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A Diagnostic Analysis Study of a Moisture Forecast Case in LFM-II

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A DIAGNOSTIC ANALYSIS STUDY OF A MOISTURE FORECAST CASE IN LFM-II

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1. Introduction

While convection by cumulus clouds and their large scale impact are known to have significant effects in numerical prediction of precipitation, there remains significant errors in grid scale solutions that destroy the chance for convective parameterization schemes to function realistically.

Some of these are explored in a specially selected single case study designed to remove circulation forecast errors (the major problem) from consideration.

2. Method of Choosing Cases

The precipitation forecasts in the LFM are very closely related to water vapor and its flux convergence in the three lowest of the four tropospheric layers. Model circulations and moisture analyses are major factors in prediction successes or failures and it is usually difficult to determine precisely which of these sources is most responsible for errors. In order to isolate attention on the impact of moisture related errors in precipitation forecasts, we adopted the following approach: we searched for examples of poor relative humidity forecasts that had exceptionally good circulation forecasts out to 36 hours. More specifically, we chose the cases which exhibited the following conditions: bad moisture forecast, i.e.,

$$|(RH)_{36,FCST} - (RH)_{36,ANL}| \geq 30\% \qquad (1)$$

and good circulation forecasts, i.e.,

$$|H_{36,FCST} - H_{36,ANL}| < 60 \text{ m} \qquad (2)$$

where $(RH)_{36,FCST}$ and $H_{36,FCST}$ are the 36-hour averaged relative humidity forecast fields in the boundary layer and troposphere, and the 36-hour height forecast at 700 mb and 500 mb respectively. The $(RH)_{36,ANL}$ and $H_{36,ANL}$ are the corresponding analysis fields.

The LFM-II is run twice daily after being initialized with 0000 GMT and 1200 GMT data. According to conditions (1) and (2), we checked the operational forecast results made by LFM-II at NMC from 1 March to 30 April 1982, and found one case (1200 GMT 10 March case) which satisfied the above criteria.

3. Circulation Description of the Case

The circulation at 500 mb developed from 1200 GMT 10 March to 0000 GMT 12 March 1982 as shown in Figures 1, 2, 3, and 4. The system at 110°W (located in Wyoming, Idaho, and Montana) in Figure 1 (1200 GMT 10 March) is a diffluent developing trough. In fact, it continuously developed and became stronger in 36 hours (see Figures 2, 3, and 4). At 0000 GMT 12 March it moved eastward to about 83°W in Ohio and Kentucky. On the surface chart, the corresponding cold high also moved southeastward. This synoptic system caused some precipitation near the east coast of the U.S. In the west, the deep cyclone which is located in the East Pacific (the center is at 135°W, 35°N) slowly filled and remained stationary for about 12 hours from the initial time (1200 GMT 10 March); then it moved slowly eastward affecting the west coast region of the U.S. The flow in the southeast sector of the cyclone was wet and warm, and continuously transported considerable moisture to the west coast mountain regions, causing further rainfall on the west coast and inland mountain regions. Precipitation in both coastal regions is shown in Figure 5.

4. The Description of RH and Height Errors

Figure 6 shows the difference of averaged relative humidity in the boundary layer and the troposphere between the 36-hour forecast and the analysis. We can see that a large error of RH appears over Kentucky, Indiana, Ohio, Illinois, Missouri, and Tennessee. The largest error is more than 50%. But as shown in Figures 7 and 8, the 36-hour circulation forecast of LFM-II is excellent. Most of the height errors at 500 mb and 700 mb are below 60 m over the U.S.

In order to determine the distribution of the RH error vertically, four grid points (i = 19, 20; j = 11, 12) of the LFM-II grid system from the major error region were chosen as typical. Then the averaged RH of the points were calculated at different levels for the various forecast times. The results are shown in Figure 9. Figure 9, shows the moisture in the boundary layer increasing with time. At 36 hours it approaches a saturated state (about 90%). The corresponding 12-, 24-, 36-hour forecasts of RH in the layer are quite accurate in pattern, but amplitude is lacking producing RH errors of somewhat less than 20%. In the higher troposphere the forecasts are substantially poorer. The worse forecast is that in the model's third layer. At 36 hours the forecast is extremely dry, i.e., the region of the four gridpoints has virtually no moisture and the RH error is more than 50%.

As Figure 10 shows, the region where the difference of RH between the 36 hour forecast and the corresponding analysis is larger than 30% expands with height and spreads northward. The axis of maximum RH error tilts north eastward with height, and the intensity of error also increases. The biggest

error of RH reached is 85% in the third layer, and propagates eastward during the forecast.

5. Diagnostic Analysis

Here we attempt to explain the reasons which cause the error discussed above. According to preliminary analysis there are two sources of errors. One is related to the daily variation of RH in the boundary layer. The boundary layer RH is greater in the morning than in the evening. Figure 11 shows that in the morning the relative humidity reaches 100% in the Arkansas, Mississippi, and Louisiana, but as Figure 12 shows, in the evening the relative humidity is below 85% in the same areas. This variation of RH is caused by heating during day or cooling during night. Because the LFM-II does not have a parameterization of radiation to strongly and correctly adjust the temperature in the boundary layer, these large diurnal RH variations are missed.

An other error source is the incorrect advection of moisture. Figure 13 shows the tracks of wet centers (W) and dry centers (D) during the 36-hour forecast time at 600 mb (about the third layer of LFM-II) for the forecast (broken line) and the analysis (solid line). It is obvious that the forecast centers of RH move faster than in reality and develop a southward tilt, especially in the 36-hour forecast. The worse situation occurs in the Ohio region where a dry center of RH is forecast, but in fact there is a wet center.

