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EFFECT OF VARYING THE LEVELS USED IN FLORIDA SEA-BREEZE SIMULATION.

BY

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FLORIDA SEA-BREEZE SIMULATION

Introduction

The meso-scale model has been coded in a way that allows arbitrary variations in the number of levels up to a maximum of 20, and in the disposition of the levels. This makes it possible to carry out a series of experiments varying the levels used for a study. In this note we describe such a series for the Florida sea breeze case study.

One conclusion reached in the course of studies by M J Bailey of the effect of an isolated hill on steady flow is germane in this context. In those studies, and the present work, an important aspect of the simulation is the treatment of gravity waves; in one case they are excited by sea breezes, in the other by flow past an isolated hill. He found, in the isolated hill work, that gravity waves that would otherwise propagate upwards were partially reflected by the vertical grid if it was not uniform. In the extreme use of such an increase in the vertical grid length with height that waves excited close to the surface could not be resolved close to the upper boundary, the waves were totally reflected. This result was obtained for a model with no form of diffusion; there was sufficient diffusion in the Florida sea breeze model to damp gravity waves and thus reduce the damaging effect of this reflection.

A second result that bears on the present work concerns the conservation properties of the model. It is not possible to change a second order accurate algorithm for advection that is conservative and involves only three points in each direction unless the vertical grid is regular. More precisely, we must impose

$$z_{k+1} - 2z_k + z_{k-1} = z_k - 2z_{k-1} + z_{k-2} \qquad (1)$$

where z_k is the height of level k, if the model is to conserve advected properties.

This theoretical result has been verified in budget calculations on simulations of cumulus convection using the model.

The integrations that we describe in this note were intended to help to answer the following questions.

1. Does the overall depth of the model matter?
2. Does the height of the bottom level matter?
3. Does the regularity of the grid matter?
4. Does the vertical resolution matter?

Seven integrations were made, including a forecast with the original choice of levels first used by Tapp and White (1975), and a forecast that did not test a change in the dispositions of the levels (see 3A and 3B below). The seven experiments and the reasons for the variations being made, are summarised in Table 1. The spacing of the levels is illustrated in Figure 1.

Fcst	No of levels	Levels
0	7	75, 660, 1520, 2120, 3020, 4220, 4820
1	7	75, 660, 1327, 2077, 2909, 3823, 4820
2	5	75, 660, 1327, 2077, 2909
3	6	10, 608, 1288, 2051, 2896, 3823
4	8	10, 580, 1150, 1720, 2290, 2860, 3430, 4000
5	10	10, 115, 304, 578, 937, 1380, 1908, 2521, 3218, 4000

0	This is the standard version of the model
1	To improve the regularity of the grid without affecting depth, bottom level height, mean resolution or resolution at the bottom.
2	Change the depth by removing the top two levels from (1)
3	To lower the bottom level
A	Contained an error in the calculation of initial values for the surface and ground temperatures
B	To remove the error in 3A
4	To increase the resolution at the top of the model by using a uniform grid that is similar to (1), (2) and (3) at the bottom.
5	To increase the resolution at the bottom.

Table 1

DISPOSITION OF LEVELS

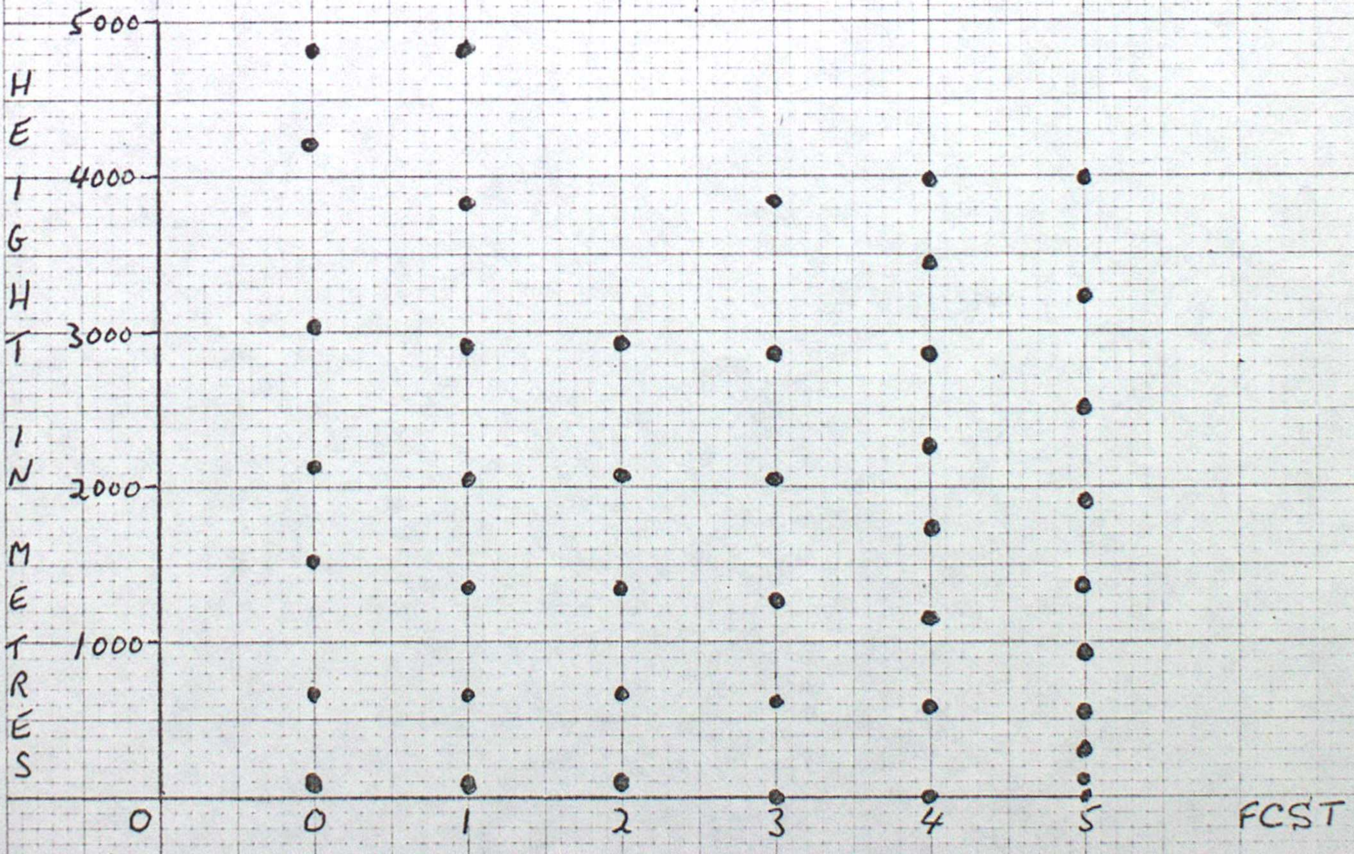


FIG 1

Forecast 1

Although it is possible to find small differences, there is no evidence in the results of forecasts 0 and 1 that the irregularity of the standard grid has had a damaging effect. It was hoped that using a more regular grid would improve the treatment of vertically propagating waves by reducing reflections. There is some sign that the vertical velocity fields are smoother in forecast 1, but the case is not well made.

Results at 9 hrs are shown in figures 2 and 3 for forecast 0, and in figures 4 and 5 for forecast 1.

Forecast 2

There are some interesting differences between the low level winds in forecasts 1 and 2, but, again, nothing to suggest that a reduction in the depth of the model damages the forecast close to the surface. The west coast frontal zone is less sharp and less vigorous at 9 hours in forecast 2, but the position is reversed at 12 hours. The near surface forecasts for 9 hrs are shown in figure 4 for forecast 1 and figure 6 for forecast 2.

Vertical sections of potential temperature and velocity in the plane of the section show more differences between these forecasts. Generalising, it can be observed that restricting the depth of the model has slightly reduced the magnitude of the vertical velocities, and has resulted in a more irregular capping inversion to the well mixed layer. The sections at 9 hours are shown in figure 7 for forecast 1 (with the top two levels removed to aid comparison) and in figure 8 for forecast 2. When examining these diagrams one should concentrate on the lowest four levels; the differences in the results for potential temperature at level 5 are an artificial result of the upper boundary condition, which applies to level 5 in forecast 2.

The conclusion drawn from this experiment is that reducing the depth of the model had very little effect on the important aspects of this forecast.

Forecast 3

Forecast 3A contained an error in the initial conditions. Two variables, surface and ground temperature, are carried so that surface exchanges of heat and momentum can be calculated, and the initial values of these two temperatures were incorrect. The error was 0.7°C in the surface temperature, and 4.3°C in the ground temperature. Comparison of 3A and 3B, in which the error was removed, shows that the maximum difference in the potential temperature at 10 m , the bottom model level, was about 0.2°C. Throughout the 12 hour forecast there were trivial differences in temperature between the forecasts. The dynamical effect was greatest at 3 hours, and, even then, it was negligible. This accords with an impression that we have gathered in other work that the initial values of surface and ground temperature have a relatively slight effect on forecasts. We should not assume that this conclusion will be correct when the model has good resolution close to the surface, and is being used to simulate events that will react quickly (eg within 1 hour) to variations in the initial surface sensible heat flux.

Comparison between forecasts 1 and 3B shows that lowering the bottom level to 10 m has increased the effect that Lake Okeechobee here on the flow, and very slightly increased the intensity of the sea breeze circulations. This change has more impact on the surface forecast than either decreasing the depth of the model or inproving the regularity of the grid. This comparison also confirms the conclusion drawn from forecast 2 that decreasing the depth of the model reduces the vertical velocities in the upper part of the model. However, with the upper boundary at 3823 m , the capping inversion in forecast 3 is reasonably smooth and regular.

The low level fields at 9 hours in forecast 3 are shown in figure 9. The sections at 9 hours for forecast 3 and the bottom 6 levels of forecast 1 are shown in figure 10 and 11 respectively.

Forecast 4

Forecast 4 should be compared with forecast 3 since both have the lowest level at 10 m . There is very little difference in the surface forecasts at 6 hours, but the frontal zones are sharper in forecast 4 at 9 hours, and the vertical velocity fields are clearer and more coherent. Again, it appears from the cross sections that the vertical velocities throughout the depth of the model are smaller and more coherent in forecast 4. These effects, which must be attributed either to the uniformity of the grid or to increased resolutions in the vertical, are small but significant when compared with the effect of the first improvement in the regularity of the grid (Forecast 1) or with the effect of changing the depth of the model.

The results at 9 hours for forecast 4 are shown in figures 12 and 13.

Forecast 5

The comparison of forecast 5 with forecasts 3 and 4 should show the effect of increased resolution close to the surface. In so far as it shows the effect of varying the resolution in the upper half of the model it confirms the results described under forecast 4.

The sea breeze front penetrates less far inland in forecast 5 than in forecasts 3 and 4, and is less sharply defined in forecast 5 than in forecast 4. The delay in the movement of the front seems to occur during the first 6 hours, after which it moves in the same way as in the other forecasts but without making up the ground lost in the first 6 hours. Examing the cross sections, it appears that the waves in the lower half of the model are treated better, ie with more coherence and lower values for the vertical velocities, in forecast 5.

Even though increasing the resolution at low levels has had an effect that is at least as marked as any of the other changes that have been tested, it is difficult to argue that the substantial cost of extra resolution close to the surface has had on important dynamical effect on the first twelve hours of this Florida sea breeze case study. The results for forecast 5 at 9 hours are shown in Figure 14 and 15.

Forecast 5 was continued to 24 hours, and compared with forecast 0. Generalising, it was observed that the increased resolution close to the surface allowed the nocturnal boundary layer to be described in greater detail in forecast 5, but without any important consequences for the forecast as a whole. The 10 m winds in forecast 5 are much lighter and backed by up to 45° from the 75 m winds in forecast 0, but the level 4 winds, which are outside the surface layer, in forecast 5 verify very well against the 75 m winds in forecast 0 at 18 hours. The lowest level in forecast 5 gets very cold, showing a good nocturnal inversion. The cross sections show much smoother flow in forecast 5 than in forecast 0, and this must be attributed to the accumulated effect of all the changes that have been described above.

The results from forecast 5 at 18 hours are shown in figure 16 and 17, and those from forecast 0 are shown in figures 18 and 19.

Conclusion

None of the changes in the vertical grid tested and reported here had a deleterious effect when a beneficial effect was expected, and vise versa. However, none of the individual changes had a large effect on the surface forecast, and it is only in the comparison between the second twelve hours of forecast 5 and 0 that there is any sign that a significant benefit might result from modifying the grid. Even when the grid resolved a very shallow nocturnal surface layer, the overall behaviour of the forecast was not affected.

The four questions posed in the introduction can now be answered in the context of a simple Florida sea breeze forecast.

1. Variations in the depth of the model have little effect on the surface forecast as long as the model is deeper than the thermally driven well mixed boundary layer. The height of the capping inversion becomes uneven (erroneously) when it is close to the upper boundary.

2. Lake Okeechobee, and presumably other surface features, have a more marked affect on the forecast when the depth of the lowest layer is reduced.

3. Increasing the regularity of the grid improves the treatment of waves excited in the boundary layer, but does not affect the overall development of the forecast.

4. Improving the resolution in the body of the model has a similar effect to (3). Improving the resolution close to the surface affects the surface forecast, and the ability of the model to describe the surface layer, but, again, does not affect the overall development of the forecast.

