LP

MET O 11 TECHNICAL NOTE NO 120

An investigation into the PMSL fields produced by the Met O 20 11-level model.

by

D.R. Roskilly

Meteorological Office (Met O 11)

London Road

Bracknell

Berkshire

United Kingdom

1. Introduction

During the forecast model inter-comparison experiments carried out in Met O 11 (Cullen 1978) it was observed that the PMSL fields produced by the 11-level, sigma, model (Saker 1975) and both the operational and sigma level Octagons are markedly different. The isobars were much smoother in the Octagon output and the 11-level model output contained considerable irregularities in the PMSL fields in particular over high ground especially the Himalayas (see FIGS 1, 2 and 3). These differences in the PMSL fields made the inter-comparisons more difficult and it was decided to investigate them to discover whether the problem lay in the 11-level model itself or in the output routines used to calculate PMSL, then, if possible, find a method to produce better PMSL charts.

In order to do this the differences between the sigma level Octagon and the 11-level model, which might affect the PMSL output, and the differences in the algorithms used to produce PMSL values were investigated one by one and the results examined. The date chosen for the start of the 5-Day forecast used in these investigations was 12Z 8.5.77. Forecasts which contain both smoothed and unsmoothed topography have already been produced for this period in the branch by the 11-level model and also by a model which uses equally spaced sigma levels (Davies 1978). For the study of the diurnal variation effects on the PMSL fields a 5-Day forecast that commenced at 12Z 14.8.77 was used.

2. Investigation of Differences

There are three main differences in the models themseleves that could affect the PMSL fields. (a) The Octagon uses topography that has been smoothed whereas the 11-level model does not. (b) The surface boundary routines used in the two models are not the same. (c) The values of sigma at the sigma levels are different. In the output routines the differences lie (a) in the algorithm used to calculate PMSL from the model parameters, and (b) in the fact that the Octagon uses a cubic spline to smooth the contours but the 11-level model does not.

2.1 Topography

FIG 4 shows the results of a forecast produced by the 11-level model where the topography has been smoothed in a similar way to that of the Octagon. The effects of this are discussed in more detail in Roskilly (1978). It can be seen here when this forecast is compared with the unsmoothed topography forecast (FIG 3) that smoothed topography goes some of the way into eliminating the irregularities in the PMSL fields over high ground such as the Himalayas and the Rockies. However this Note did not recommend that smoothed topography be used in the 11-level model as it tends to degrade the forecast. In any case it is clear that this is not the complete answer as quite large areas of irregularities remain in the PMSL fields over the Himalayas. Also the isobars are still not as smooth as those produced by the Octagon.

2.2 Boundary Layer Scheme

Although in these experiments the Octagon boundary routine was not tested in the 11-level model because of programming difficulties the effects of changing the normal 11-level model boundary routine (Saker 1975) to a much more simplified scheme (Davies 1978) have been studied. FIG 5 shows the results of incorporating this simplified routine into the 11-level model. There are some changes in the resulting forecast away from topographic affects, for instance a more realistic central pressure of the low pressure area over NE Russia. As regards to areas of high ground the values of PMSL over the Rockies and Himalayas are higher and more correct. Also over the Himalayas the large pressure gradients have been decreased. However the roughness in the isobars and the larger areas of irregularities over the mountains still remain. Therefore although the boundary routine needs some further investigation, it does not seem to be a major factor in the production of bad PMSL fields.

2.3 PMSL Algorithm

The algorithm used to calculate PMSL in the 11-level model during the inter-comparison experiment was as follows:-

FORMULA 1

$$PMSL = P_* \ EXP \left[\phi_* / R(T_{11} + 3.316 \times 10^{-4} \times \phi_*) \right]$$

P_* = Surface Pressure

ϕ_* = Surface Ht.

T_{11} = Temperature on sigma level 11 (lowest level)

R = Gas constant

(See Rowntree (1976))

whereas the sigma level Octagon uses:-

FORMULA 2

$$PMSL = P_{11} \left[\frac{T_{11} + 0.0065/G \times \phi_{11}}{T_{11}} \right]^{G/0.0065 \times R}$$

$$\phi_{11} = \phi_* + \left[RT_{11} \ln \left(\frac{1.0}{S} \right) \right]$$

and $P_{11} = S \times P_*$

S = value of sigma on the level used.

Also a cubic spline is included in the Octagon output routines to help smooth the contours.

FIG 6 shows the result when Formula 2 and a cubic spline are used in the output routines of a normal 11-level model forecast. There is considerable improvement in these PMSL fields when compared with the output which uses the old routines (FIG 3). Apart from some irregularities over the Himalayas the PMSL fields over high ground are much more realistic and are very similar to those produced by the sigma level Octagon (FIG 2). The isobars are also much smoother than before.

FIG 7 shows the effects of these same output routines on the 11-level model forecast with smoothed topography. It is obvious when FIGS 3, 6 and 7 are compared that the major improvements over high ground are due to the use of the Octagon algorithm in the 11-level model output routines.

2.4 Final adjustment of Algorithm and inclusion of all previously mentioned modifications

It is clear from Sec 2.3 that the Octagon output routines when used on the 11-level model produce the better PMSL fields. However a different value of sigma is incorporated in the PMSL algorithm when used on the 11-level model than when it is used on the Octagon. Therefore in order to eliminate this difference the Octagon output routines were used on a forecast done by the equally spaced sigma level model mentioned in the Introduction.