Figures 14, 15, and 16 are the analysis of precipitable water in the tropospheric layer and height charts at 700 mb from 0000Z 11 March to 0000Z 12 March 1982 respectively. The corresponding 12-, 24-, 30-, 36-hour forecast charts are shown in Figures 17, 18, 19, and 20. From the analyses, it is apparent the warm, moist southwest flow from the Gulf of Mexico continuously moves northeastwards during 36 hours into the eastern part of the U.S. The intensity and area of flow also increase. It provides sufficient moisture

in the region to cause rainfall near the east coast at 0000 GMT 12 March as shown in Figure 5. In addition the trough which is located in the middle of the northern part of the U.S. moves slowly eastward. The dry area behind the trough also moves slowly eastward and becomes weaker. But as shown in the LFM-II 36-hour forecasts (Figures 17, 18, 19, and 20) the intensity of the Gulf of Mexico flow is weaker and the dry area is smaller than the analysis. The forecast of the northern trough is faster than reality and it blocks the Mexico Gulf flow that should otherwise move northward. The dry area behind the trough remains the same intensity and moves more rapidly during the 36-hour forecast. All the above are factors in the large error of RH over Kentucky, Ohio, Indiana, Illinois, and Missouri and cause the rainfall to be smaller and weaker in the eastern part of the U.S. as shown in Figure 5.

6. "Magic" Moisture in Rocky Mountains

As in the earlier description, the wet and warm southeast flow which comes from east Pacific is blocked by the Rockies. Most of the moisture remains on the West Coast as shown in Figures 14, 15, and 16. But it is clear that a spurious supply of moisture appears in the Rocky Mountain region by 24 hours. At 36 hours the region expands and moves eastward (see Figures 18, 19, and 20). This spurious moist area does not exist on the lee side of the Rocky Mountains in the analysis charts as shown in Figures 15 and 16; a question must be raised in regard to its source. Additionally as in section 3, why does the third layer become extremely dry? The direction of lower tropospheric flow relative to the mountains provides a clue as to the source of the spurious moisture. On the one hand, the lee side of the Rocky Mountains

is located to the east of the trough as shown in Figure 21. It is well known that upward vertical motion normally appears in that area (see Figure 22). So the wet area in the troposphere on the lee side of the Rocky Mountains is mainly caused by the vertical transport of W (the precipitable water) flux from the boundary layer where ω (ω=dp/dt) is negative (see Figure 22). Conversely, the dry area appearing in Kentucky and Ohio must be caused by downward motion (see Figure 22 and 23); in that region there is a ridge at 500 mb (see Figure 21) and a cold high at the surface. Thus the results are qualitatively correct in a synoptic sense. On the other hand, downward motion exists in the lee side of the Rocky Moutains at 470 mb (approximately the interface between the second and third layers of the LFM-II) as shown in Figure 23. Although some upward motion ($\omega < 0$) exists there, it is rather smaller and weak. In this situation, the downward motion at 471 mb can also produce some moisture in the third layer. We will show that this moisture is spurious.

In the LFM-II [1], [2], the following formula is used to calculate the vertical flux of precipitable water W

$$\left(\frac{\partial \sigma W}{\partial \sigma}\right)_k = \frac{1}{\Delta \sigma k} [\sigma_k W_k - \sigma_{k+1} W_{k+1}] \tag{3}$$

which is derived by assuming that the specific humidity q varies linearly with pressure. For the third layer

$$\frac{\partial W_3}{\partial t} = -\frac{1}{\Delta \sigma_3} [\sigma_3 W_3 - \sigma_4 W_4] f \ldots$$

$$= -\frac{1}{2\Delta \sigma_3} (W_3 + W_3) \sigma_3 + \frac{1}{2\Delta \sigma_3} (W_3 + W_4) \sigma_4$$