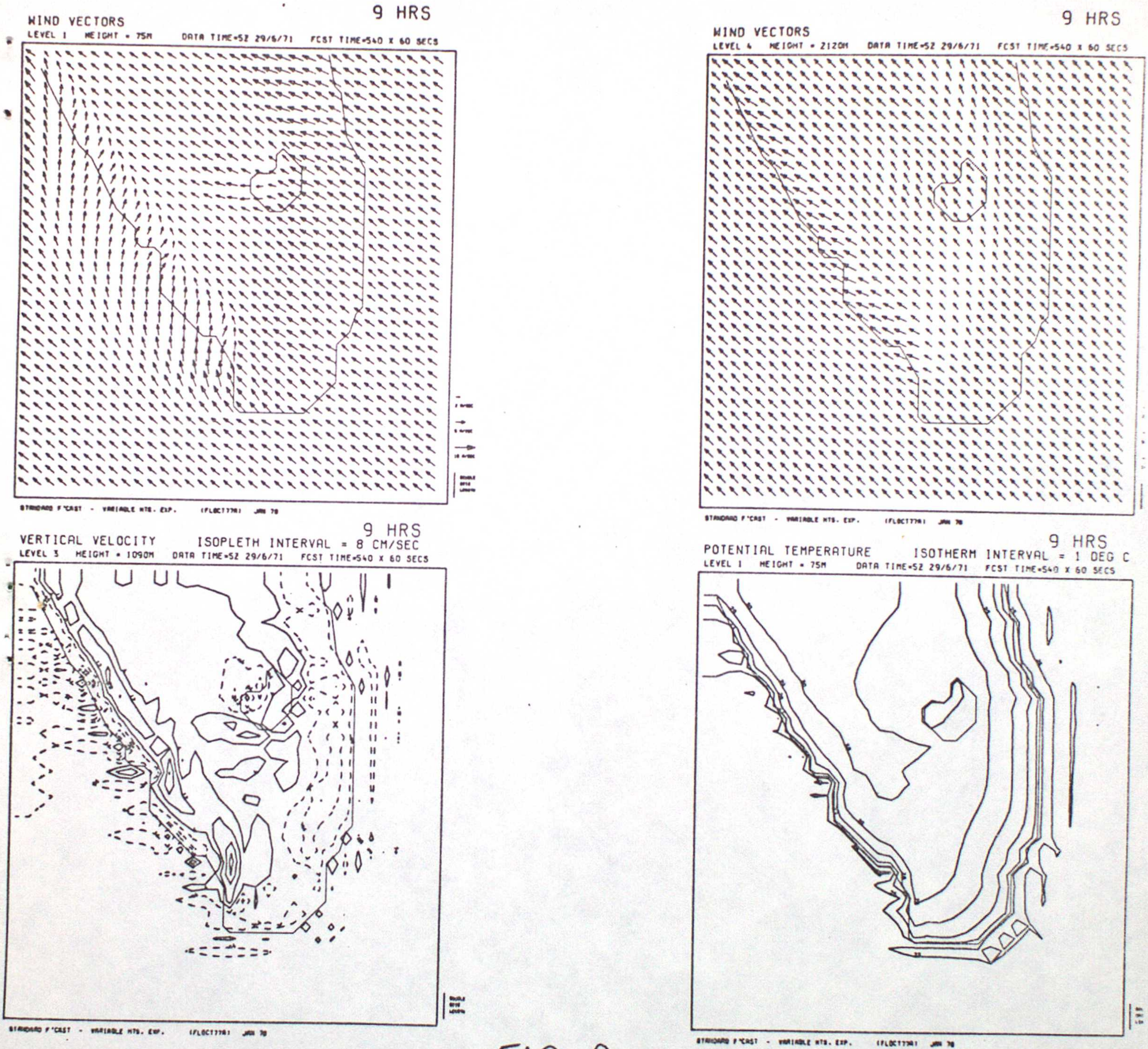
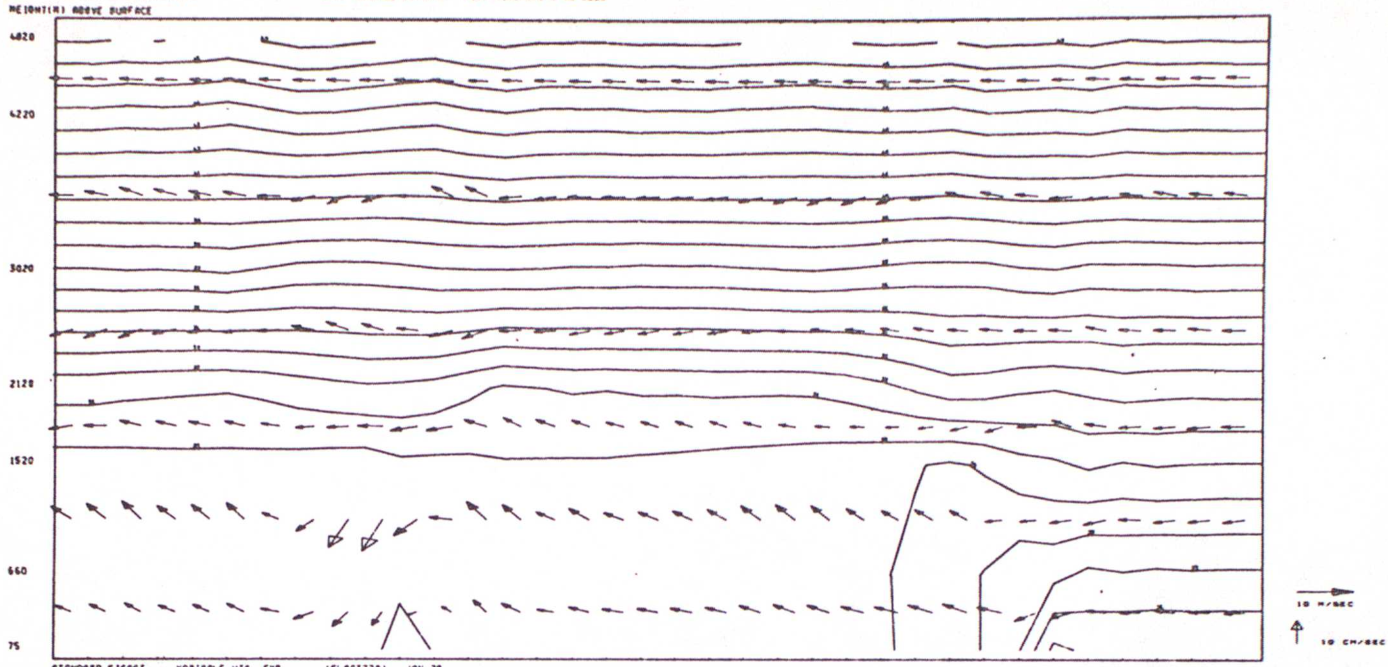

WIND VECTORS
9 HRS
LEVEL 1 HEIGHT = 75M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
STANDARD F'CAST - VARIABLE HTS. EXP. (FLOCT77A) JAN 78
WIND VECTORS
9 HRS
LEVEL 4 HEIGHT = 2120M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
STANDARD F'CAST - VARIABLE HTS. EXP. (FLOCT77A) JAN 78
VERTICAL VELOCITY
ISOPLETH INTERVAL = 8 CM/SEC
9 HRS
LEVEL 3 HEIGHT = 1090M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
STANDARD F'CAST - VARIABLE HTS. EXP. (FLOCT77A) JAN 78
POTENTIAL TEMPERATURE
ISOTHERM INTERVAL = 1 DEG C
9 HRS
LEVEL 1 HEIGHT = 75M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
STANDARD F'CAST - VARIABLE HTS. EXP. (FLOCT77A) JAN 78

FIG 2
FCSTO

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS

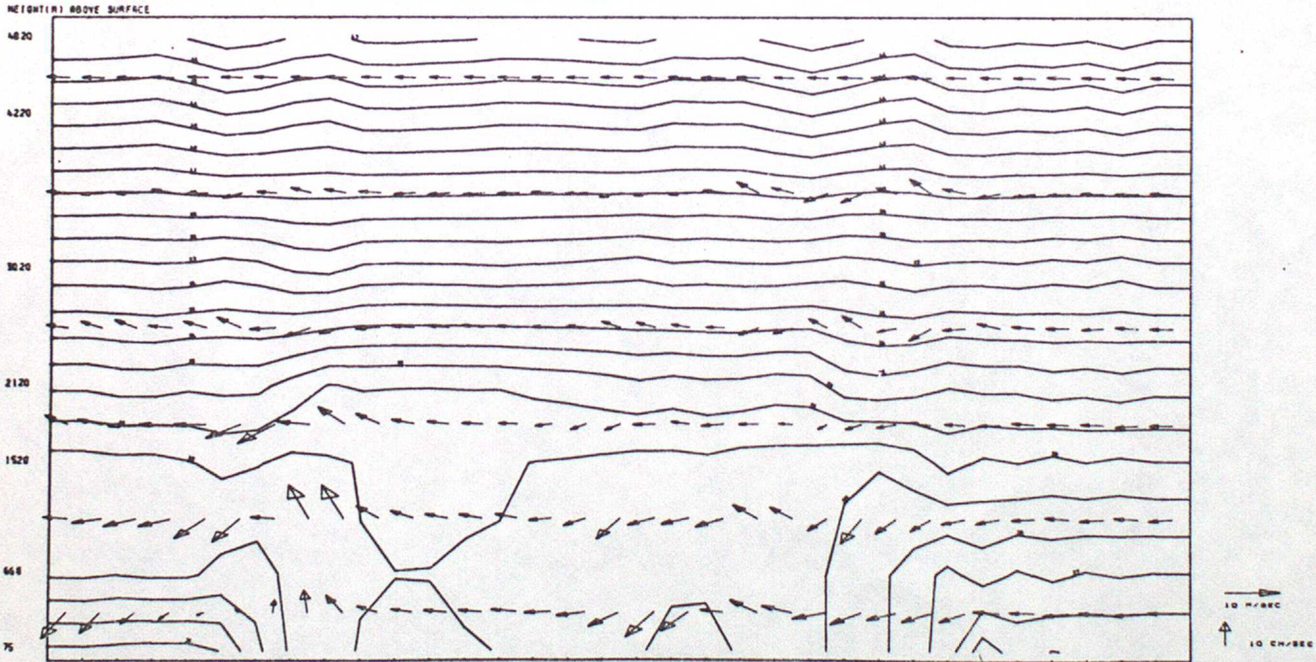


N-S STANDARD F'CAST - VARIABLE HTS. EXP. (FLOCT77A) JAN 78

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS



W-E STANDARD F'CAST - VARIABLE HTS. EXP. (FLOCT77A) JAN 78

FIG 3
FCST O

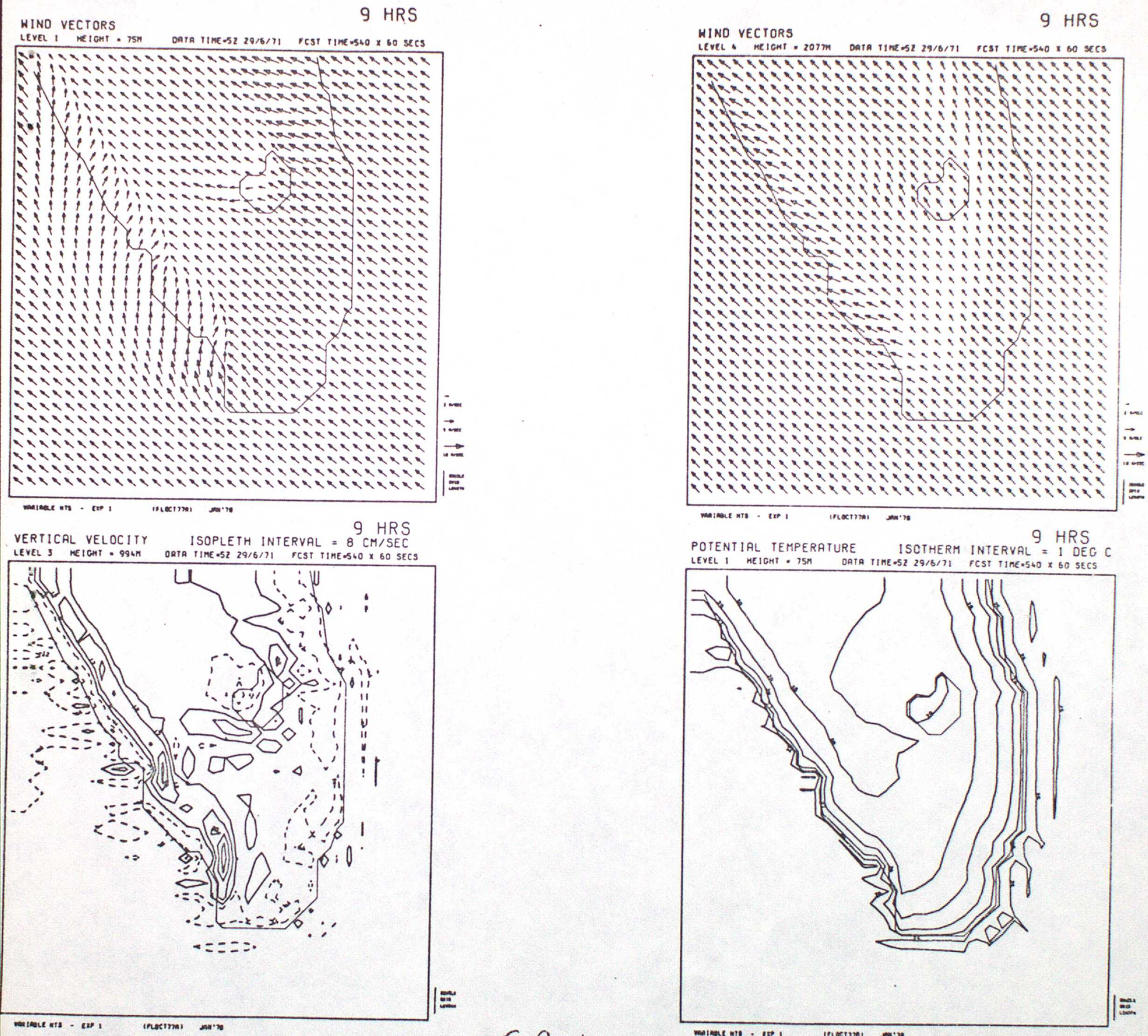

WIND VECTORS
9 HRS
LEVEL 1 HEIGHT = 75M DATA TIME=5Z 29/6/71 FCST TIME=540 X 60 SECS
WIND VECTORS
9 HRS
LEVEL 4 HEIGHT = 2077M DATA TIME=5Z 29/6/71 FCST TIME=540 X 60 SECS
VERTICAL VELOCITY ISOPLETH INTERVAL = 8 CM/SEC
9 HRS
LEVEL 3 HEIGHT = 994M DATA TIME=5Z 29/6/71 FCST TIME=540 X 60 SECS
POTENTIAL TEMPERATURE ISOTHERM INTERVAL = 1 DEG C
9 HRS
LEVEL 1 HEIGHT = 75M DATA TIME=5Z 29/6/71 FCST TIME=540 X 60 SECS