This model has its lowest sigma level at sigma = .95455, close to that of the Octagon. FIG 8 shows the PMSL output from this forecast when the Octagon algorithm plus smoothed topography and a simlified boundary routine is used. It is very similar to that in FIG 7 with regards to PMSL fields over high ground but even closer to the values of PMSL achieved by the Octagon in FIG 2. One possibility here is that these changes may not be due to the modifications to the sigma value used but to an improvement in the forecast due to the different sigma levels used in this model. FIG 9 shows this models PMSL output when smoothed topograph is incorporated in the forecast and the normal 11-level model output routines are used. It does show some improvement in the values of PMSL over the Rockies when compared to FIG 5. However the main problems of irregular PMSL fields over high ground and the roughness in the isobars remain.

2.5 Conclusion

These tests show that although both the type of topography and the type of boundary routine used have a part to play in the resulting PMSL fields produced the major influence on the output is the algorithm used to calculate PMSL. It was also shown that when the above differences between the Octagon and the 11-level model have been eliminated, and the Octagon algorithm when used in the 11-level model is adjusted so that the sigma level and lapse rate used are the same as in the Octagon then the PMSL outputs from the two models over high ground are very similar.

3. Investigation of improved PMSL Algorithm

In Sec 2 of this Note it has been shown that the output algorithm used for the Octagon is far better at producing the correct PMSL values over high ground than the one at present used (FORMULA 1). Therefore this Section is devoted to the optimisation of this algorithm for future use on the 11-level model.

There are two ways this can be done:- (a) by changing the sigma level used and (b) by changing the lapse rate used.

3.1 Choice of sigma level

The problem in obtaining the best sigma level is choosing one that is low enough in the atmosphere so that the errors introduced by assuming lapse rates and extrapolating down through the lower layers to PMSL are minimised (ideally in this respect the surface would be the best level to use), but at the same time far enough up in the atmosphere so that the algorithm is not over influenced by diurnal variations transmitted up from the surface.

Diagrams 1 to 4 show temperature profiles at 3 levels (surface to level 10) at selected points over the N Hemisphere during a 5-Day forecast by the 11-level model which commenced at 12Z 14.8.77. It is evident that in only the extreme case, that of a point over the interior of Algeria (Diagram 4), is level 10 noteably affected by diurnal variations at the surface. Over this period the maximum diurnal variation here is $7^{o}K$ at level 10. If one assumes a surface pressure of 990 MB, a surface geopotential of 1600 m^2/s^2 and temperatures of $310^{o}K$ and $303^{o}K$ at level 10 and introduce these values into the proposed algorithm it gives a diurnal variation of PMSL of 0.4 MB. This is very reasonable under these conditions.

One problem of selecting a sigma level so low in the model is caused by the deep stable layers typical in the winter over continents. As shown in Diagram 5 the obvious answer to this is to select a higher sigma level. This would solve the adverse effects of this phenomenon but reintroduce the errors due to extrapolating over large distances to MSL (see Diagram 6). Also the Environment Lapse Rate drawn schematically in Diagram 6 is more typical and occurs more often in the atmosphere than that drawn in Diagram 5. Therefore a better way is to choose a lapse rate for the algorithm that produces a compromise between these two extremes.

3.2 Algorithm Lapse Rate

As seen in Sec 2.3 the sigma level Octagon PMSL algorithm uses the ICAN lapse rate of 6.5°K/KM. This combined with sigma = .93701 for sigma level 10 produces the results shown in FIG 10. Rowntree (1976) suggests that a better approximation to use is the average observed lapse rate between the sigma level in use and a point half way between the ground and MSL. This ties in with the idea of the adjustment to the lapse rate mentioned above (Sec 3.1). When these calculations are worked through a lapse rate of approximately 5°K/KM is arrived at.

FIG 11 shows a PMSL chart produced with this lapse rate used from level 10, and when compared to FIG 10 the pressures over the Rockies and Greenland are higher and somewhat closer to the actual. However both these charts do seem to produce rather worse PMSL fields over the Himalayas than those produced using smoothed topography and a simplified boundary routine as in FIG 8, or even those from the normal 11-level model using this algorithm from level 11 with a 6.5°K/KM lapse rate as in FIG 6. Therefore these necessary adjustments in the algorithm do seem to degrade the PMSL output in this area but when smoothed topography is incorporated in the model this modified algorithm produces the PMSL fields shown in FIG 12. This shows much improved PMSL fields over the Himalayas and suggest that some form of smoothed topography is necessary in this area.

Conclusion

It has been shown above that when the necessary adjustments are done to the Octagon PMSL algorithm and a lapse rate of 5°K/KM from level 10 (sigma = .93701) is used very good PMSL charts can be obtained from the normal 11-level model data apart from an area over the Himalayas. Smoothed topography considerably improves the PMSL fields in this area, however Roskilly (1978) suggests that smoothed topography used over the whole of the N Hemisphere degrades the forecast but also indicates that some limited form of smoothed topography in the area of the Himalayas may actually improve the forecast. Therefore the introduction of of some form of filter to smooth the topography in this region to both improve the forecast and the PMSL fields seems to be an answer to this problem. Alternatively the PMSL fields in this area could be smoothed by applying a filter in the output routines.

References

Saker, N.J. 1975 An 11-layer General Circulation Model.
MET O 20.
Technical Note NO II/30.

Cullen, M.J.P. 1978 Six case studies from the forecast model intercomparison experiments (2/77-4/78).
MET O 11.
Technical Note No. 113.

Rowntree, P.R. 1976 Derivation of Sea Level Pressure and 1000 MB geopotential below ground.
MET O 20.
Technical Note No. II/82.

Davies, T. 1978 The use of equally spaced sigma levels and layers in a Met O 20 11-level model.
MET O 11.
Technical Note No. 121.

Roskilly, D.R. Three case studies of 5-Day forecasts using the 11-level, sigma, model with smoothed and unsmoothed topography.