But no vapor is permitted to remain within the fourth layer

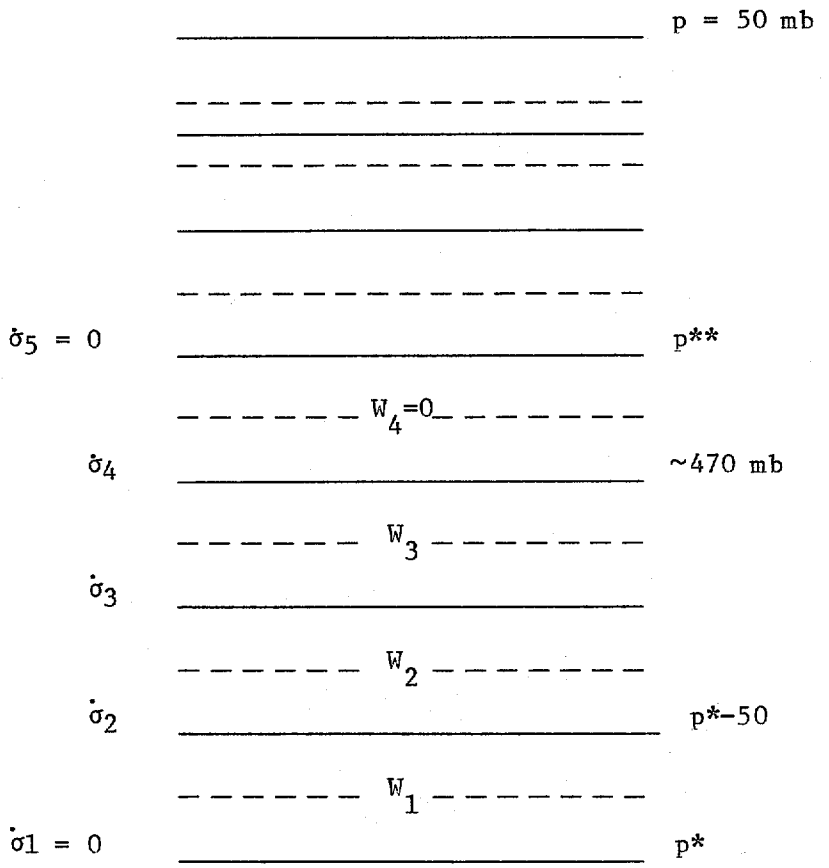


Figure 24

So

$$\frac{\partial W_3}{\partial t} = -\frac{1}{2\Delta\sigma_3}(W_2 + W_3)\,\dot{\sigma}_3 + \frac{1}{2\Delta\sigma_3}\,W_3\,\dot{\sigma}_4 + \ldots$$

It is obvious that if there is downward motion from the fourth layer, i.e., at about 470 mb

$$\dot{\sigma}_4 \text{ or } \omega_4 > 0 \qquad (5)$$

the precipitable water in the third layer W_3 will increase with time. Because the second term on the right side in equation (4) is greater than zero. This spurious transport of moisture from the fourth layer into the third

layer may produce the situation shown in Figure 20.

In order to avoid the trouble, the second term on the right side of equation (4) can be eliminated by assuming the value of precipitable water W_4 is set to zero, thereby permitting no moisture flux through the interface between the third and the fourth layer.*

In summary then we are able to discern significant synoptic scale moisture errors in LFM forecasts exclusive of analysis errors. These errors can destroy the integrity of short range precipitation forecast even when the predicted motion fields may be classified as excellent (top 5% in forecast accuracy).

Inadequate resolution and incomplete treatment of upper level moisture can be identified as two of the error sources for the case presented here. The third error source evident in most summer conditions is the lack of amplitude in the diurnal temperature wave existing in the model.

*This technique was implemented on 25 February 1982 in the operational LFM.

Figures

Fig. 1 500 mb LFM analysis of heights/vorticity valid 12Z Wed 10 Mar 1982

Fig. 2 500 mb LFM analysis of heights/vorticity valid 00Z Thu 11 Mar 1982

Fig. 3 500 mb LFM analysis of heights/vorticity valid 12Z Thu 11 Mar 1982

Fig. 4 500 mb LFM analysis of heights/vorticity valid 00Z Fri 12 Mar 1982

Fig. 5 6 hr observed precipitation amounts valid 00Z Fri May 1982
The contours are the 36 hour LFM forecast of precipitation.

Fig. 6 The difference between 36 hr fcst and analysis at 00Z 12 Mar 1982 of mean RH.

Fig. 7 The difference between 36 hr fcst and analysis at 00Z 12 Mar 1982 of 700 mb heights.

Fig. 8 The difference between 36 hr fcst and analysis at 00Z 12 Mar 1982 of 500 mb height.

Fig. 9 Vertical distribution of RH error (four gridpoints average)

Fig. 10 Vertical distribution of maximum RH error

Fig. 11 Boundary layer analyzed RH valid at 12Z 11 Mar 1982

Fig. 12 Same as Fig. 11 valid at 00Z 11 Mar 1982

Fig. 13 Analyzed and observed tracks of wet center, dry centers for the forecast period 3/10/82 12Z to 3/12/82 00Z

Fig. 14 H_{700} and precip water in the troposphere at 00Z 11 Mar 1982

Fig. 15 H_{700} and precip water in the troposphere at 12Z 11 Mar 1982

Fig. 16 H_{700} and precip water in the troposphere at 00Z 12 Mar 1982

Fig. 17 12 hr fcst of H_{700} and precip water in the troposphere (valid time: 00Z 11 Mar 1982)

Fig. 18 24 hr fcst of H_{700} and precip water in the troposphere (valid time: 12Z 11 Mar 1982)

Fig. 19 20 hr fcast of H_{700} and precip water in the troposphere (valid time: 18Z 11 Mar 1982)

Fig. 20 36 hr fcast of H_{700} and precip water in the troposphere (valid time: 00Z 12 Mar 1982)

