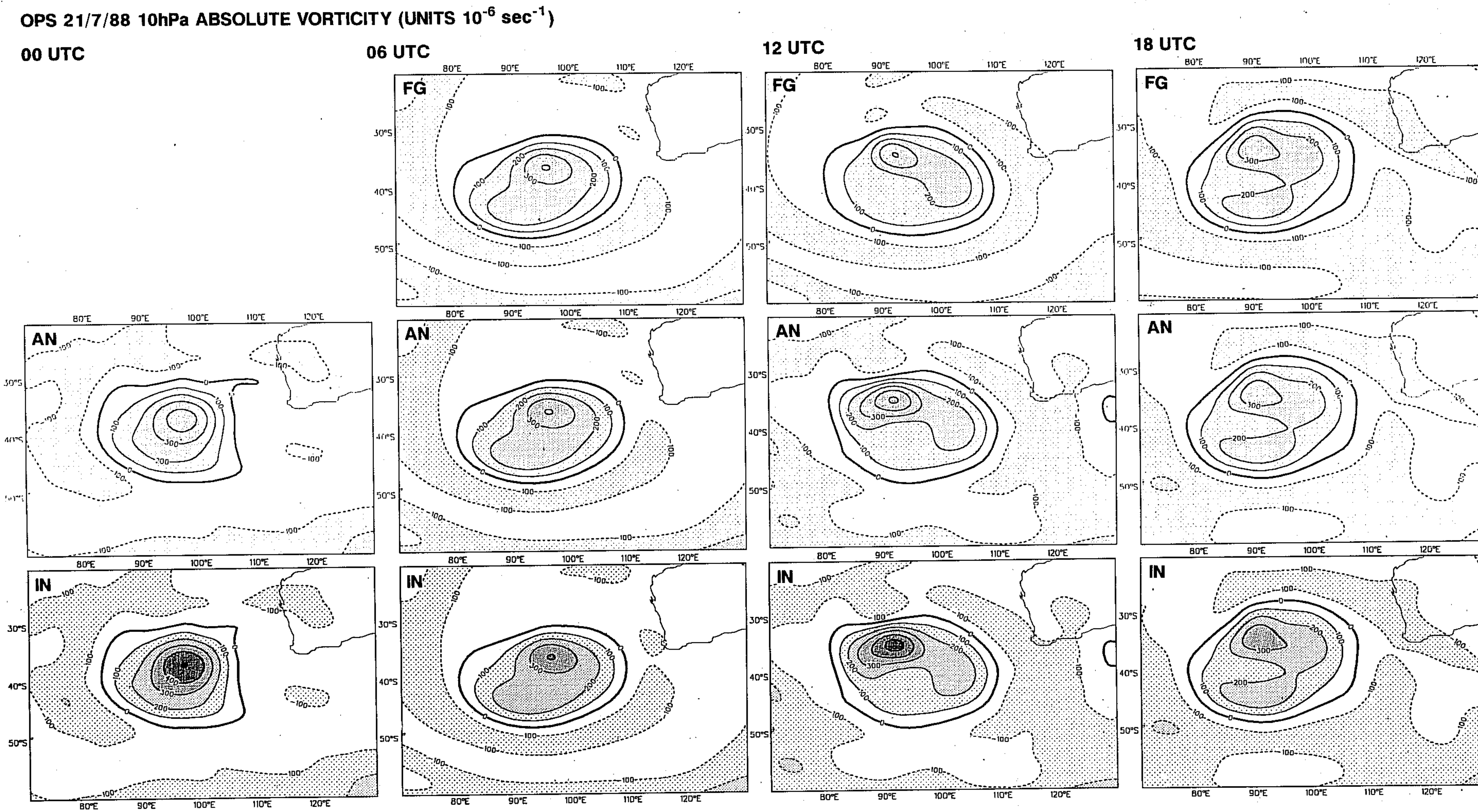

Fig. 10 As Fig. 9, but for the 21st July 1988.