ACTUAL FOR 12Z 8·5·77

SURFACE PRESSURE ISOBARS AT 4MB INTERVALS

0 HR.FORECAST. DATA TIME 12 Z 11 / 5 / 77. VERIFICATION TIME 12 Z 11 / 5 / 77

SE VERSION

FIG 2

SIGMA LEVEL OCTAGON USING NORMAL OCTAGON OUTPUT ROUTINES

:2Z 08/05/77 VT 12Z 11/05/77 T+72 SURFACE PRESSURE (4MB INT) UPDATE

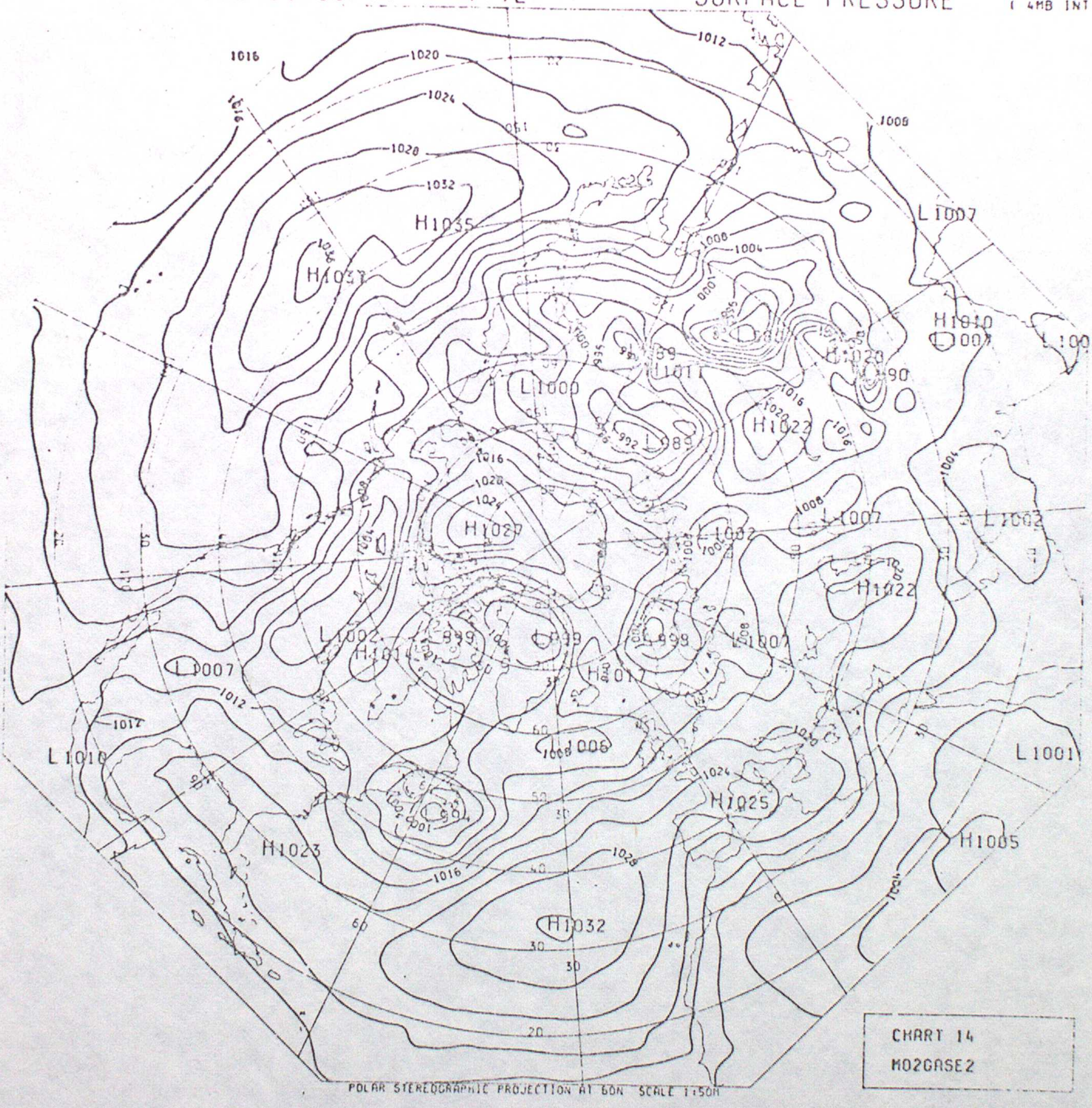


FIG 3

STANDARD 11-LEVEL MODEL WITH UNSMOOTHED TOP. AND USING FORMULA 1 IN THE PMSL ALGORITHM.