Fig. 21 36 hr fcst 500 mb heights/vorticity valid 00Z 12 Mar 1982

Fig. 22 36 hr fcst 950 mb (DP/DT) vertical velocity

The contour lines are the 36 hr fcst of precip water

Fig. 23 36 hr fcst 470 mb (DP/DT) vertical velocity

The contour lines are the 36 hr fcst of precip water

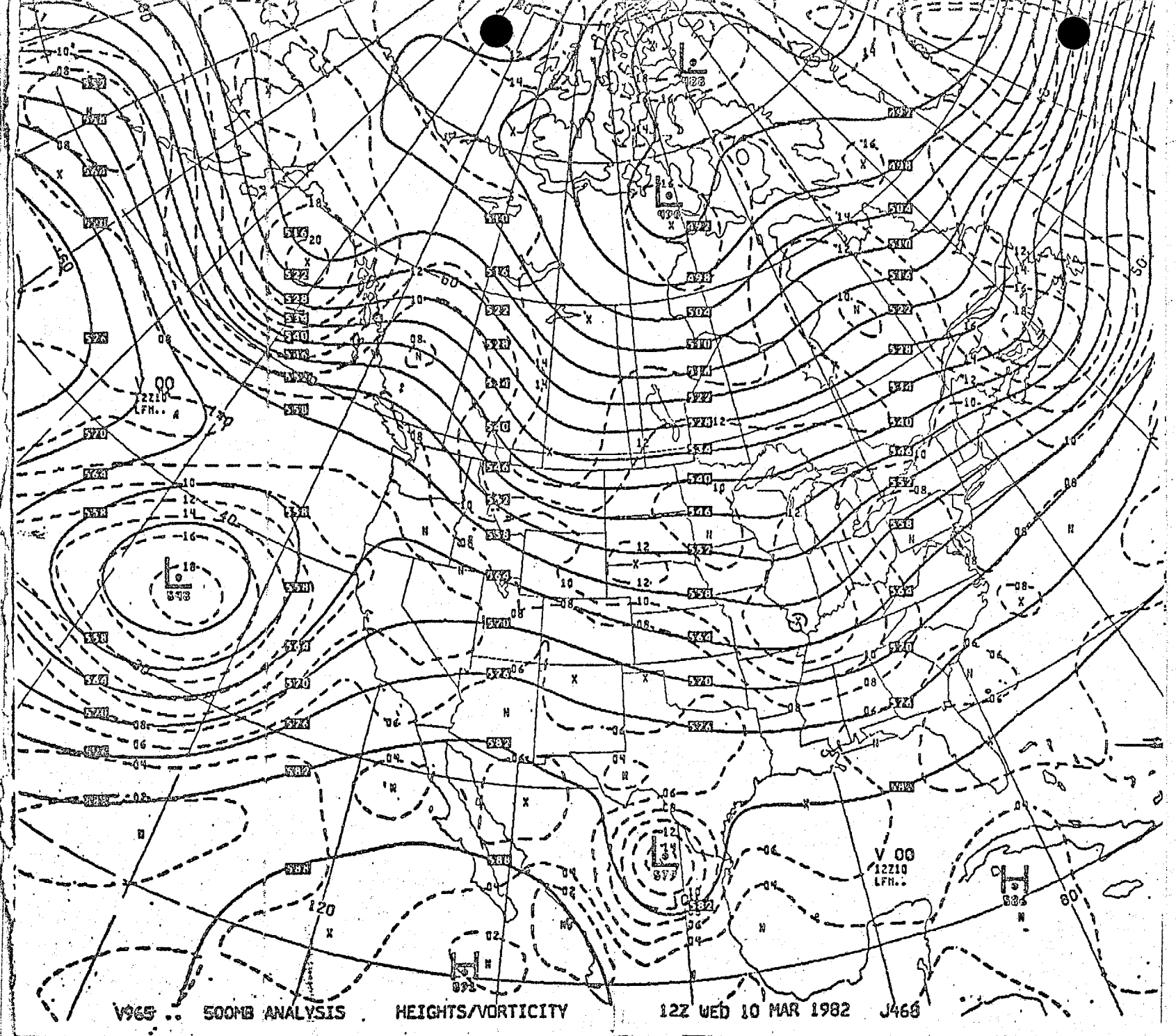
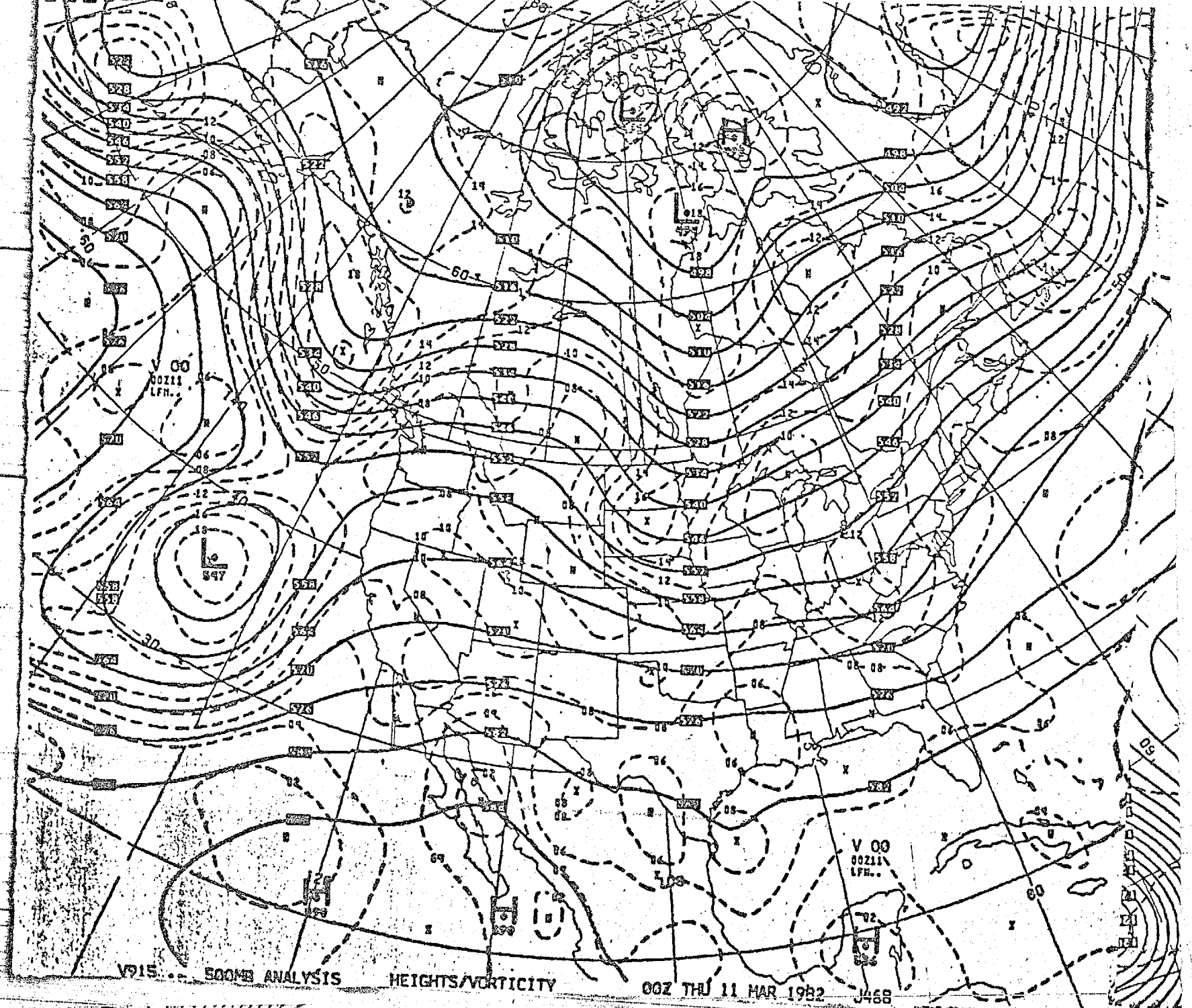