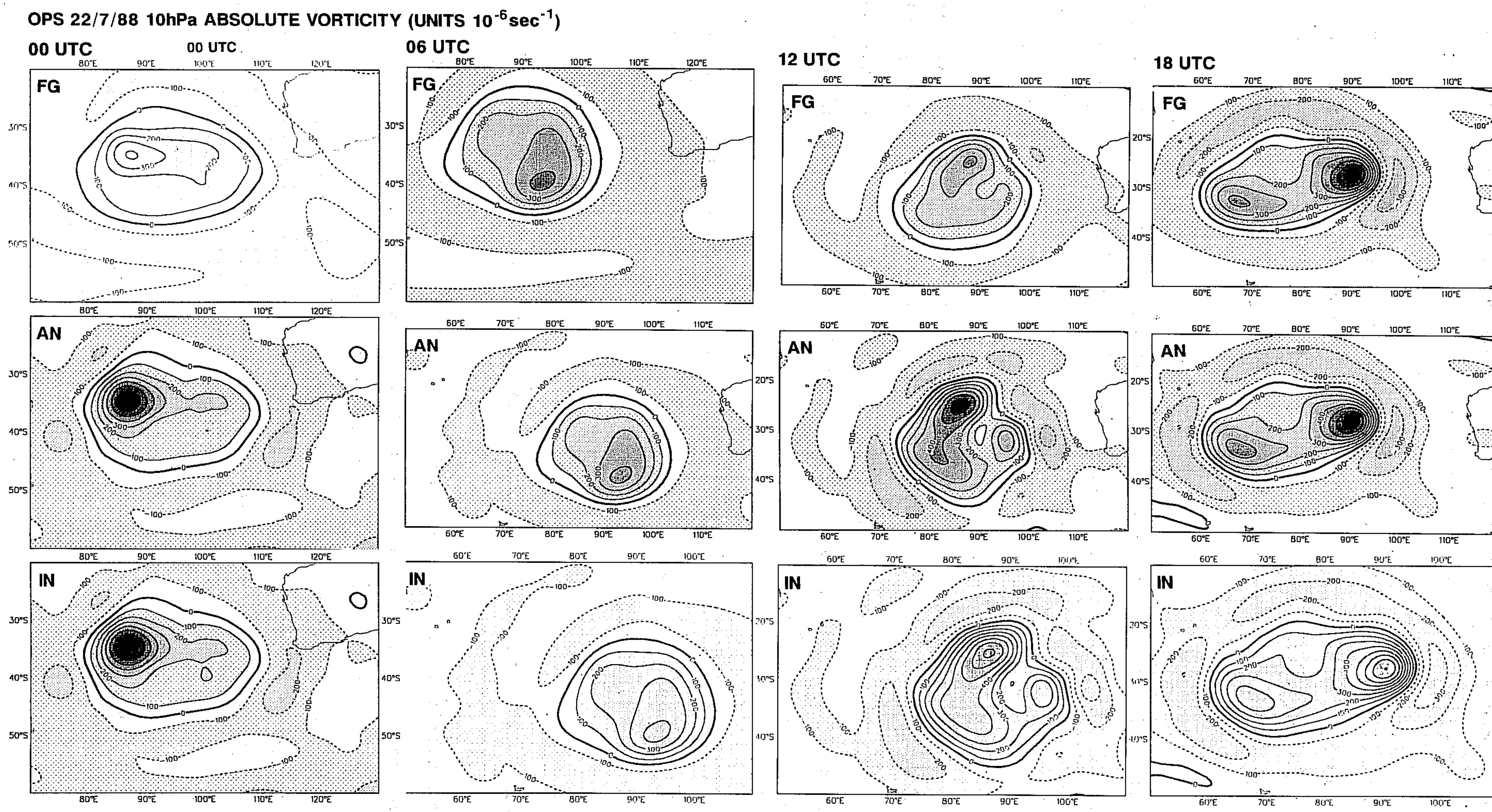

Fig. 11 As Fig. 9, but for the 22nd July 1988.

analysis. These values have been chosen as a compromise between diagnosing the problem at an early stage and 'over-reaction'.

This seems a reasonable approach, given that analysis is not possible within such a region using the current technique. The choice of 50 hPa as a cut off level again seems reasonable; in the case studied, all the ascents rejected using the above approach had previously been rejected at 70 hPa (and accepted above).

A two day assimilation has been carried out from 12 UTC on the 19th (I15) using the above modification to the analysis. Figs 12 through 14 contrast the evolution of the feature in the operational and modified assimilations. The first guess is shown at the top, uninitialised analyses in the middle, and initialised analyses at the bottom. Two cycles are shown in each figure, with the operational and modified schemes side by side. Both assimilations start with a region of positive vorticity, and differences are modest at 12 and 18 UTC on the 19th. However, as the feature amplifies in the operational assimilation, it is held in check by the modified assimilation. The latter shows no signs of instability.

Very little development of the feature occurs in the modified assimilation, presumably, what little there is could be removed by tightening the vorticity check still further.