PMSL

FIG 4

STANDARD 11-LEVEL MODEL WITH SMOOTHED TOP. USING FORMULA 1 IN THE PMSL ALGORITHM

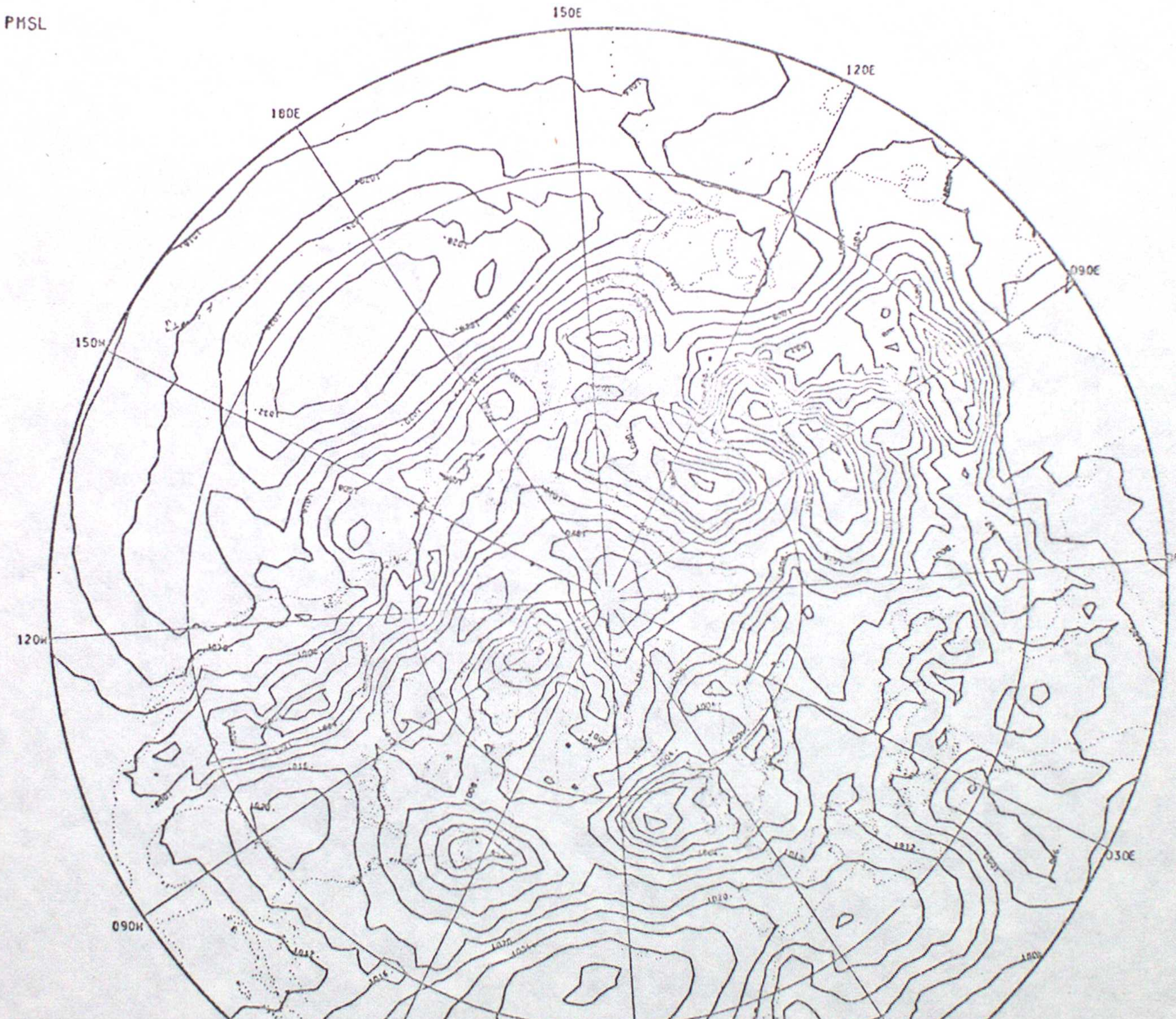


FIG 5

11-LEVEL MODEL WITH SIMPLIFIED BOUNDARY ROUTINE AND UNSMOOTHED TOP. USING FORMULA 1 IN THE PMSL ALGORITHM

FIG 6

STANDARD 11-LEVEL MODEL WITH UNSMOOTHED TOP. USING FORMULA 2 IN THE PMSL ALGORITHM AND A LAPSE RATE OF 6.5°K/KM FROM LEVEL 11

FIG 7

STANDARD 11-LEVEL MODEL WITH SMOOTHED TOP USING FORMULA 2 IN THE PMSL ALGORITHM AND A LAPSE RATE OF 6.5°K/KM FROM LEVEL 11

EQUALLY SPACED SIGMA LEVELS MODEL WITH SMOOTHED TOP. USING FORMULA 2 IN THE PMSL ALGORITHM AND A LAPSE RATE OF 6·5°K/KM FROM LEVEL 11