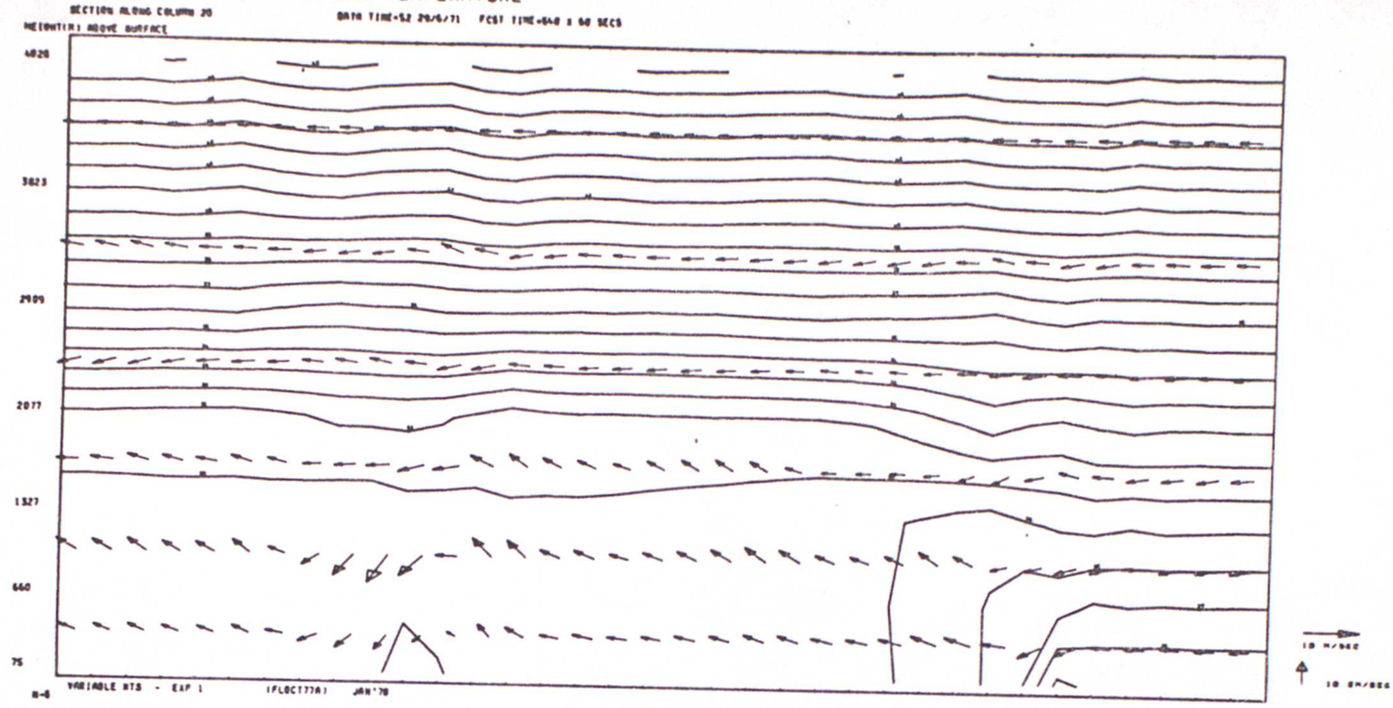
FIG 4

FCST 1

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS



9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS

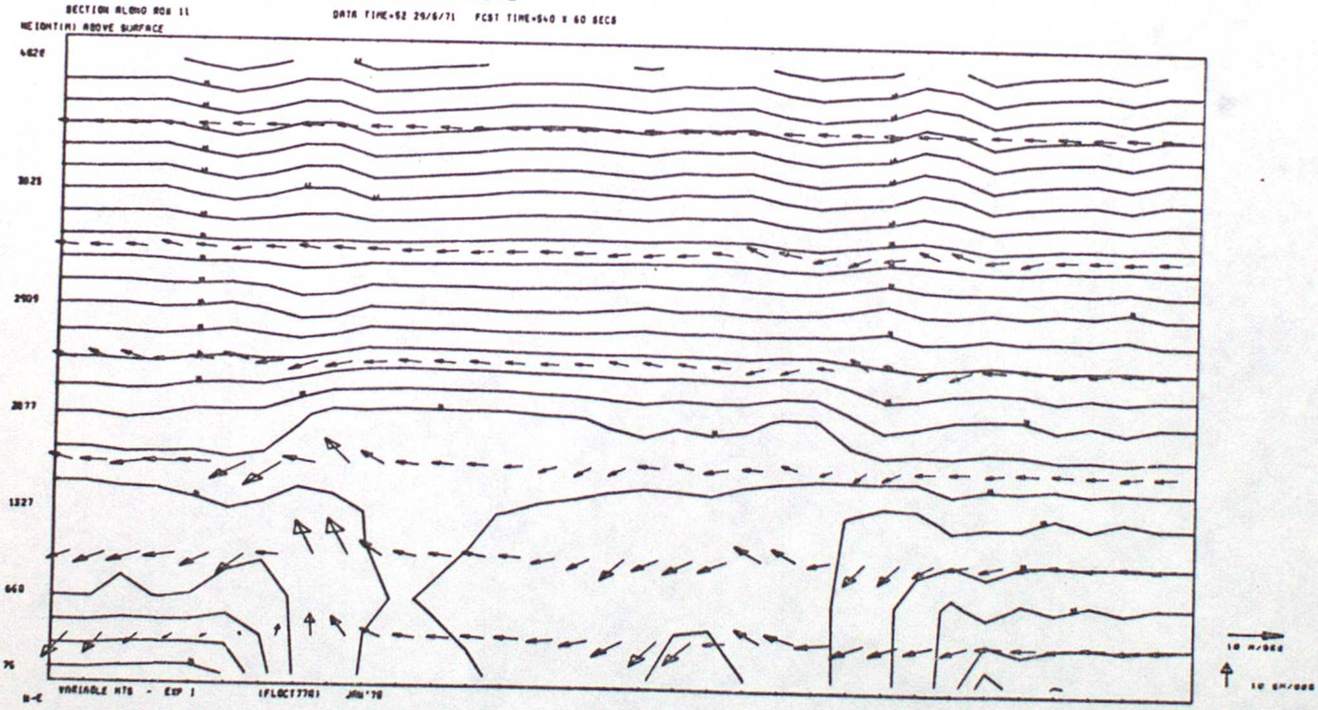


FIG 5

FCST 1

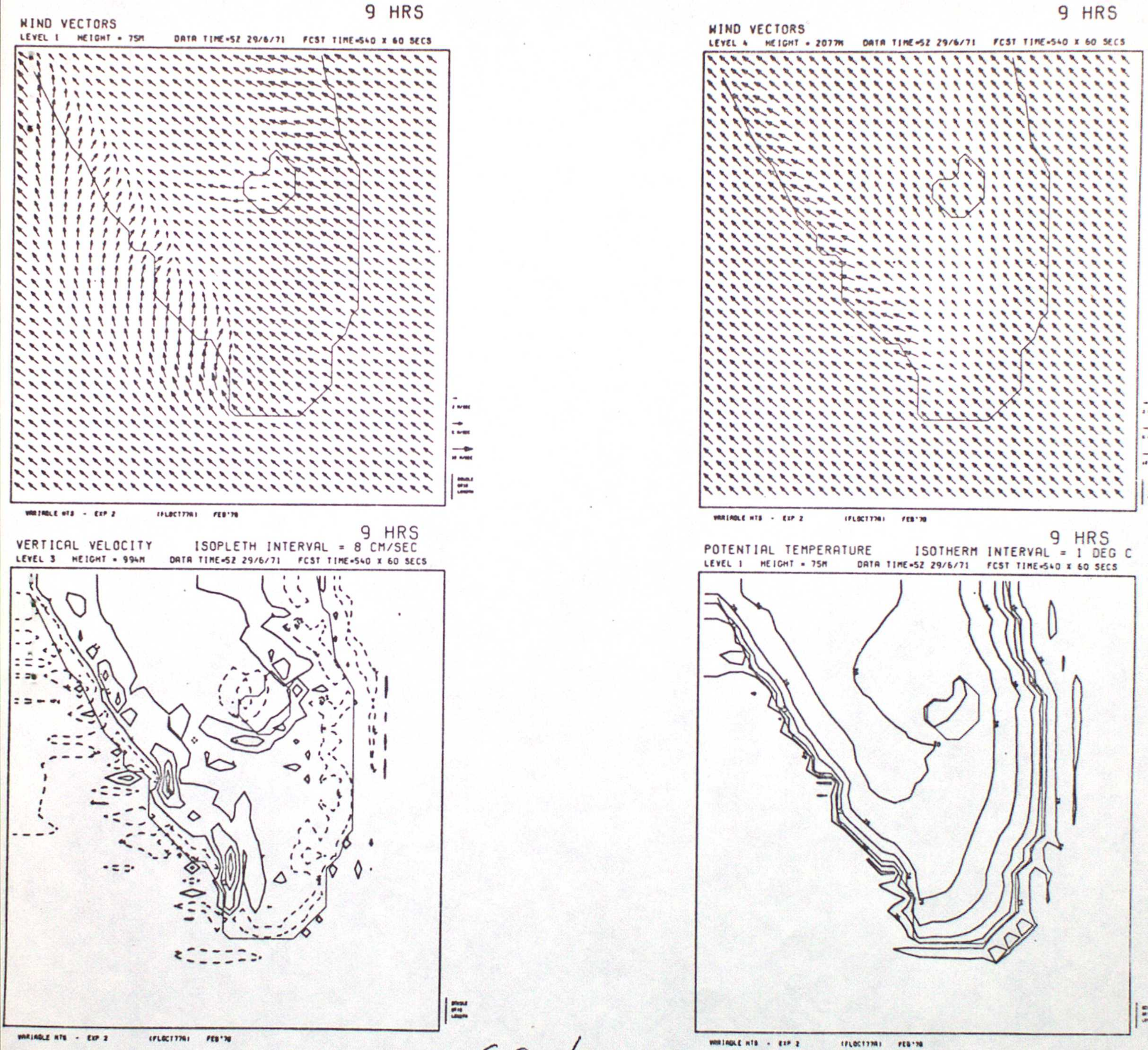
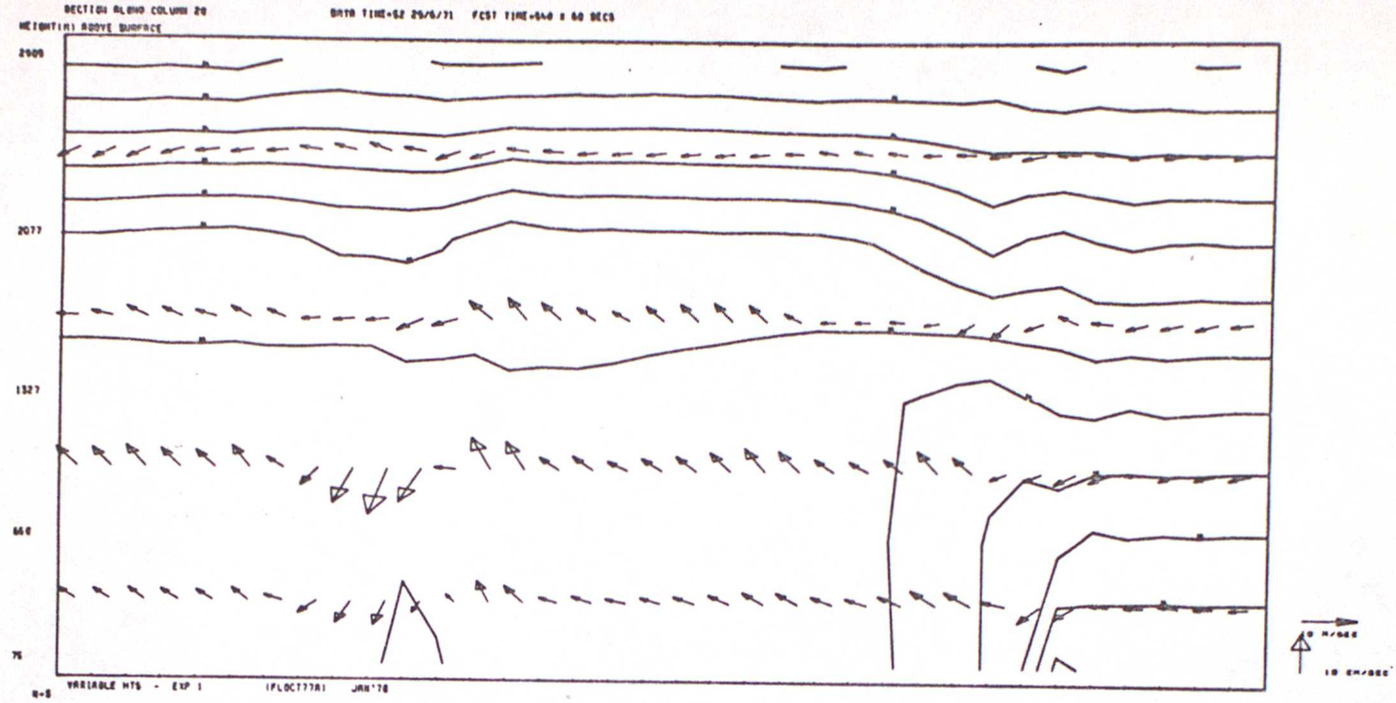