V965 .. 500MB ANALYSIS HEIGHTS/VORTICITY 12Z WED 10 MAR 1982 J468

Fig 1

Fig 2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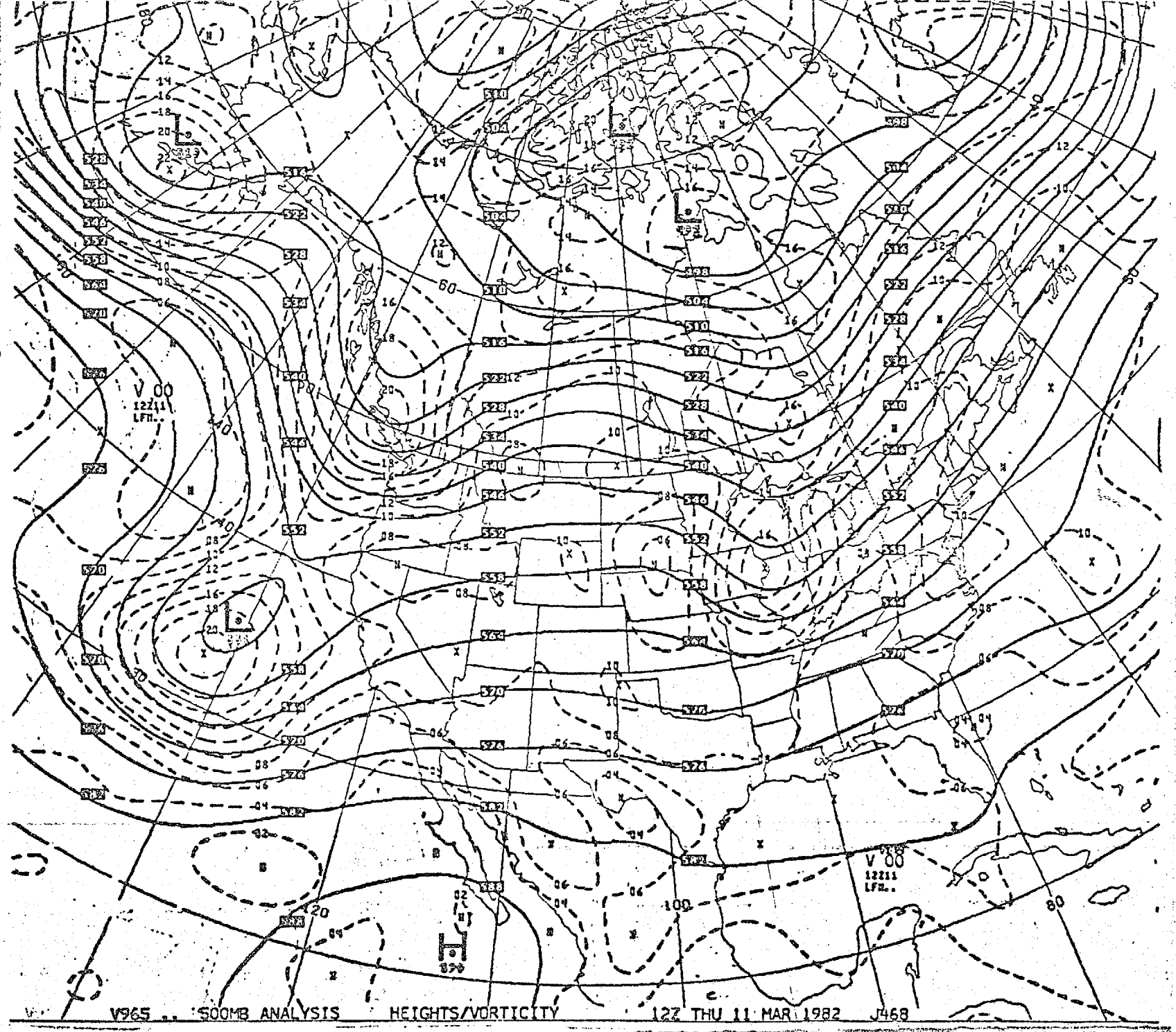
00Z THU 11 MAR 1982 J468