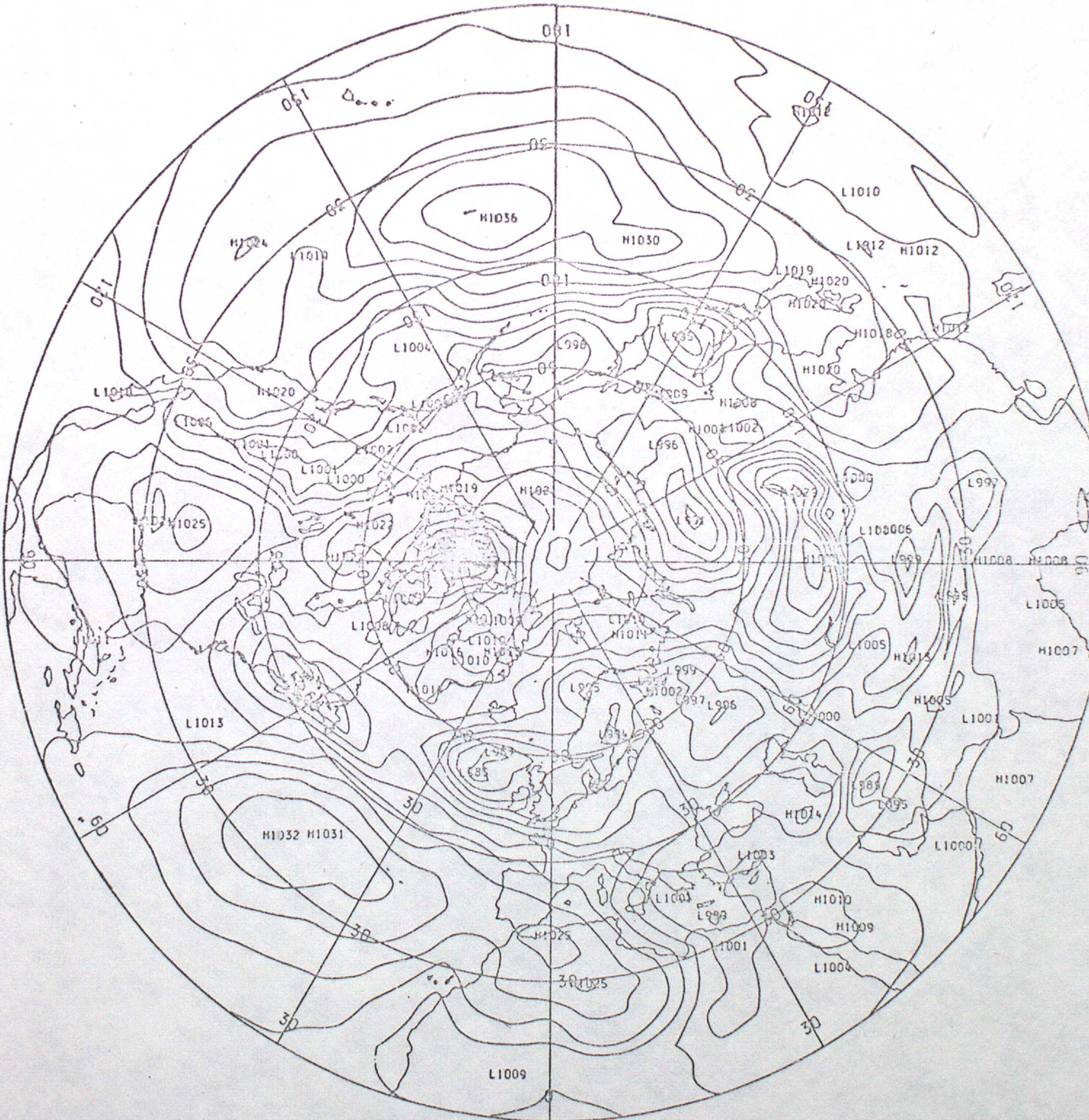


FIG 9

EQUALLY SPACED SIGMA LEVELS MODEL WITH UNSMOOTHED TOP. USING FORMULA 1 IN THE PMSL ALGORITHM

FIG 10

STANDARD 11-LEVEL MODEL WITH UNSMOOTHED TOP. USING FORMULA 2 IN THE PMSL ALGORITHUM AND A LAPSE RATE OF 6.5°K/KM FROM LEVEL 10

FIG 11

STANDARD 11-LEVEL MODEL WITH UNSMOOTHED TOP. USING FORMULA 2 IN THE PMSL ALGORITHM AND A LAPSE RATE OF 5°K/KM FROM LEVEL 10

STANDARD 11-LEVEL MODEL WITH SMOOTHED TOP. USING FORMULA 2 IN THE PMSL ALGORITHM AND A LAPSE RATE OF 5°K/KM FROM LEVEL 10