9 HRS
WIND VECTORS
LEVEL 1 HEIGHT = 75M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 2 (FLOCT77A) FEB'78
9 HRS
WIND VECTORS
LEVEL 4 HEIGHT = 2077M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 2 (FLOCT77A) FEB'78
9 HRS
VERTICAL VELOCITY ISOPLETH INTERVAL = 8 CM/SEC
LEVEL 3 HEIGHT = 994M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 2 (FLOCT77A) FEB'78
9 HRS
POTENTIAL TEMPERATURE ISOTHERM INTERVAL = 1 DEG C
LEVEL 1 HEIGHT = 75M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 2 (FLOCT77A) FEB'78

FIG 6
FCST 2

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS



9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS

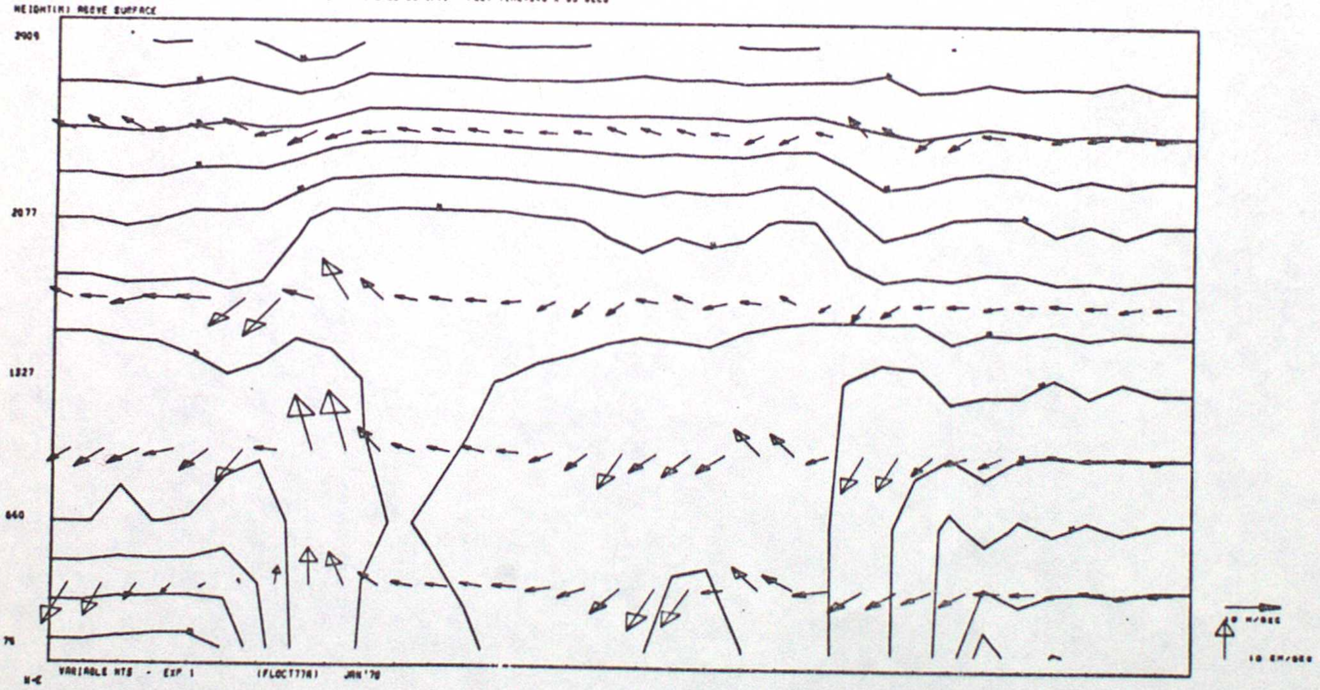
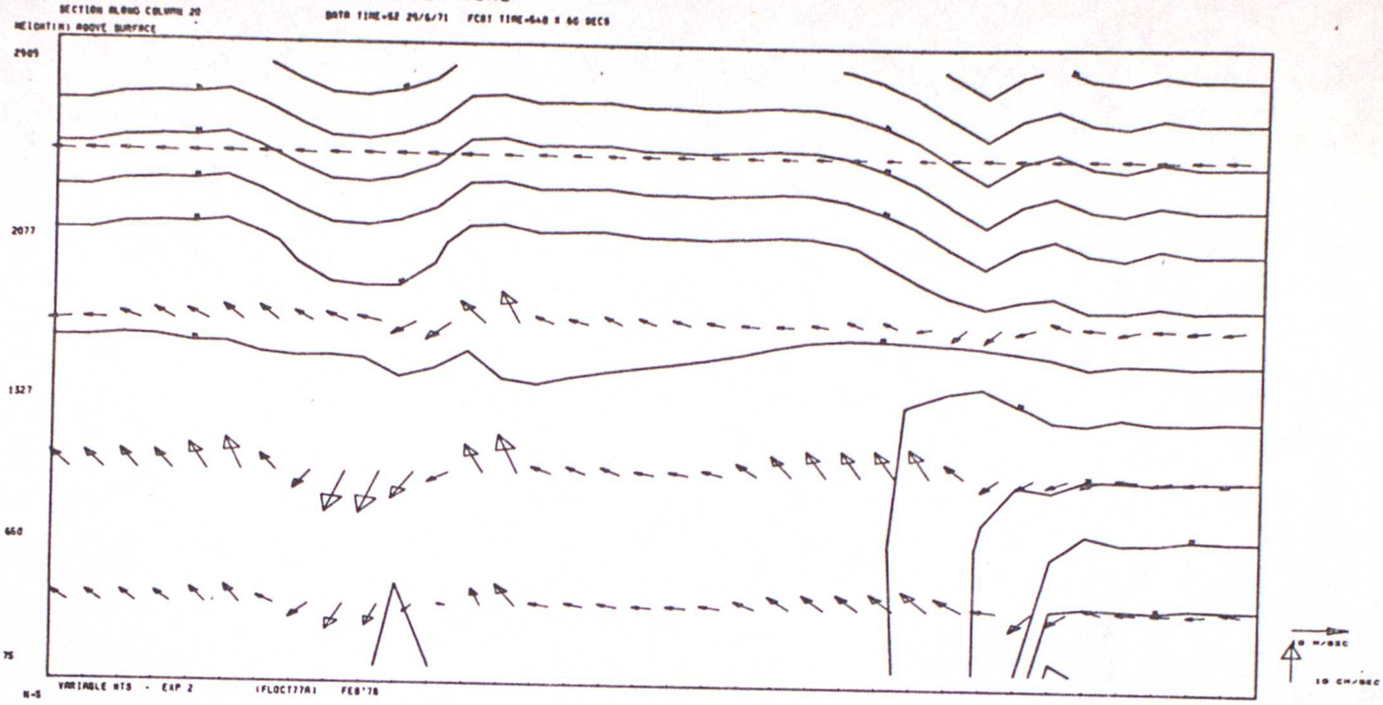


FIG 7
FCST 1

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20   DATA TIME=52 29/6/71   FCST TIME=540 X 60 SECS



9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11   DATA TIME=52 29/6/71   FCST TIME=540 X 60 SECS

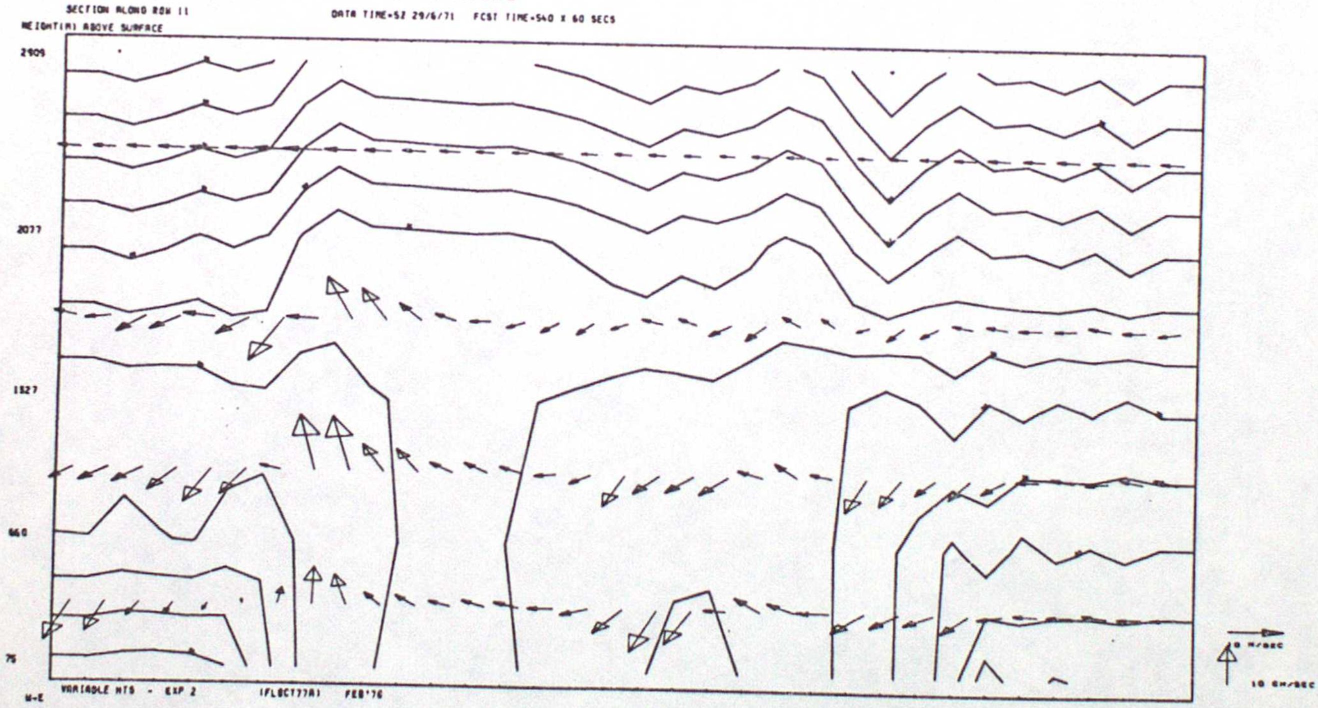


FIG 8
FCST 2

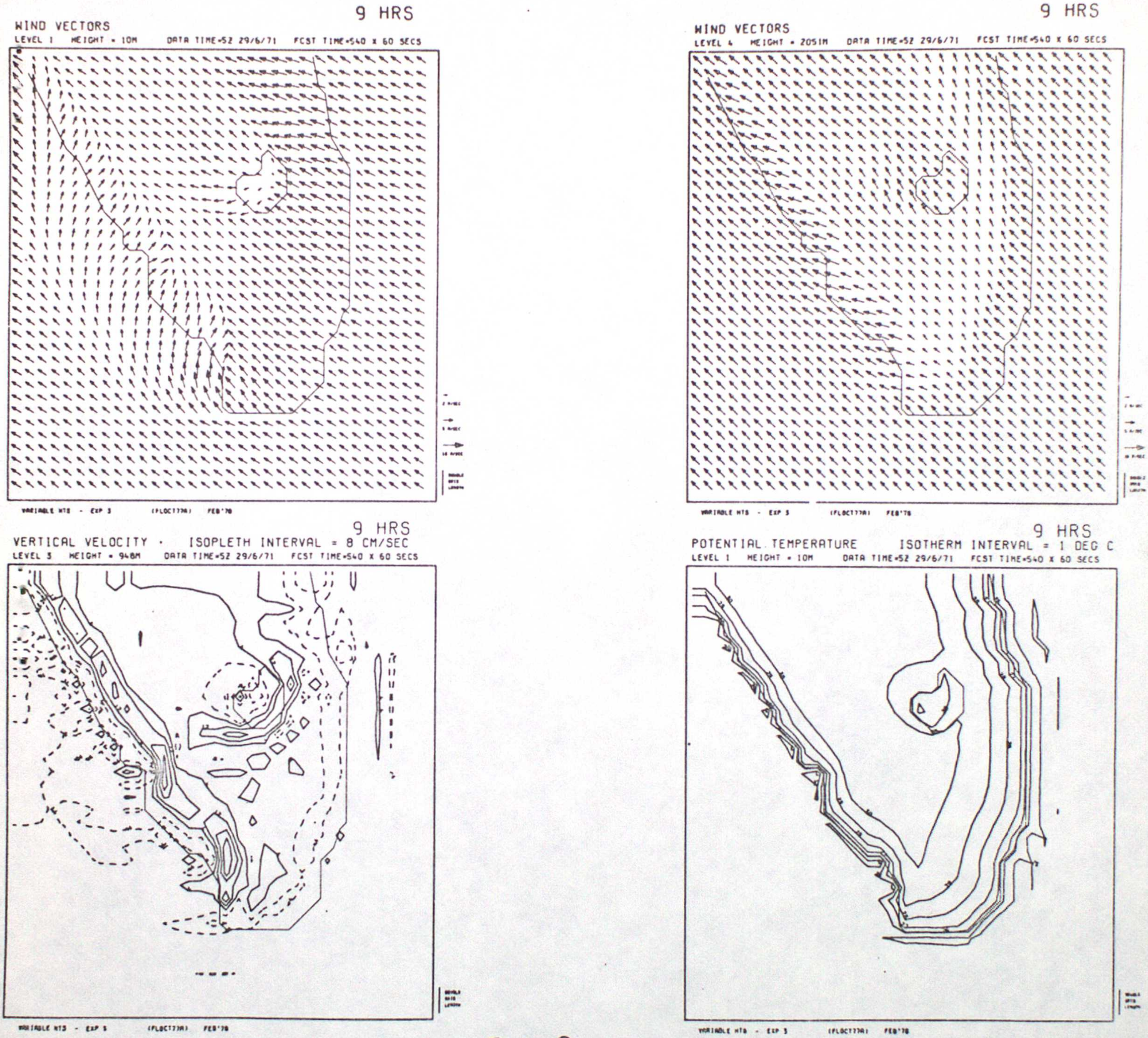
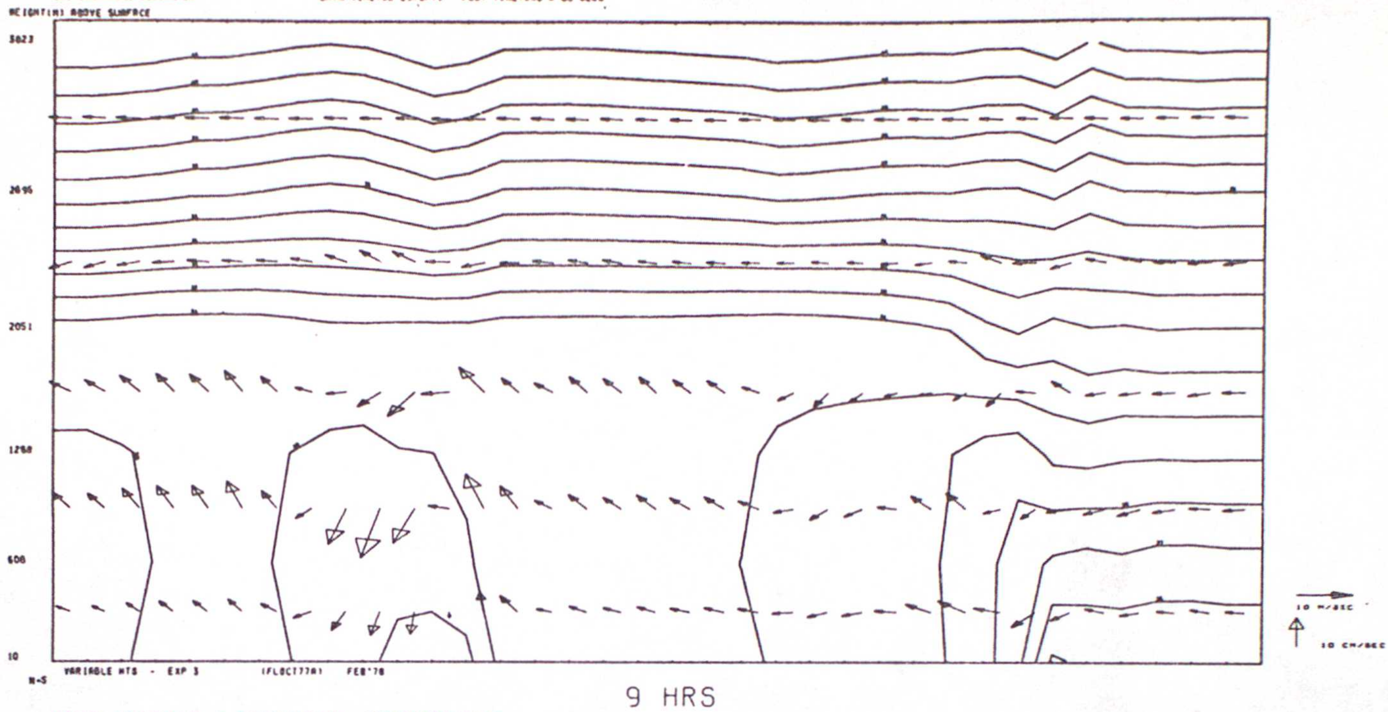