5. SUMMARY

The assumption of 'normal' gradient wind balance of the first guess, and near geostrophic balance of the first guess errors, used in the current OI analysis can lead to instability of the assimilation system when assimilating data in strongly ageostrophic model flows. Such conditions occur from time to time at the top model level. A solution is proposed which monitors the conditions likely to trigger such instabilities, and rejects the data in these regions at such times. Data, if used, will be wrongly interpreted at such times. The modification is shown to be fully effective in controling the development of the vortex, no sign of instability is observed.

A side effect of the proposed change will be to tidy up the stratospheric analyses, making them more useful for diagnostic studies.

OPS 21/7/88 10hPa ABSOLUTE VORTICITY (UNITS 10^{-6} sec^{-1})

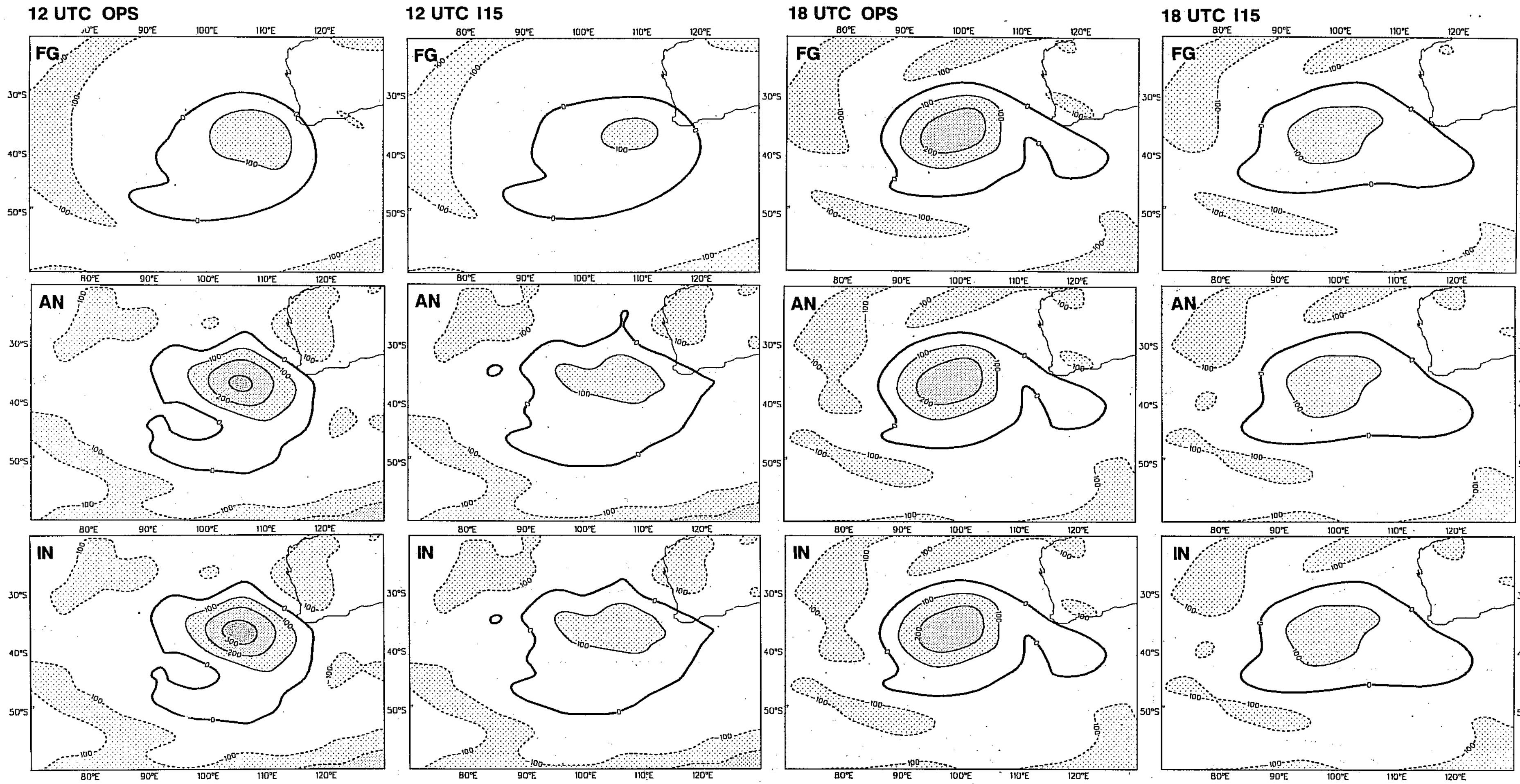