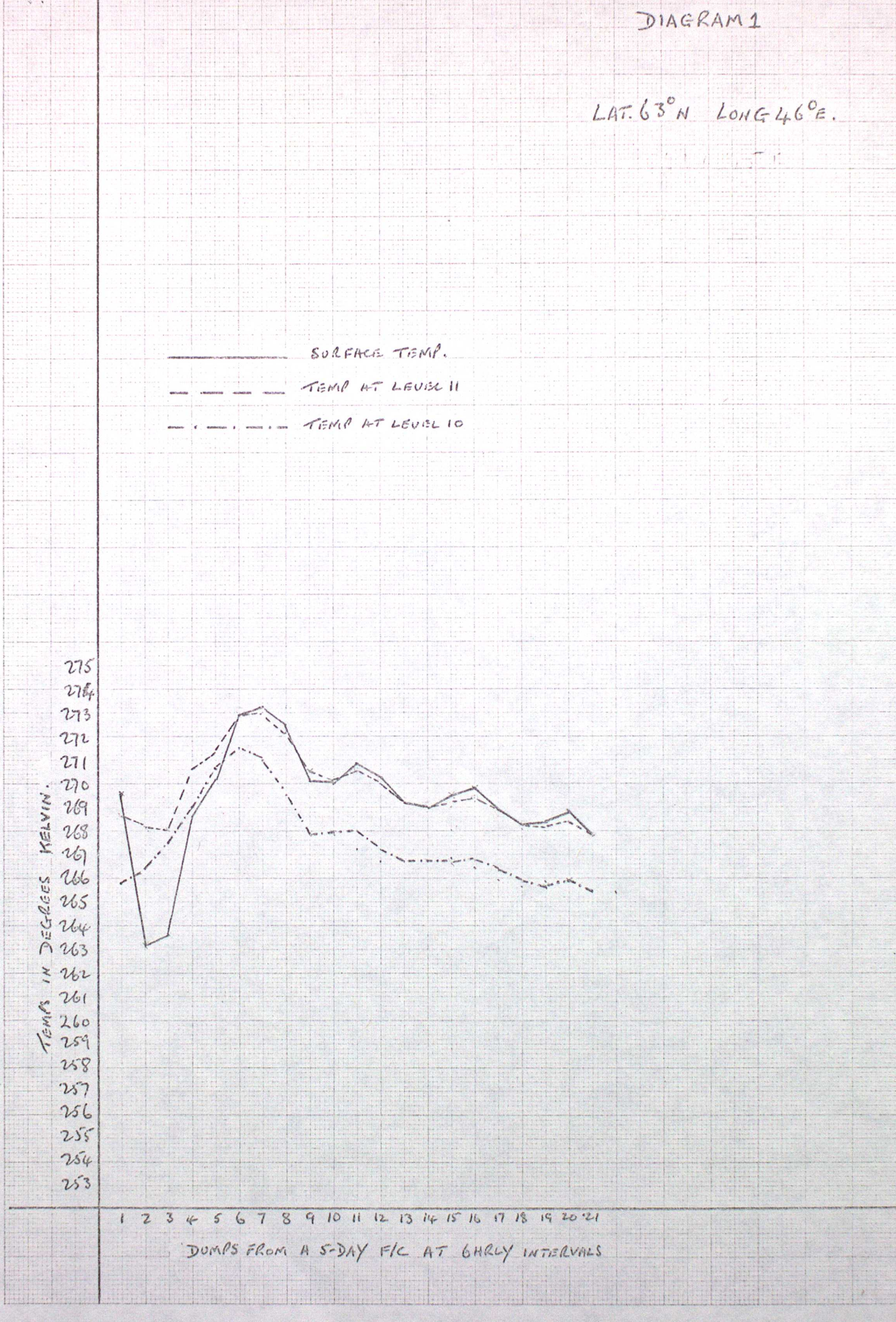


DIAGRAM 1
LAT. 63°N LONG 46°E.
SURFACE TEMP.
TEMP AT LEVEL 11
TEMP AT LEVEL 10
TEMPS IN DEGREES KELVIN.
275
274
273
272
271
270
269
268
267
266
265
264
263
262
261
260
259
258
257
256
255
254
253
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
DUMPS FROM A 5-DAY F/C AT 6HRLY INTERVALS