9 HRS
WIND VECTORS
LEVEL 1 HEIGHT = 10M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 3 (FLOCT77A) FEB'78
9 HRS
WIND VECTORS
LEVEL 4 HEIGHT = 2051M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 3 (FLOCT77A) FEB'78
9 HRS
VERTICAL VELOCITY · ISOPLETH INTERVAL = 8 CM/SEC
LEVEL 3 HEIGHT = 948M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 3 (FLOCT77A) FEB'78
9 HRS
POTENTIAL TEMPERATURE ISOTHERM INTERVAL = 1 DEG C
LEVEL 1 HEIGHT = 10M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
VARIABLE HTS - EXP 3 (FLOCT77A) FEB'78

FIG 9
FCST 3

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS



9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS

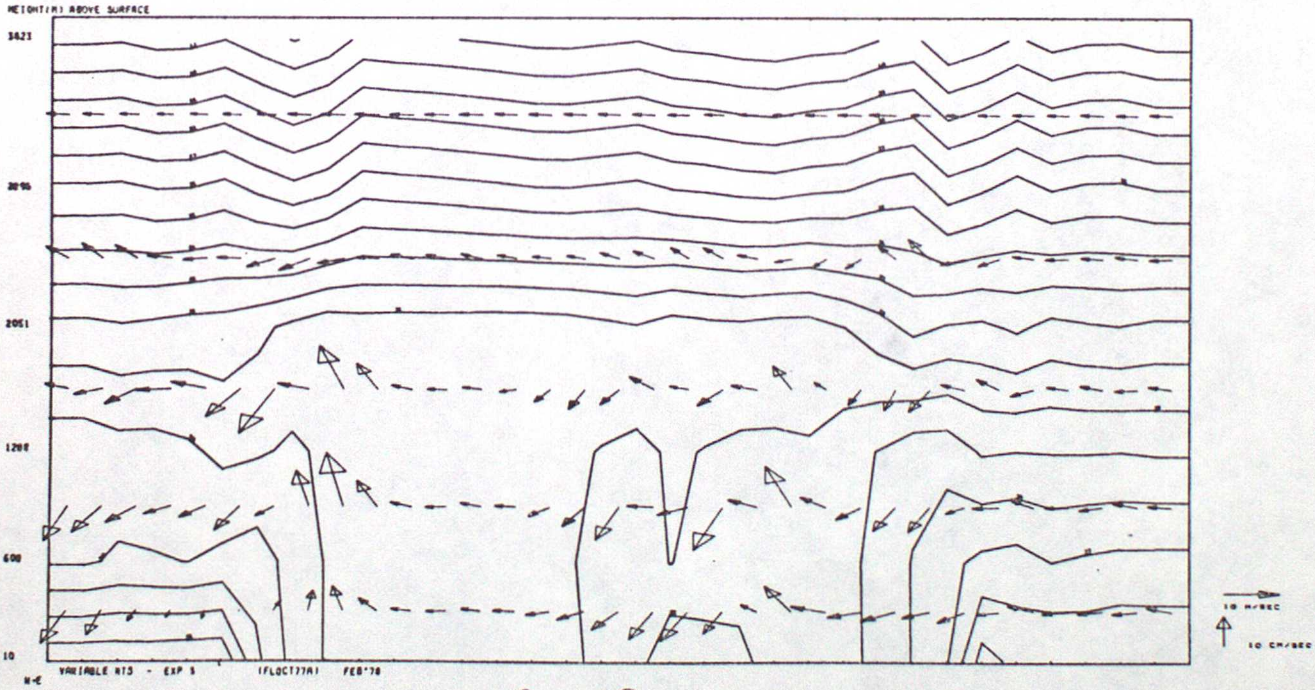
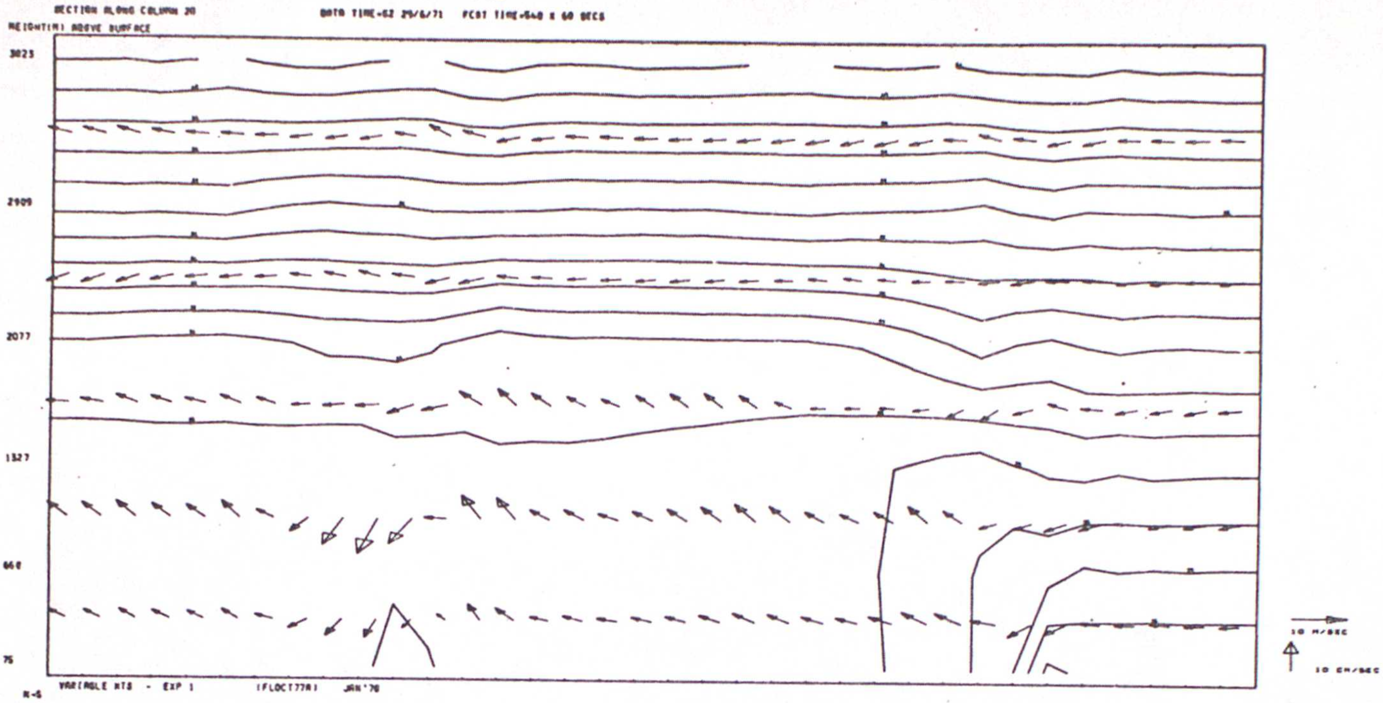


FIG 10
FCST 3

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME-52 29/6/71 FCST TIME-540 X 60 SECS



9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME-52 29/6/71 FCST TIME-540 X 60 SECS