Fig. 12 The vertical component of absolute vorticity at 10 hPa on the 19th July 1988. The 1st (left) column shows 12 UTC values for the operational assimilation (as Fig. 9), and the 2nd column shows values for the modified assimilation at the same time. The 3rd column shows 18 UTC values for the operational assimilation (as Fig. 9), and the 4th (right) column shows values for the modified assimilation at the same time. The top row shows the first guess used for the analysis for these times; the centre row shows the uninitialised analysis for these times; and the lower row the analyses after initialisation.
Contour units are 10^{-6} s^{-1}, contour lines are drawn at intervals of $100*10^{-6}$ sec^{-1}; the zero contour is drawn as a heavy solid line; positive values as thin solid lines; and negative values as thin dashed lines.
Values of over 10^{-4} sec^{-1}, or less than -10^{-4} sec^{-1}, are shaded.

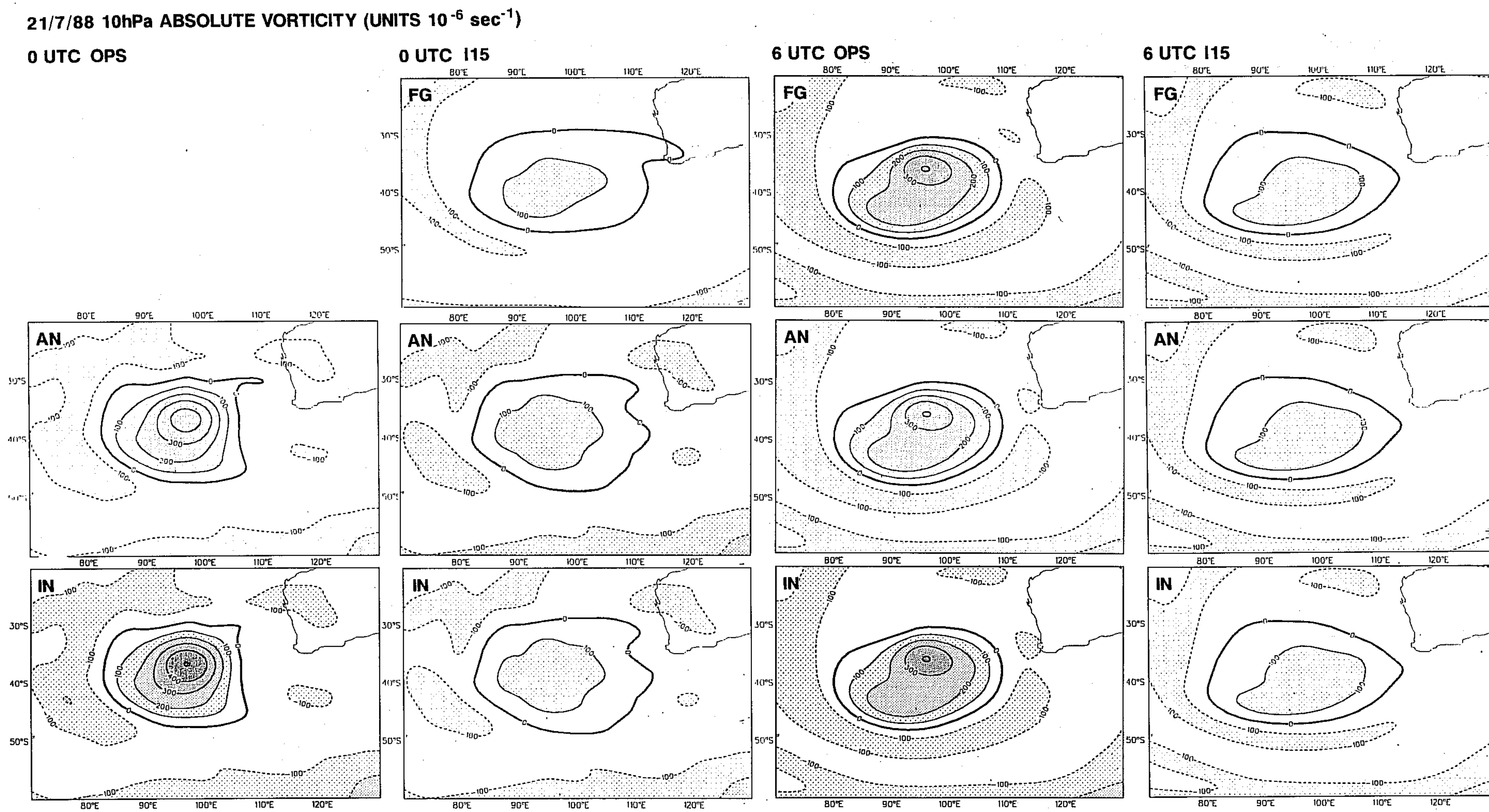

Fig. 13 As Fig. 12, but for 0 UTC and 6 UTC on the 21st July 1988.