DIAGRAM 2

LAT 53°N 1.5°W

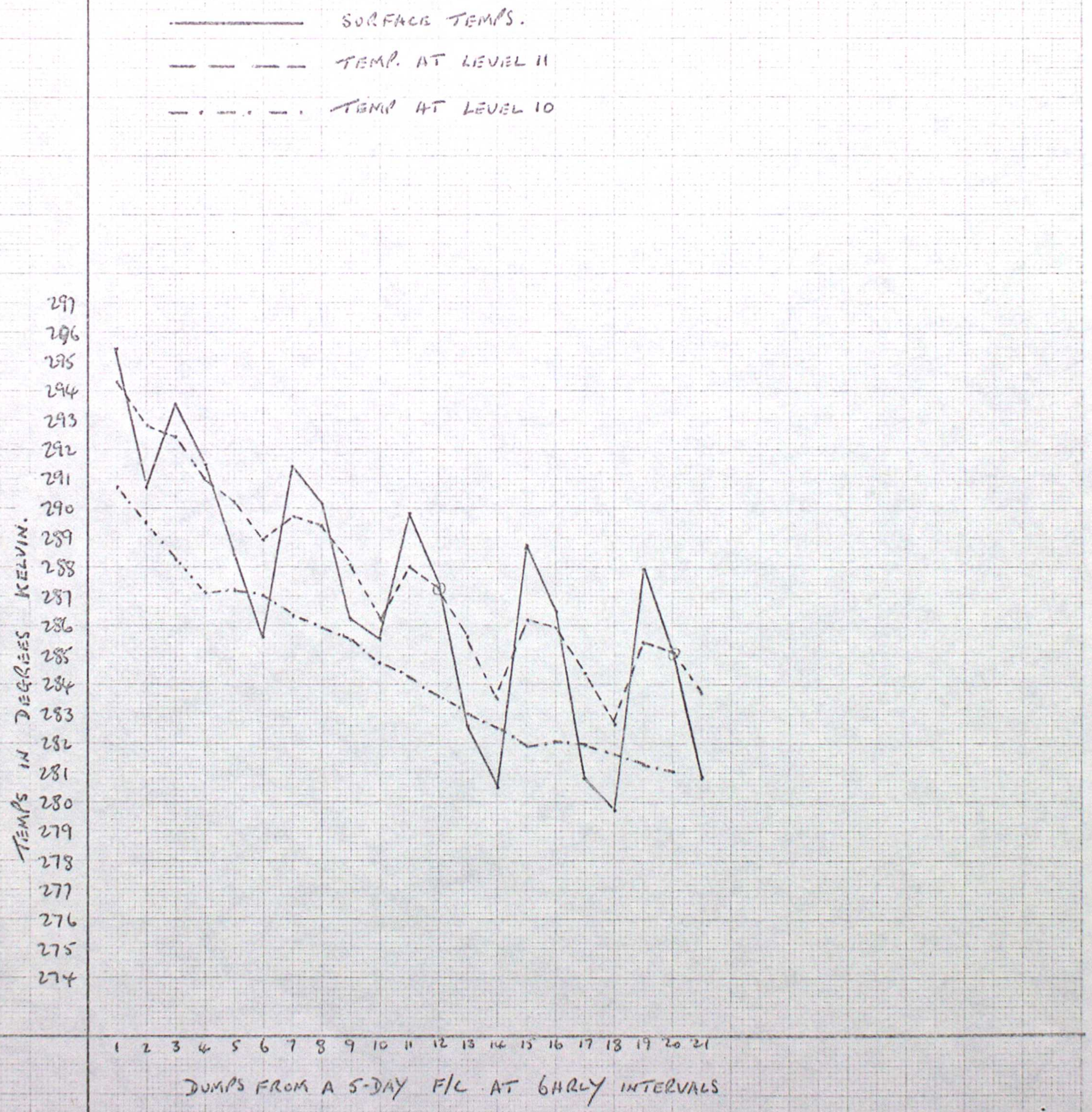


DIAGRAM 3

LAT 45°N LONG 101°W

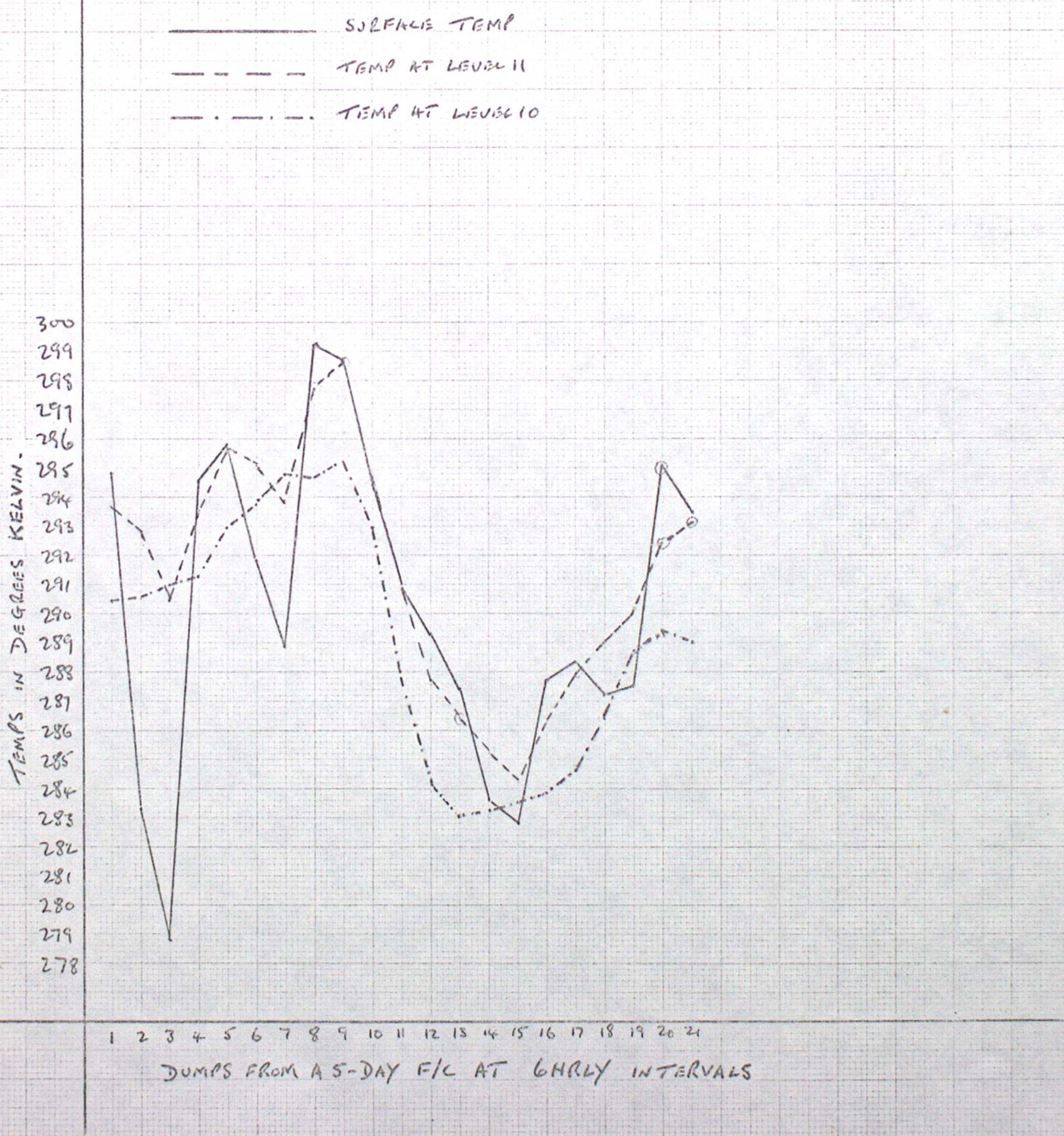
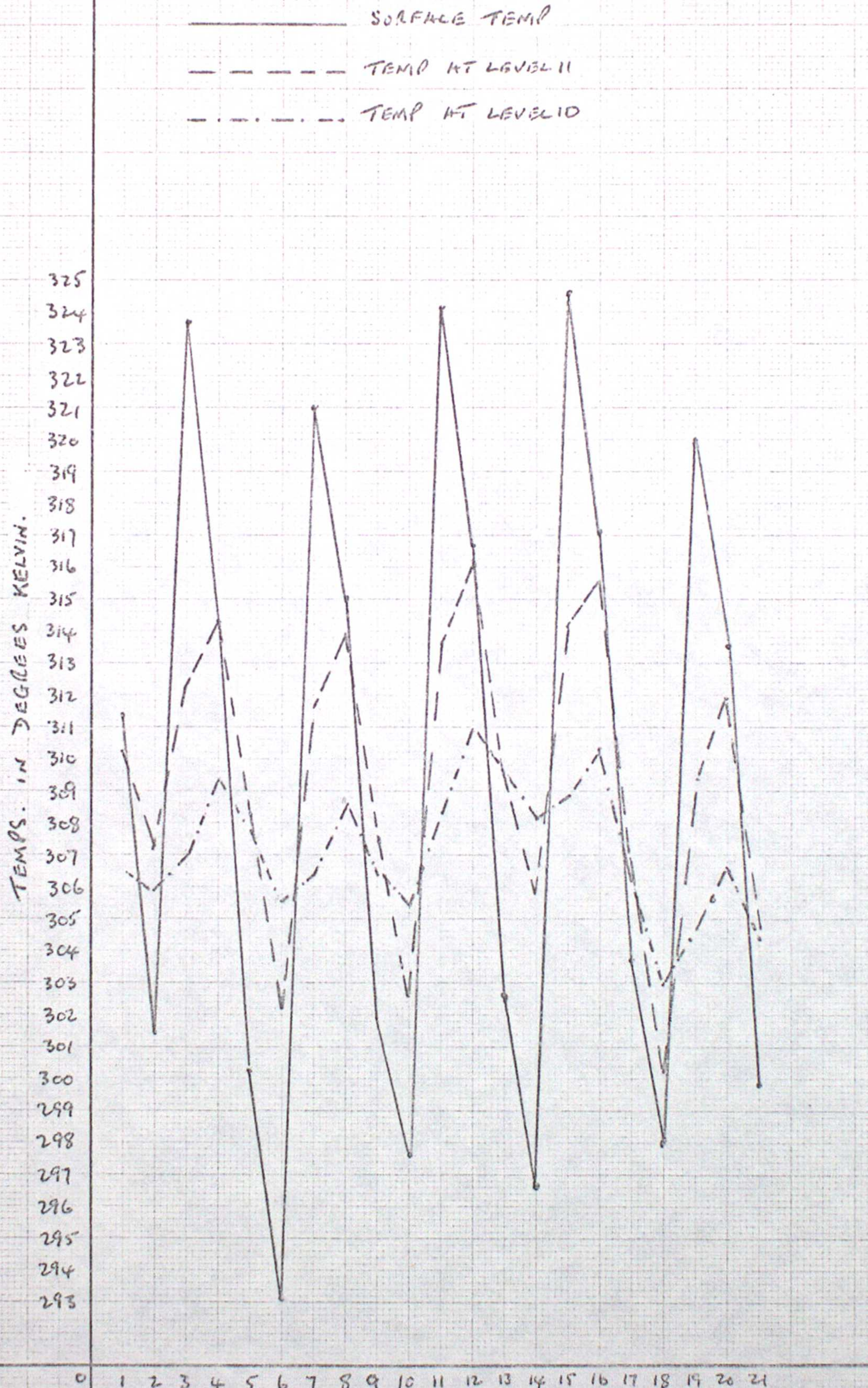