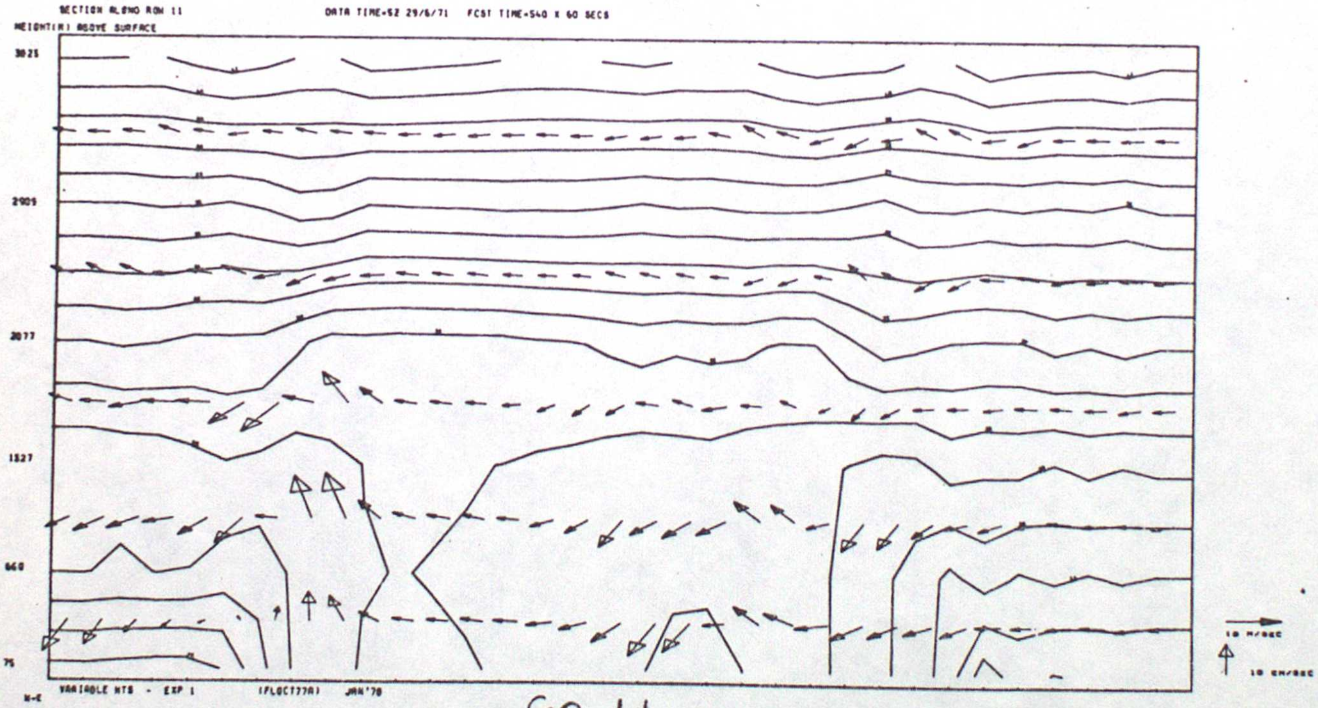


FIG 1.1

FCST 1

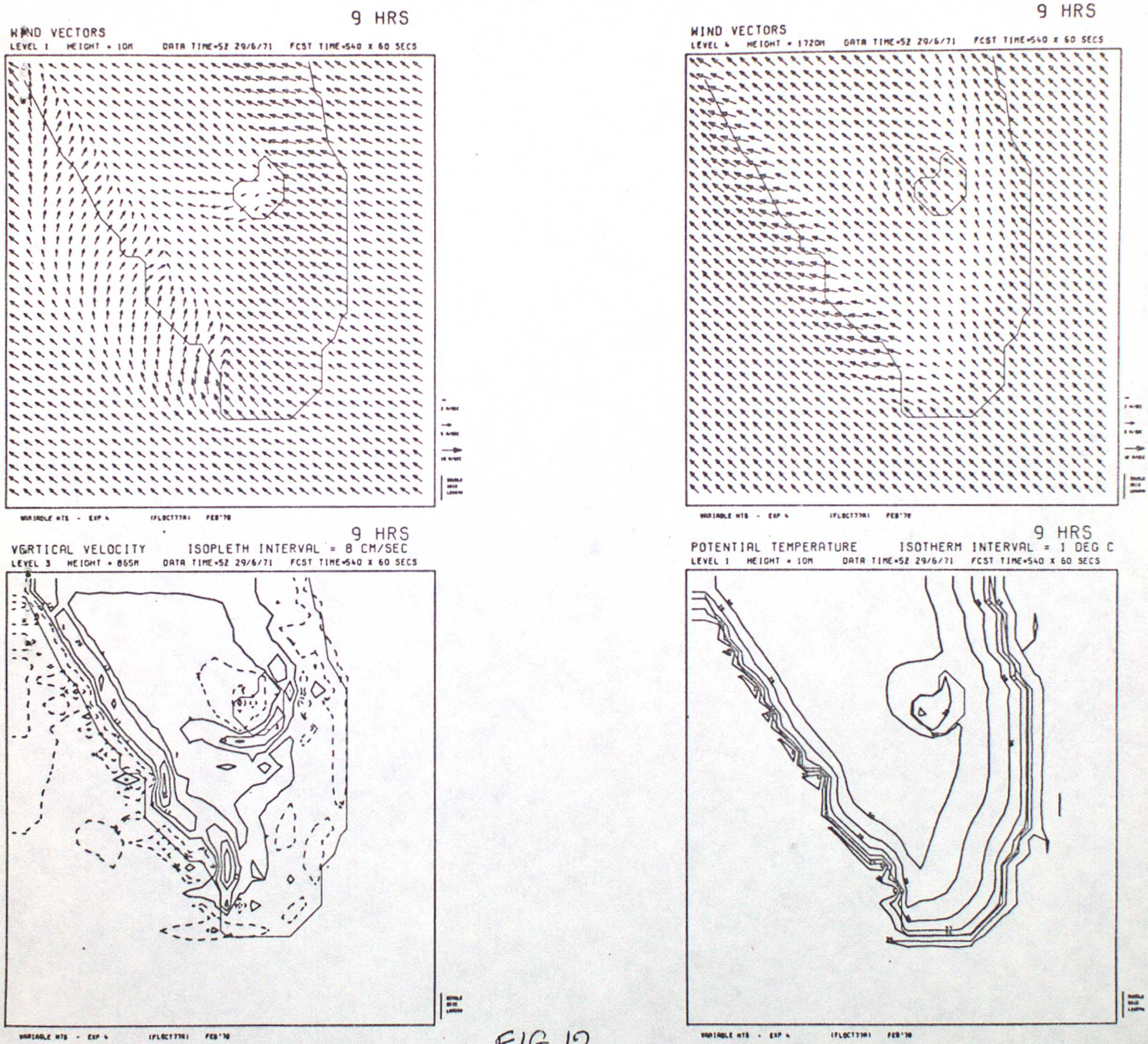
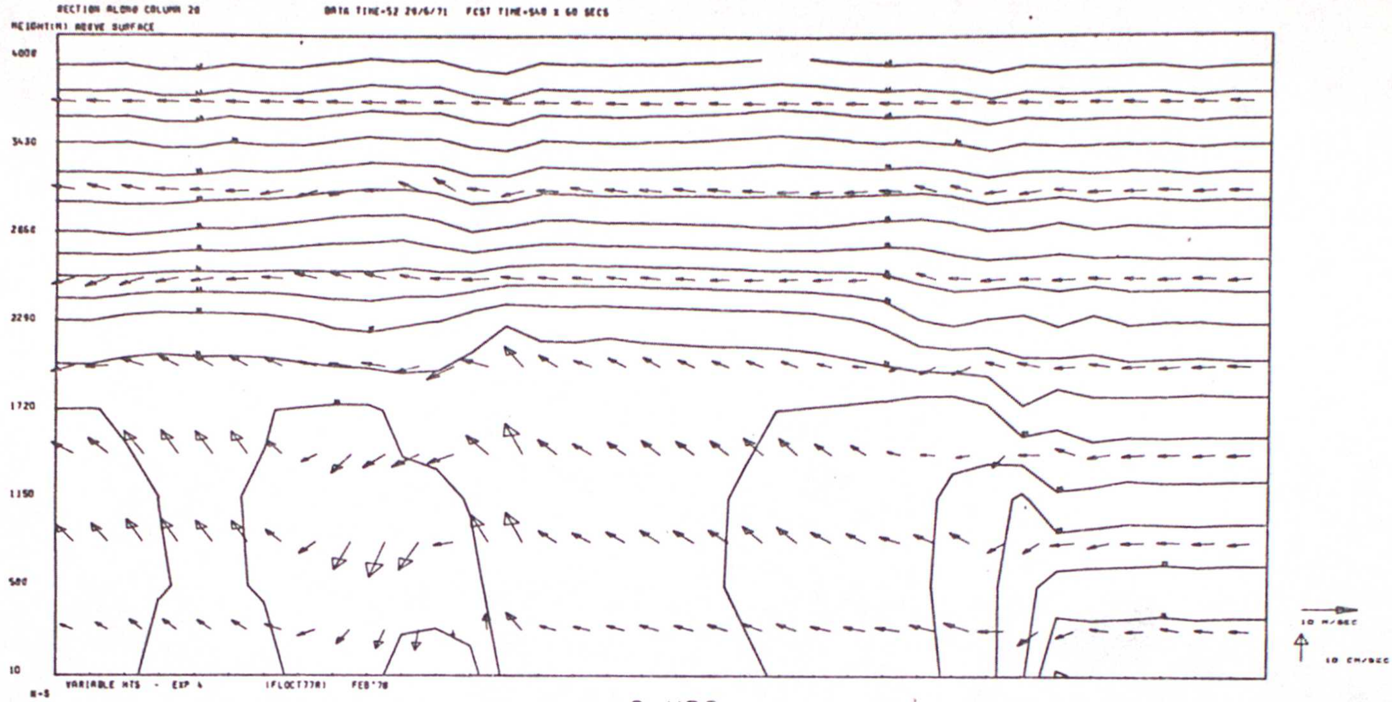

9 HRS
WIND VECTORS
LEVEL 1 HEIGHT = 10M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
9 HRS
WIND VECTORS
LEVEL 4 HEIGHT = 1720M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
9 HRS
VERTICAL VELOCITY ISOPLETH INTERVAL = 8 CM/SEC
LEVEL 3 HEIGHT = 865M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS
9 HRS
POTENTIAL TEMPERATURE ISOTHERM INTERVAL = 1 DEG C
LEVEL 1 HEIGHT = 10M DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS

FIG 12

FCST 4

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE



9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

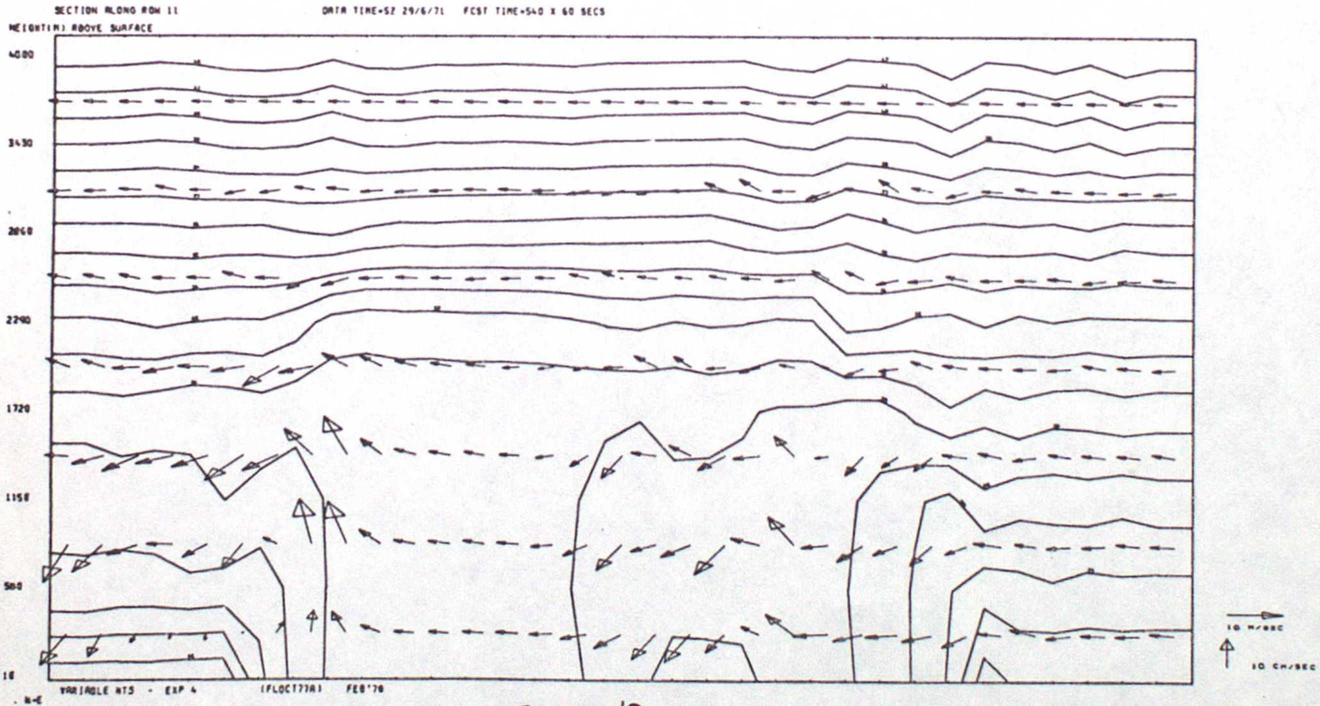
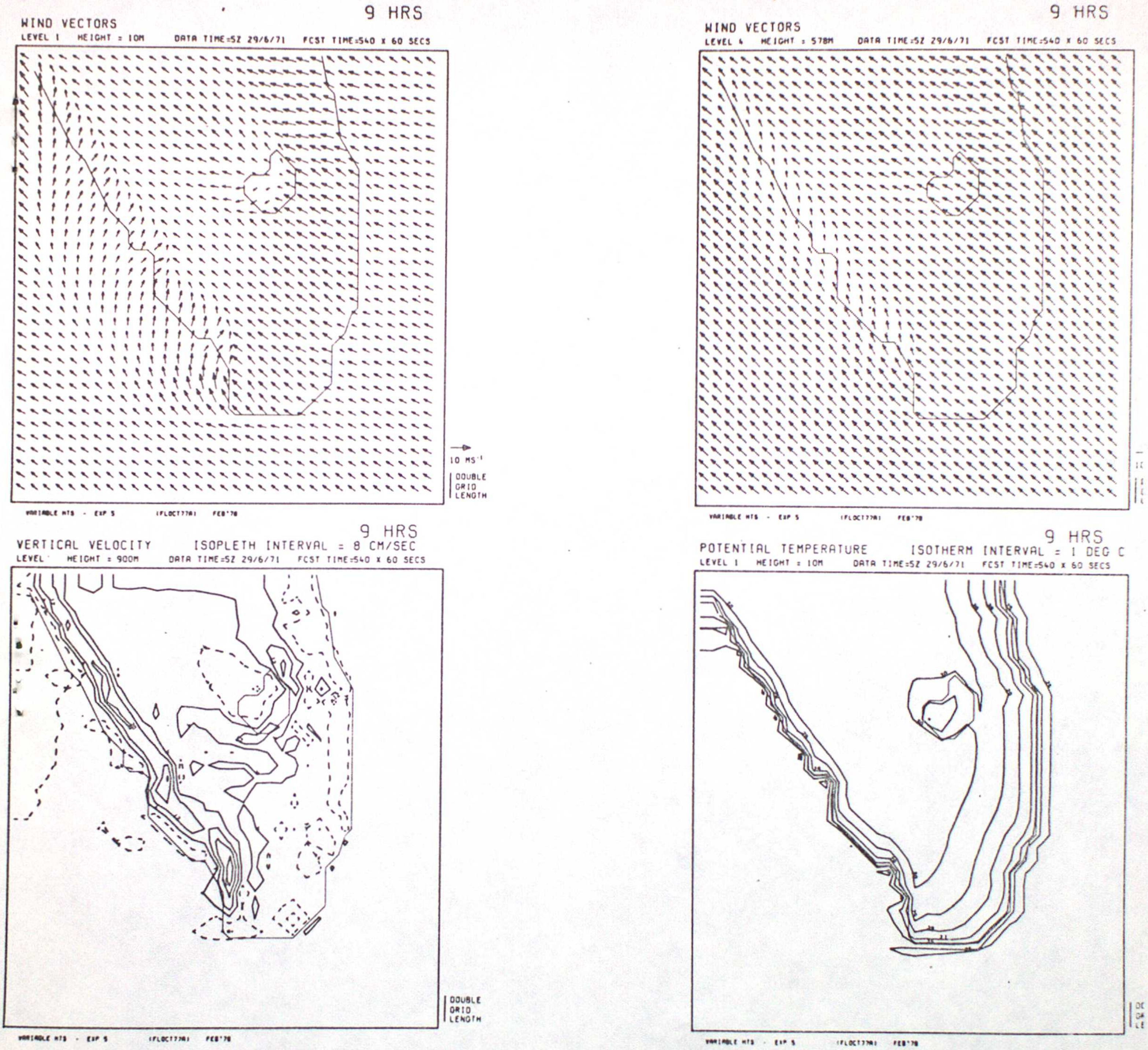


FIG 13
FCST 4



9 HRS
WIND VECTORS
LEVEL 1 HEIGHT = 10M DATA TIME=5Z 29/6/71 FCST TIME=540 x 60 SECS
10 MS⁻¹
DOUBLE GRID LENGTH
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78
9 HRS
WIND VECTORS
LEVEL 4 HEIGHT = 578M DATA TIME=5Z 29/6/71 FCST TIME=540 x 60 SECS
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78
9 HRS
VERTICAL VELOCITY ISOPLETH INTERVAL = 8 CM/SEC
LEVEL HEIGHT = 900M DATA TIME=5Z 29/6/71 FCST TIME=540 x 60 SECS
DOUBLE GRID LENGTH
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78
9 HRS
POTENTIAL TEMPERATURE ISOTHERM INTERVAL = 1 DEG C
LEVEL 1 HEIGHT = 10M DATA TIME=5Z 29/6/71 FCST TIME=540 x 60 SECS
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78