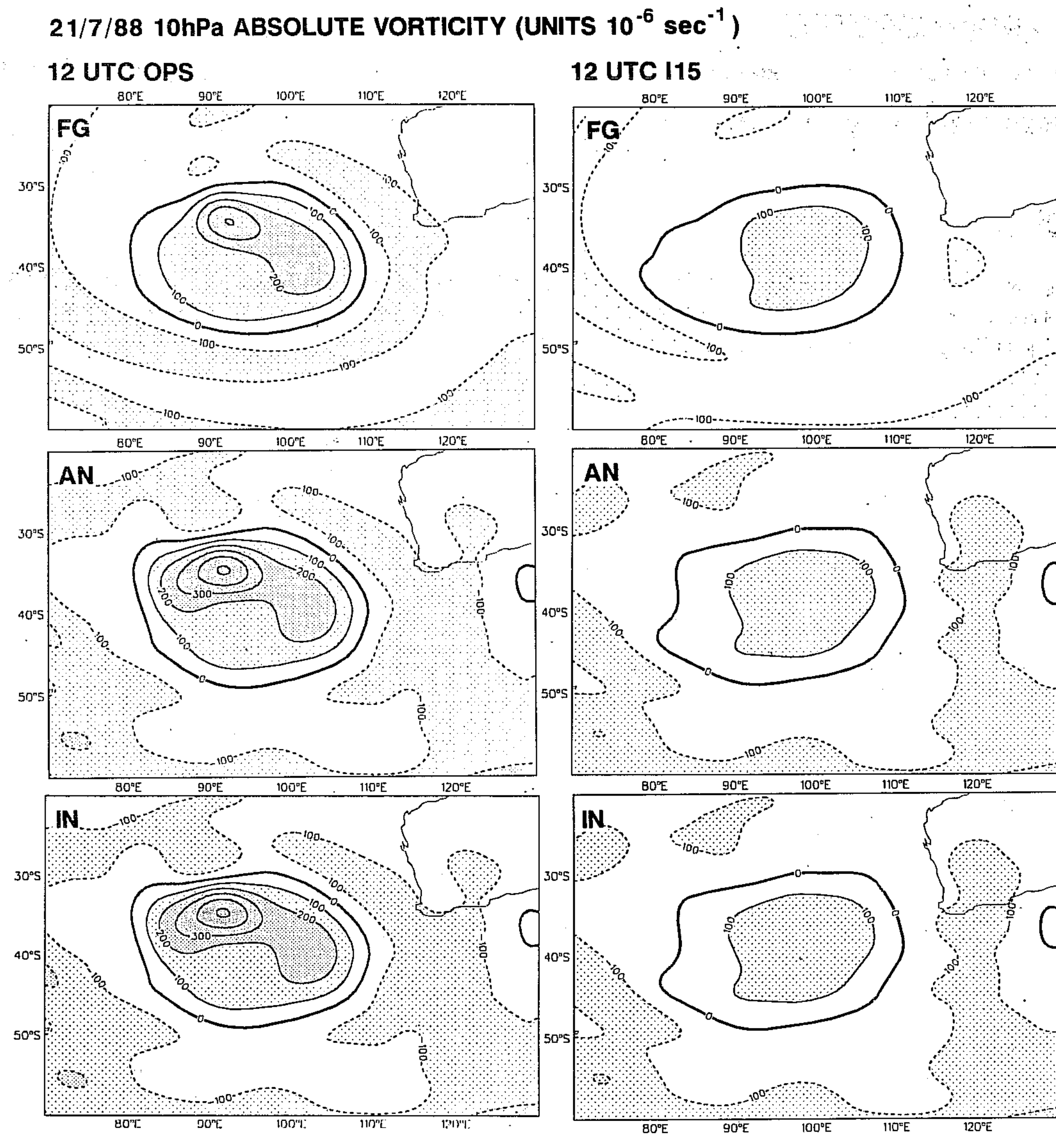

Fig. 14 As Fig. 12, but for 12 UTC 21st July 1988.

6. ACKNOWLEDGEMENTS

Thanks to Drasko for answering questions on the analysis code, and Peter for help with producing analysis statistics.

REFERENCE

Simmons, A. J. and M. Jarraud, 1984: The design and performance of the ECMWF operational model. ECMWF Seminar on numerical methods for weather prediction, 5-9 September, 1983, pp 113-164.