Fig 3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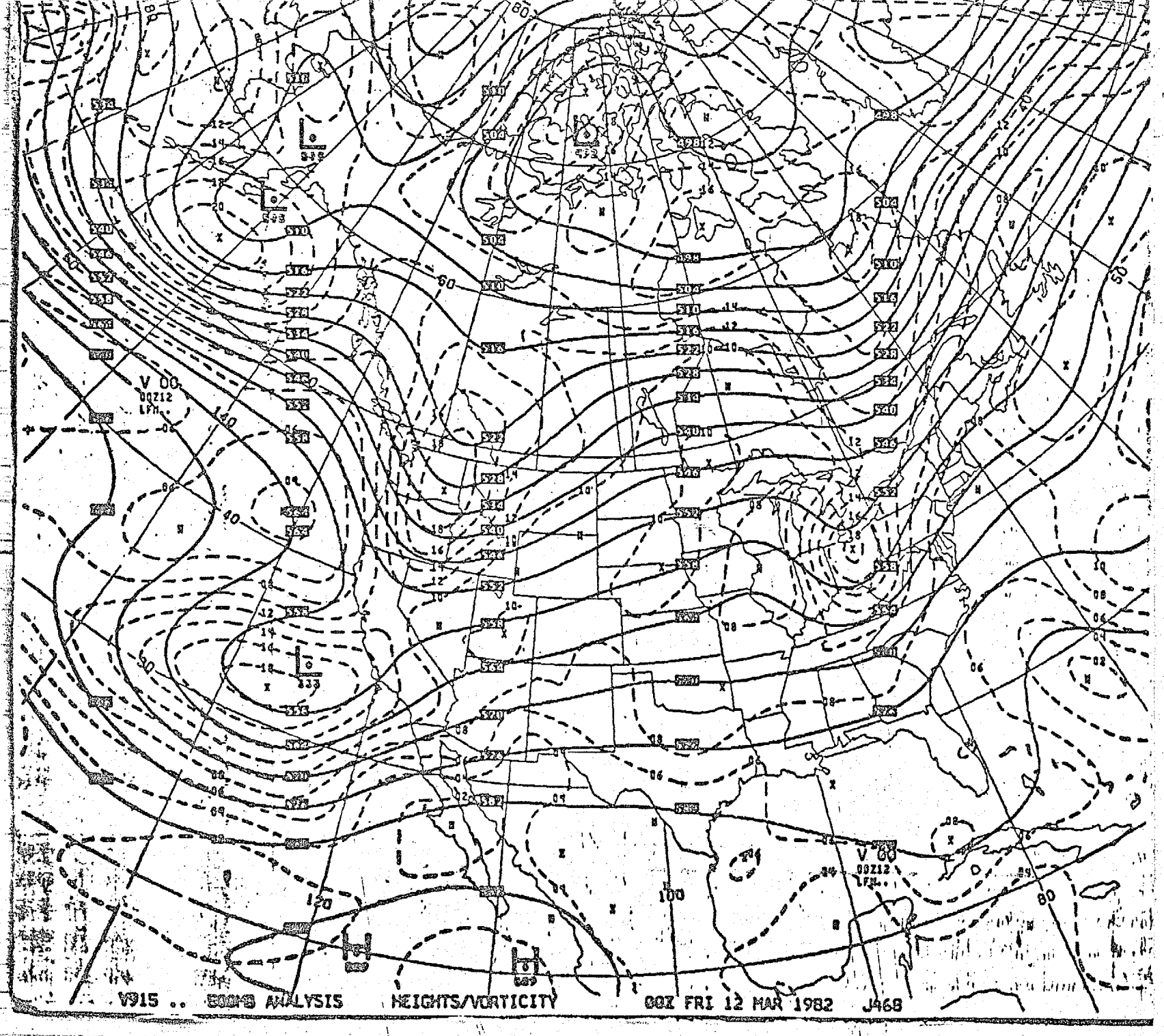
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Fig 4