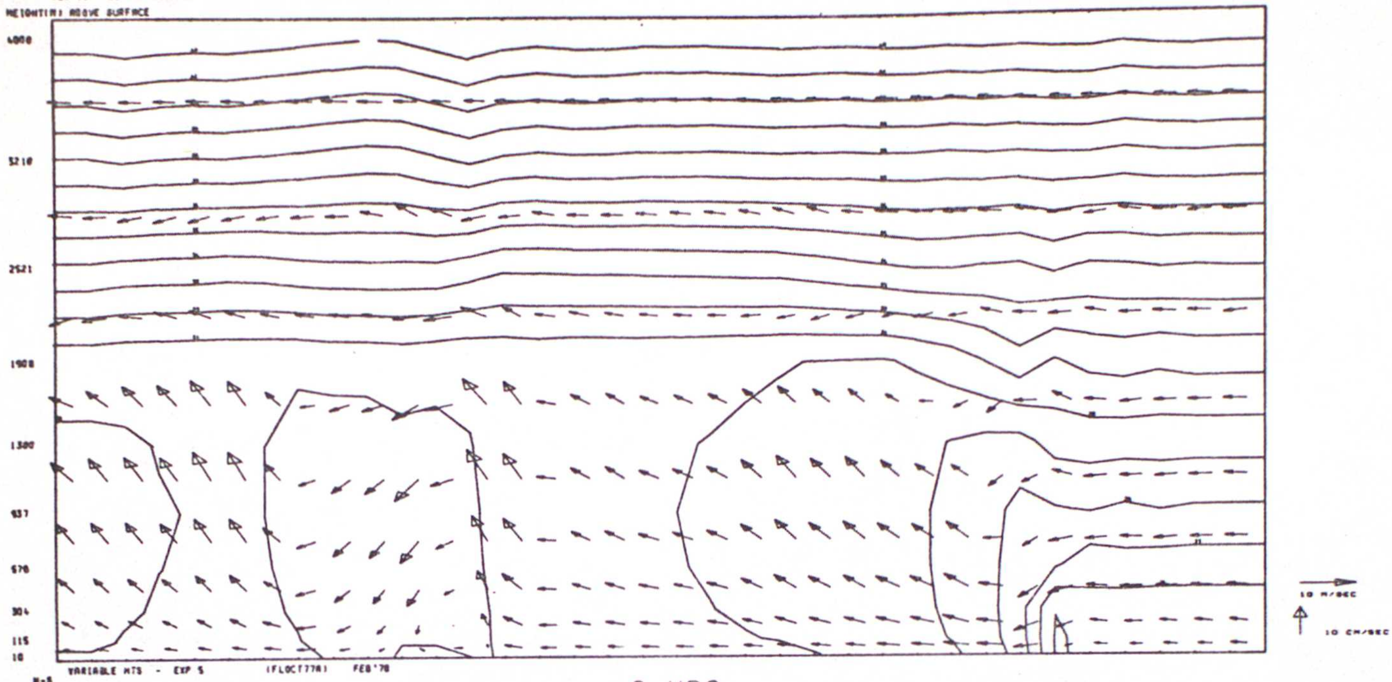
FIG 14

FCST 5

9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS



9 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME=52 29/6/71 FCST TIME=540 X 60 SECS

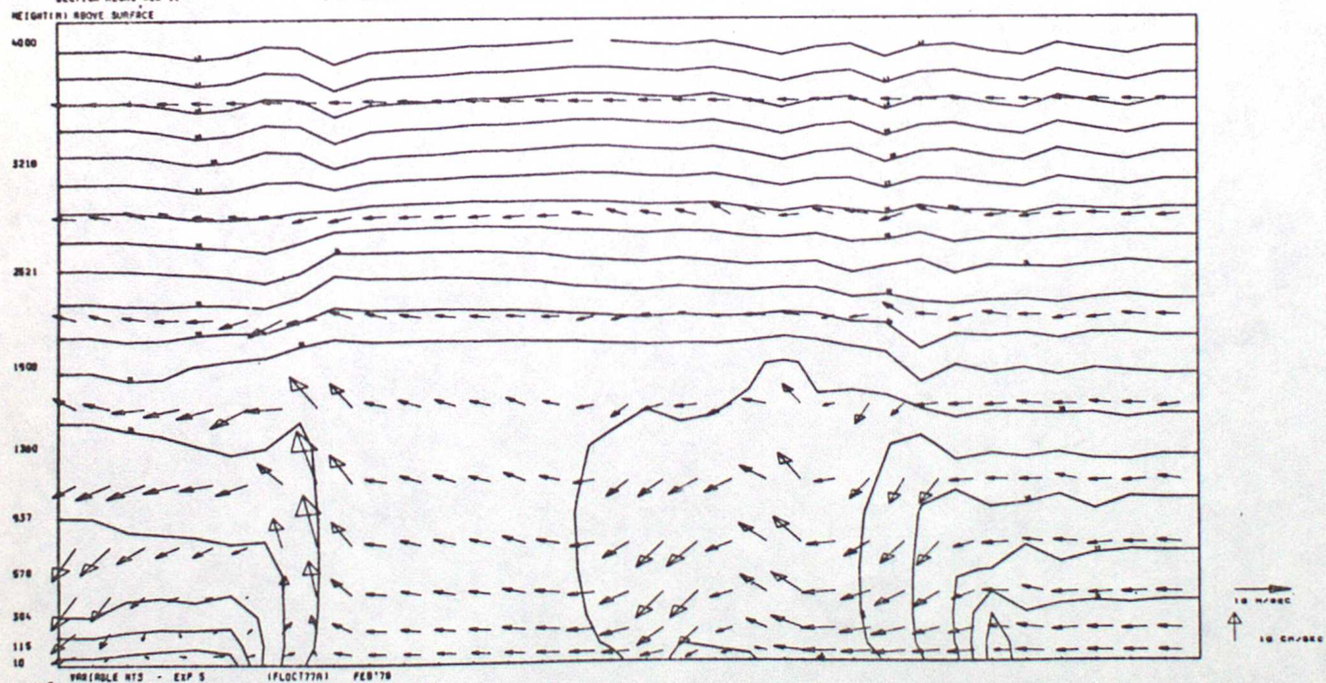


FIG 15
FCST 5

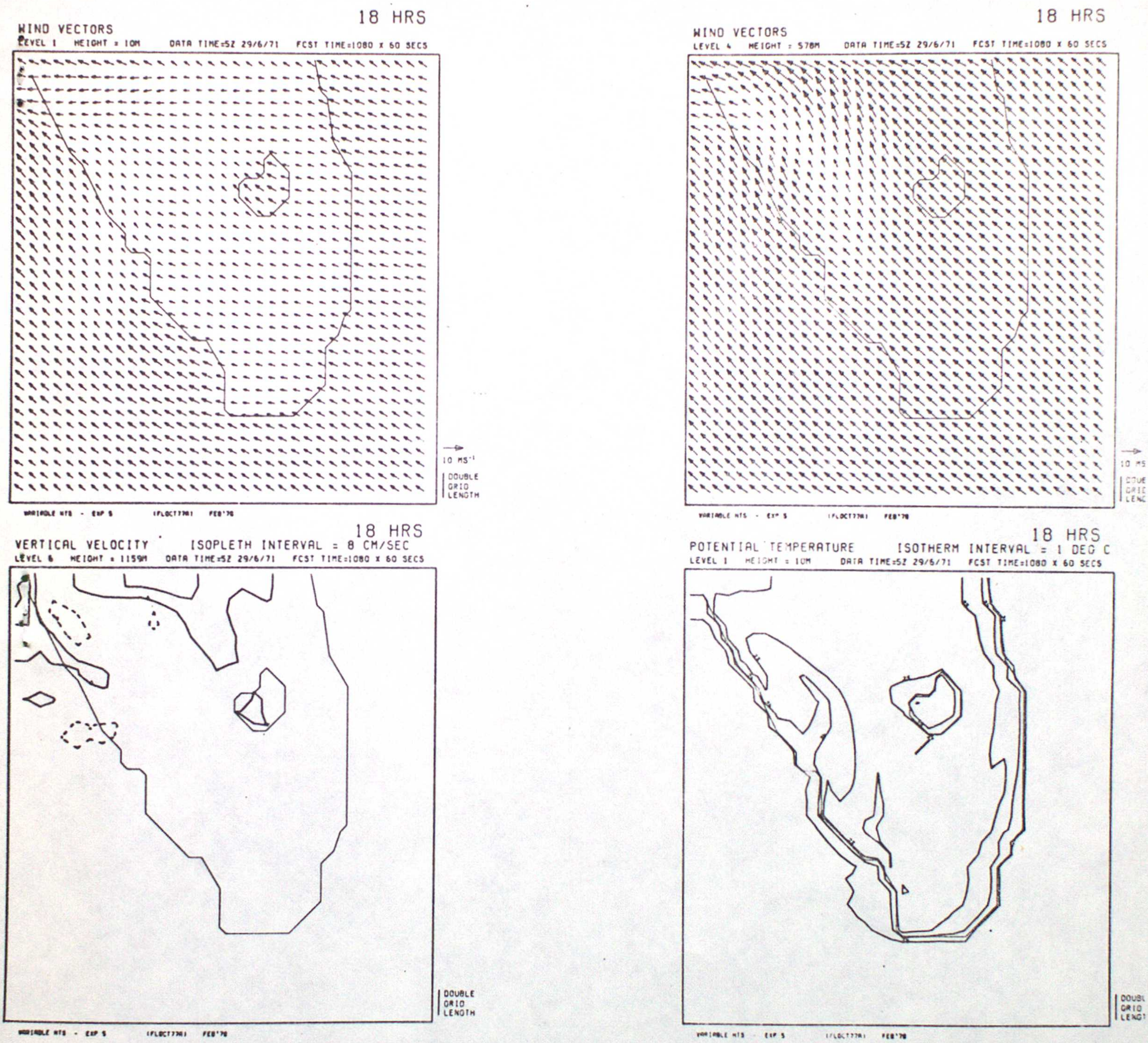

18 HRS
WIND VECTORS
LEVEL 1 HEIGHT = 10M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS
10 MS⁻¹
DOUBLE GRID LENGTH
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78
18 HRS
WIND VECTORS
LEVEL 4 HEIGHT = 578M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78
18 HRS
VERTICAL VELOCITY ISOPLETH INTERVAL = 8 CM/SEC
LEVEL 6 HEIGHT = 1159M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS
DOUBLE GRID LENGTH
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78
18 HRS
POTENTIAL TEMPERATURE ISOTHERM INTERVAL = 1 DEG C
LEVEL 1 HEIGHT = 10M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS
VARIABLE HTS - EXP 5 (FLOCT77A) FEB'78

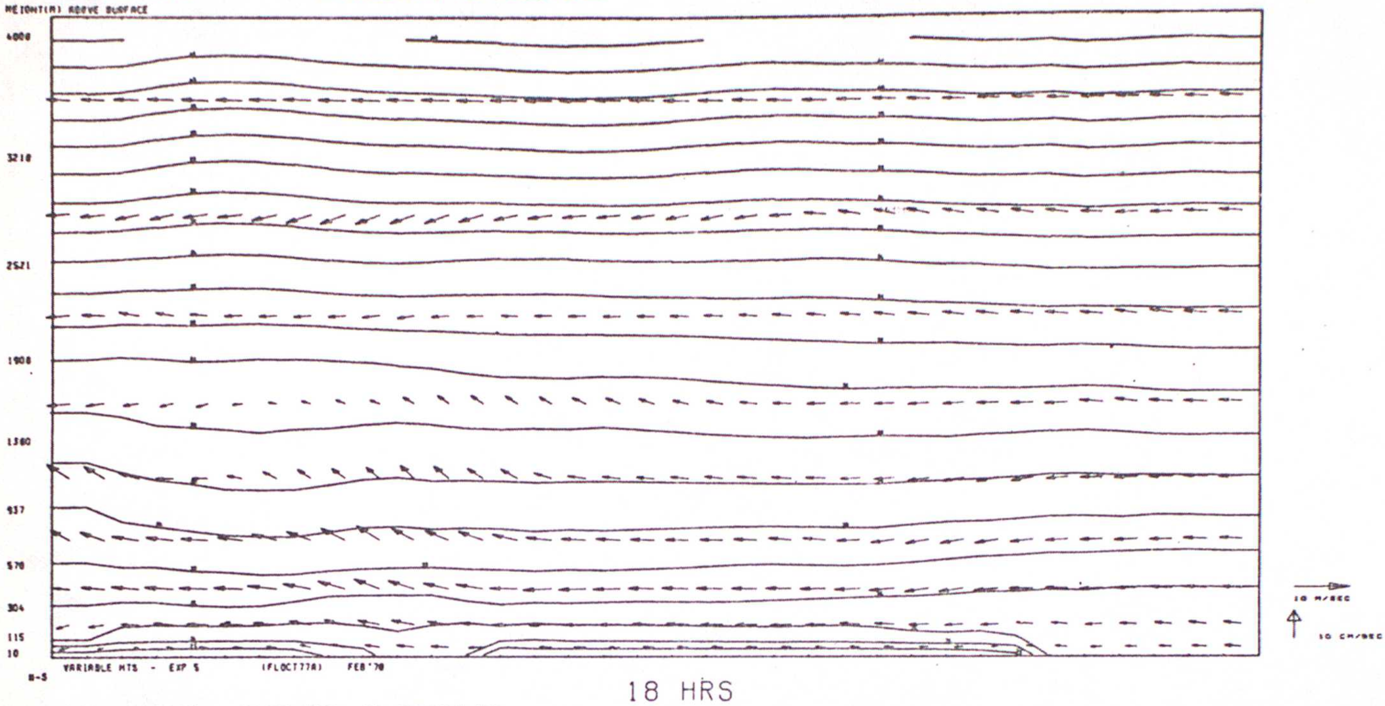
FIG 16

FCST 5

18 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME-52 29/6/71 FCST TIME=1080 X 60 SECS