DIAGRAM 4

LAT. 31°N LONG 06°E



— . — . —— ALGORITHM LAPSE RATE.

———————— ENVIRONMENT LAPSE RATE.

DIAGRAM 5

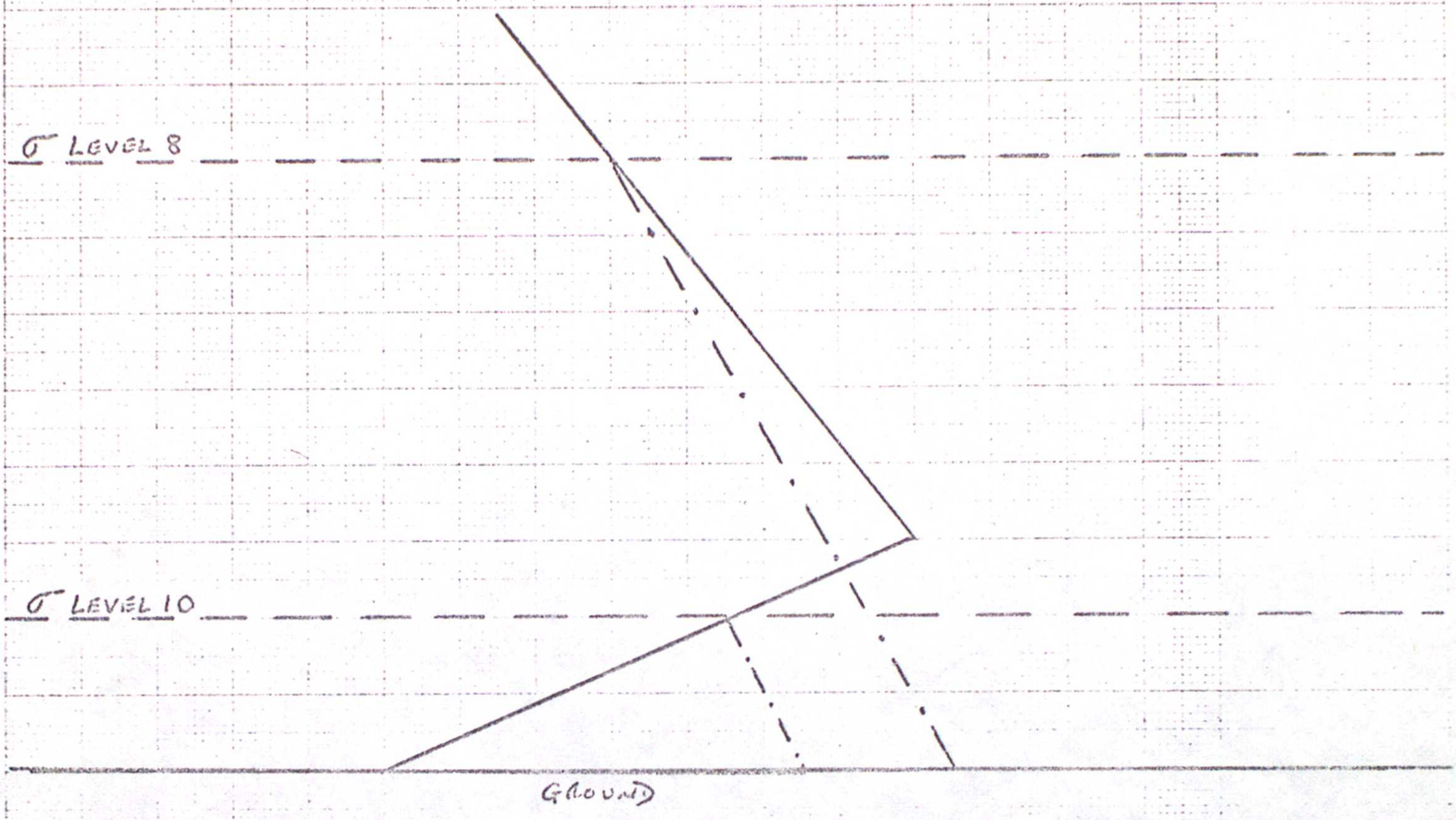


DIAGRAM 6