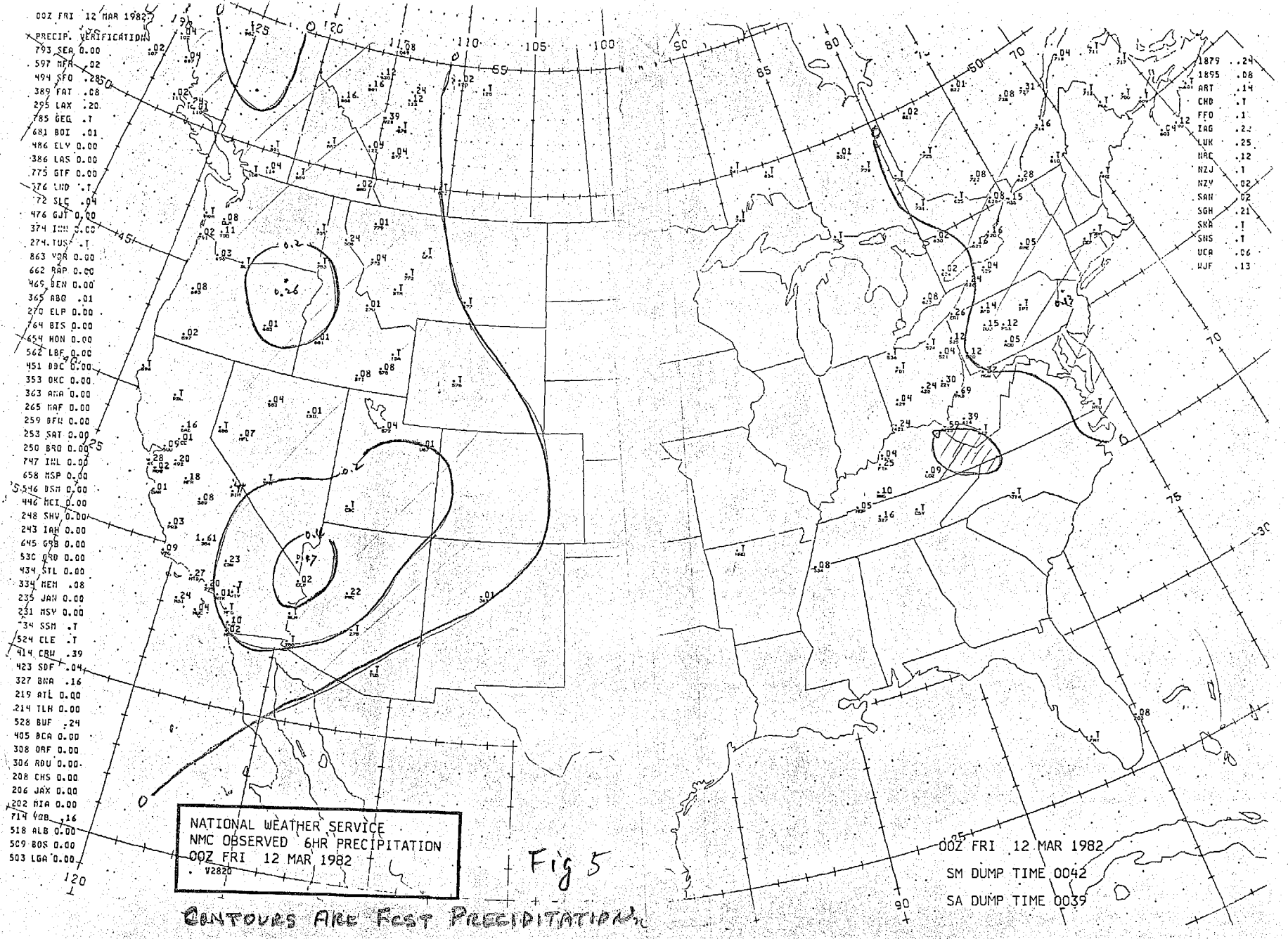
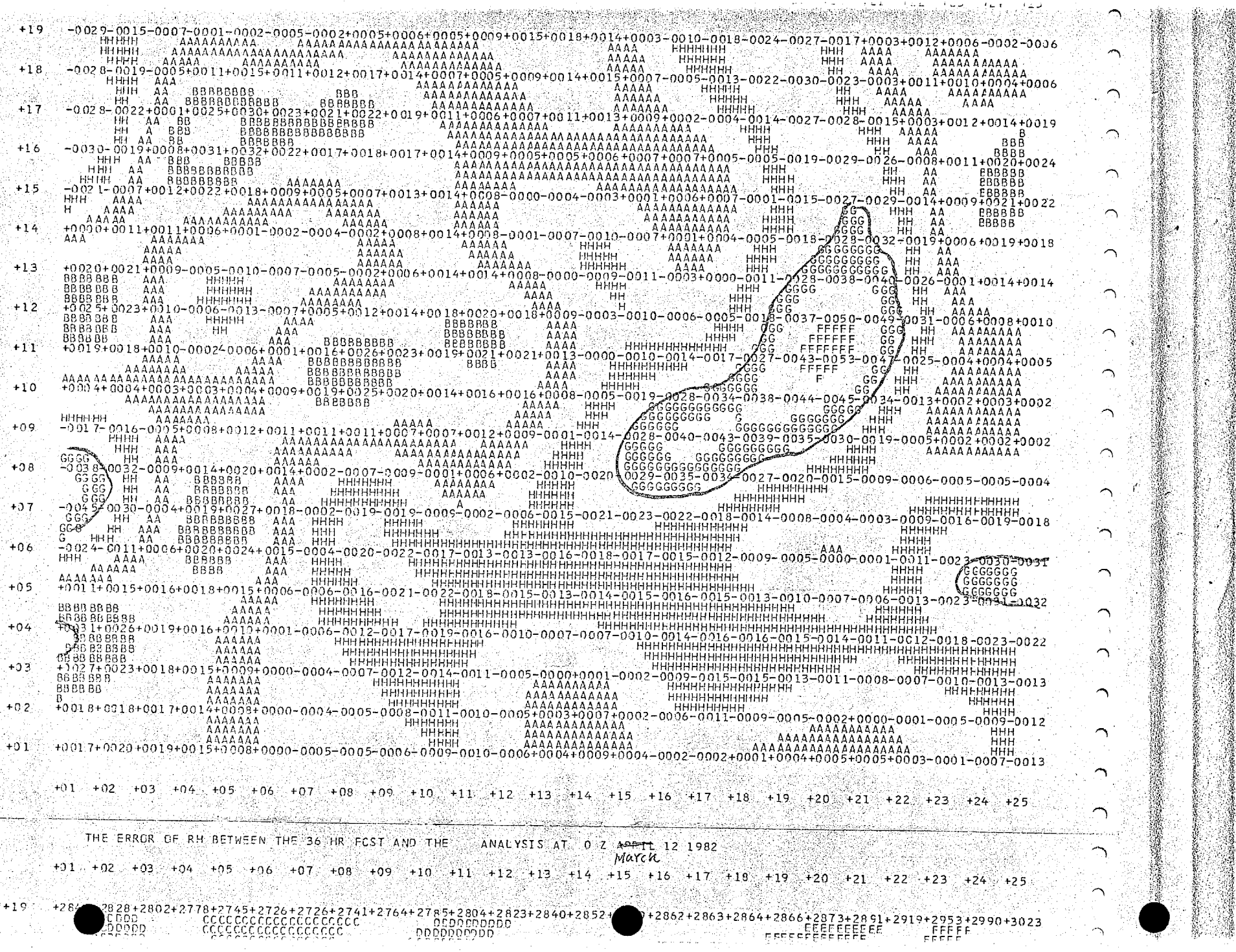