18 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME-52 29/6/71 FCST TIME=1080 X 60 SECS

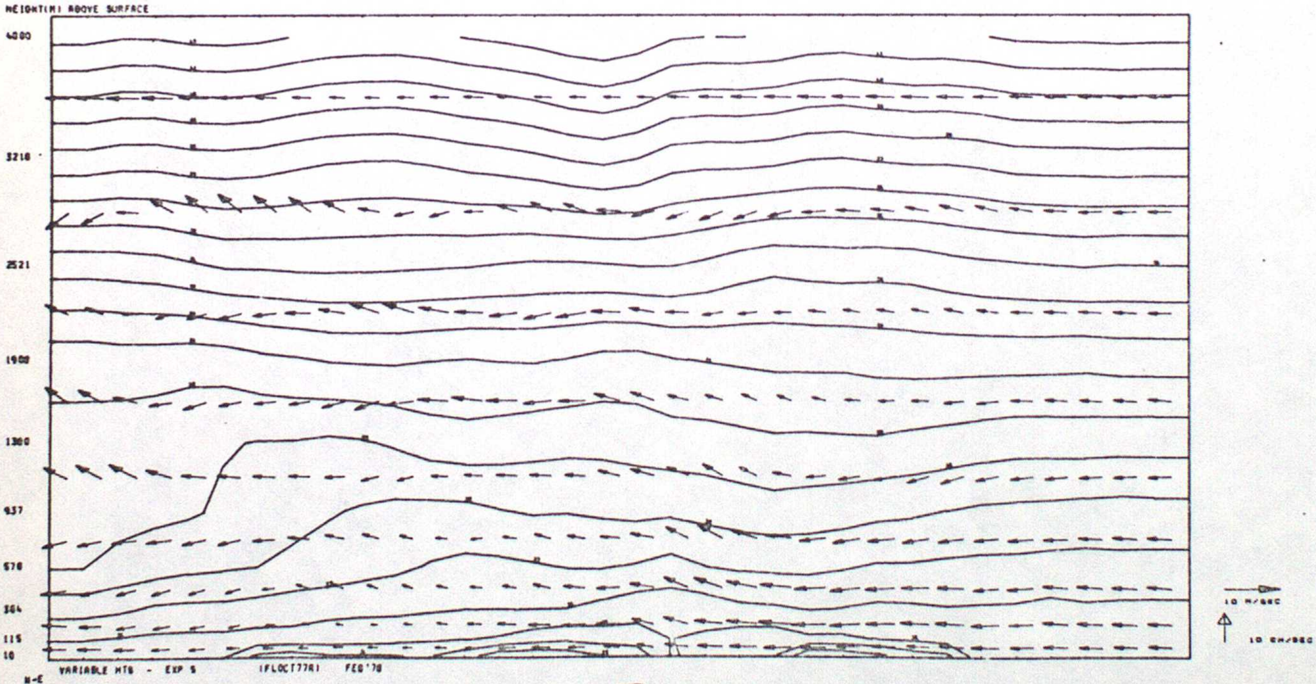


FIG 17
FCST 5

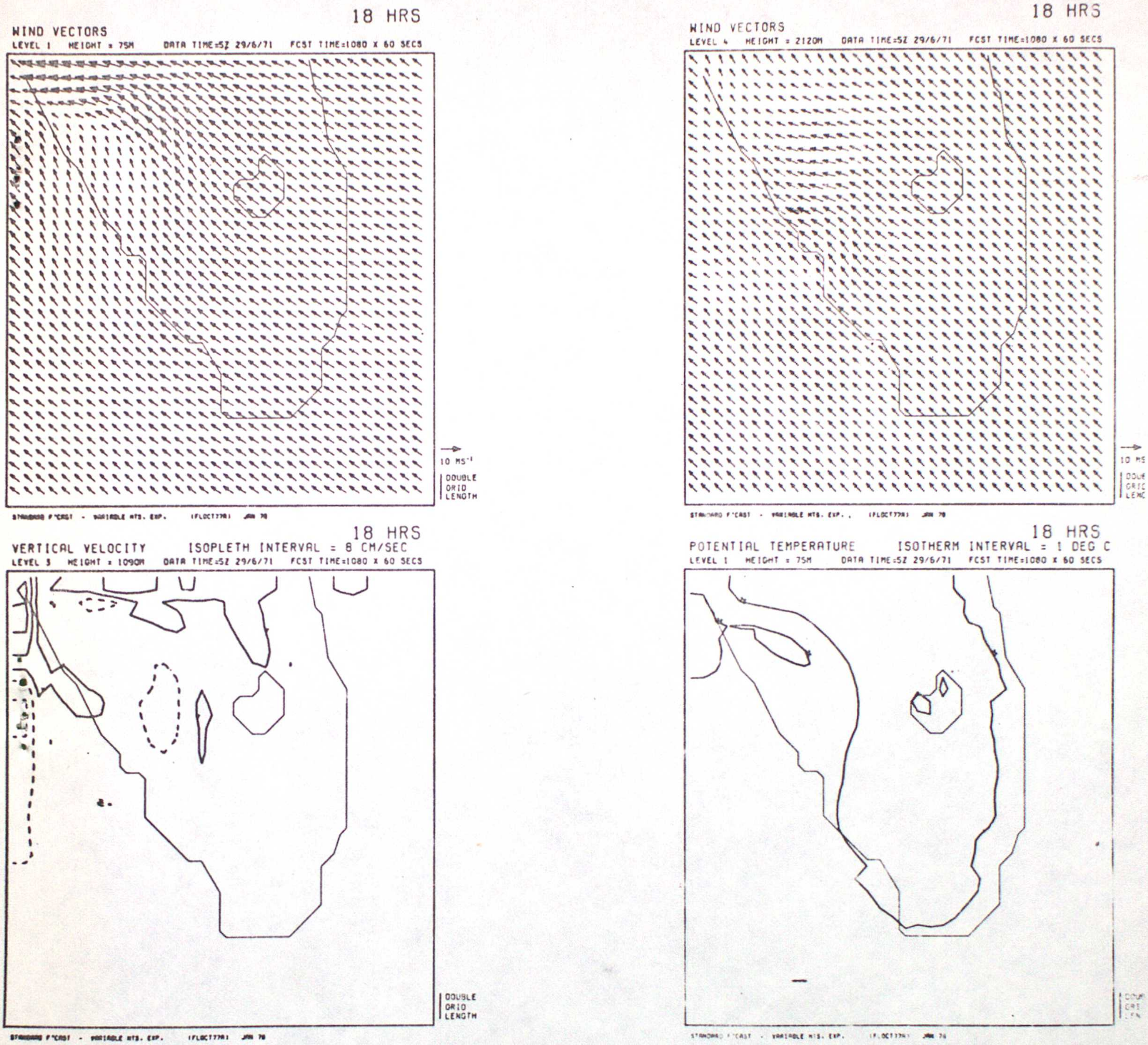

18 HRS
WIND VECTORS
LEVEL 1 HEIGHT = 75M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS
10 MS⁻¹
DOUBLE GRID LENGTH
18 HRS
WIND VECTORS
LEVEL 4 HEIGHT = 2120M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS
18 HRS
VERTICAL VELOCITY ISOPLETH INTERVAL = 8 CM/SEC
LEVEL 3 HEIGHT = 1090M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS
DOUBLE GRID LENGTH
18 HRS
POTENTIAL TEMPERATURE ISOTHERM INTERVAL = 1 DEG C
LEVEL 1 HEIGHT = 75M DATA TIME=5Z 29/6/71 FCST TIME=1080 X 60 SECS

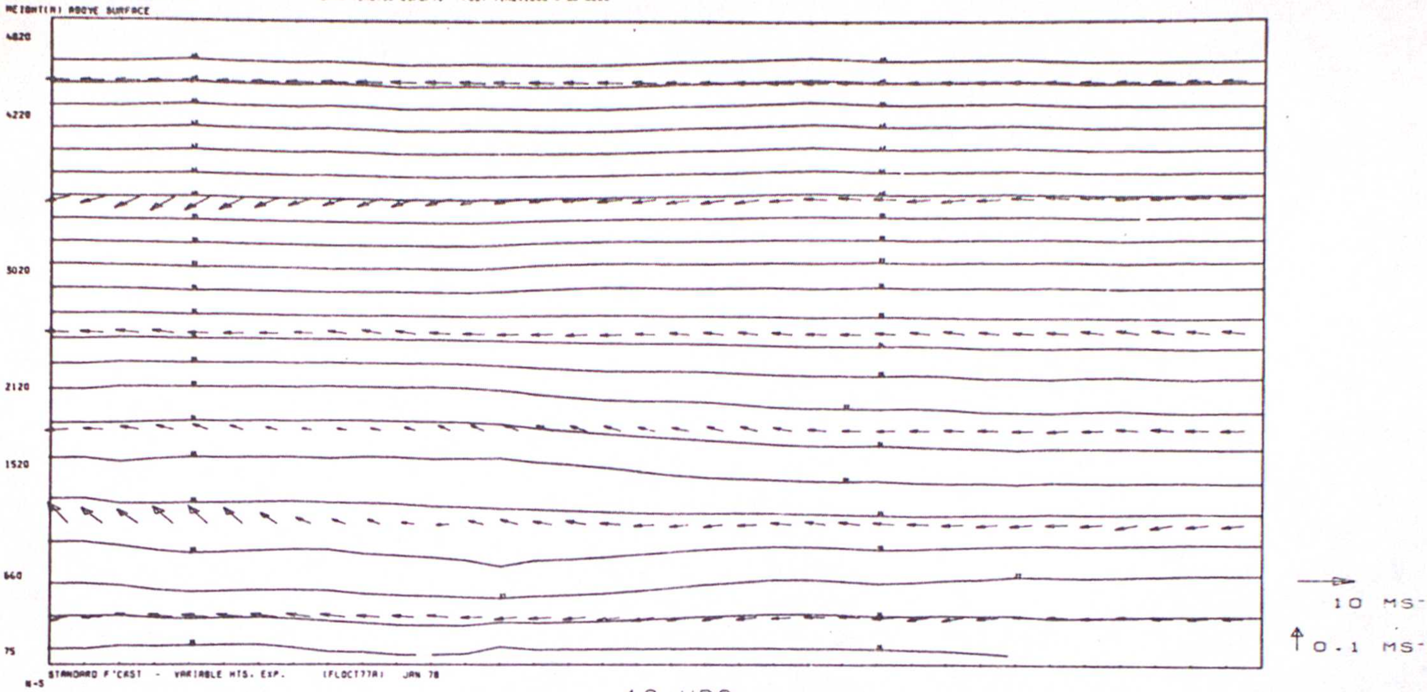
FIG 18

FCST O

18 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG COLUMN 20 DATA TIME:5Z 29/6/71 FCST TIME:1080 X 60 SECS



18 HRS

WIND VECTORS & POTENTIAL TEMPERATURE

SECTION ALONG ROW 11 DATA TIME:5Z 29/6/71 FCST TIME:1080 X 60 SECS

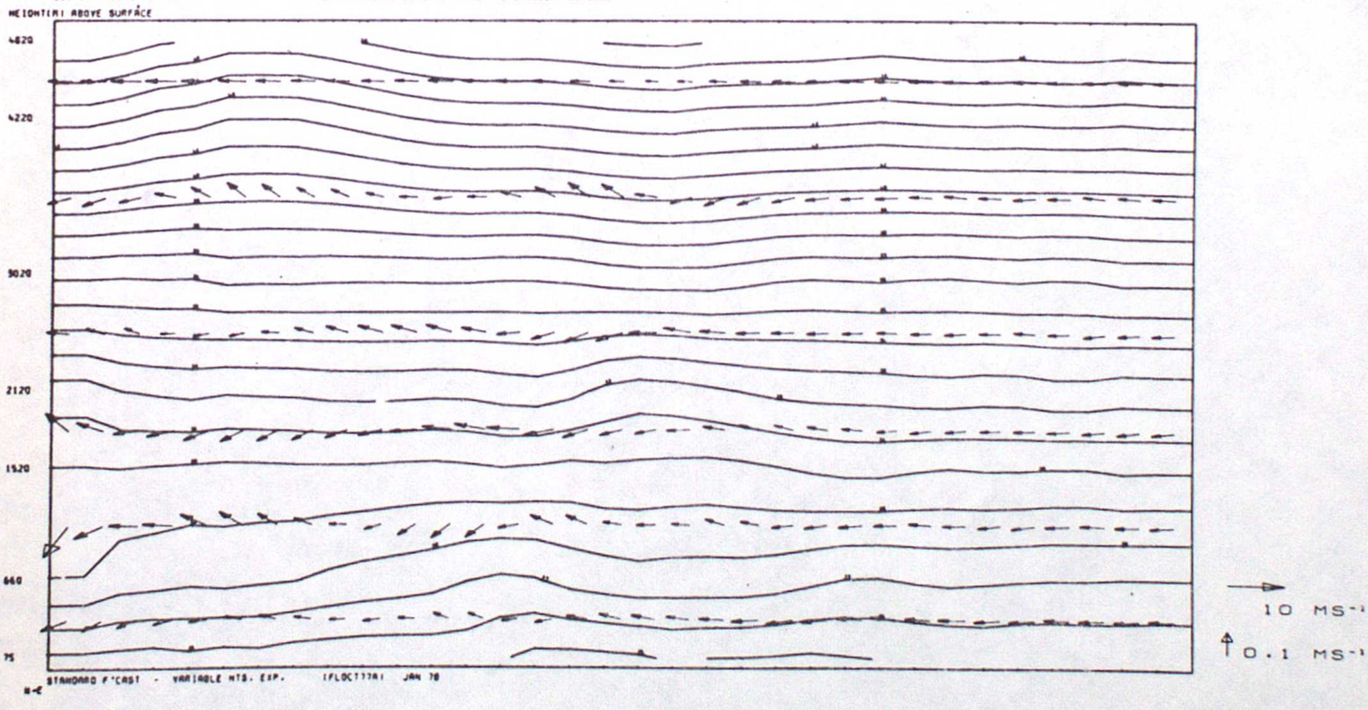


FIG 19
FCST O