Fig 5

CONTOURS ARE FCST PRECIPITATION

Fig 6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+18
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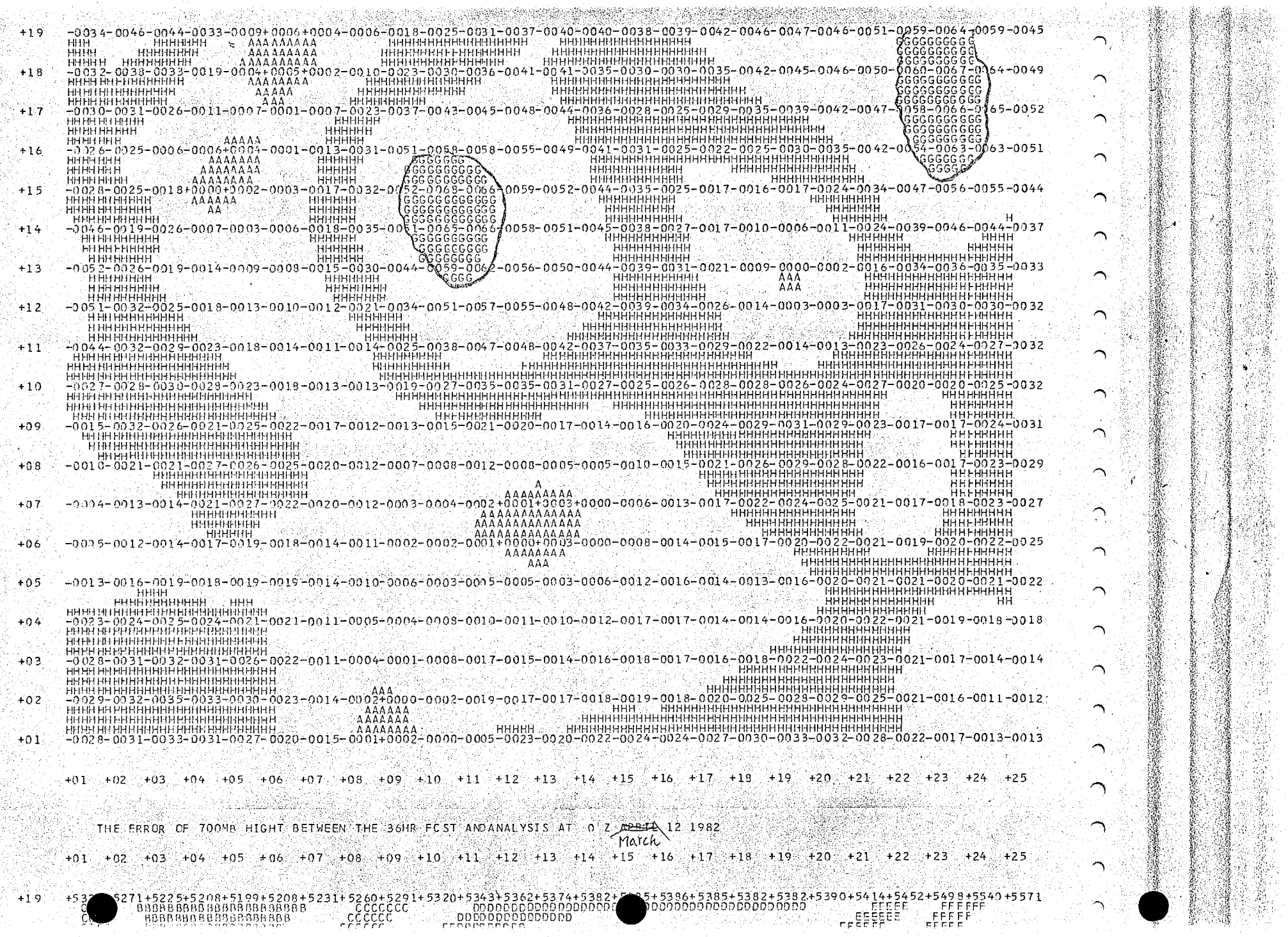
+01
+01 +02 +03 +04 +05 +06 +07 +08 +09 +10 +11 +12 +13 +14 +15 +16 +17 +18 +19 +20 +21 +22 +23 +24 +25
THE ERROR OF RH BETWEEN THE 36 HR FCST AND THE ANALYSIS AT 0 Z ~~APRIL~~ March 12 1982
+01 +02 +03 +04 +05 +06 +07 +08 +09 +10 +11 +12 +13 +14 +15 +16 +17 +18 +19 +20 +21 +22 +23 +24 +25

Fig 7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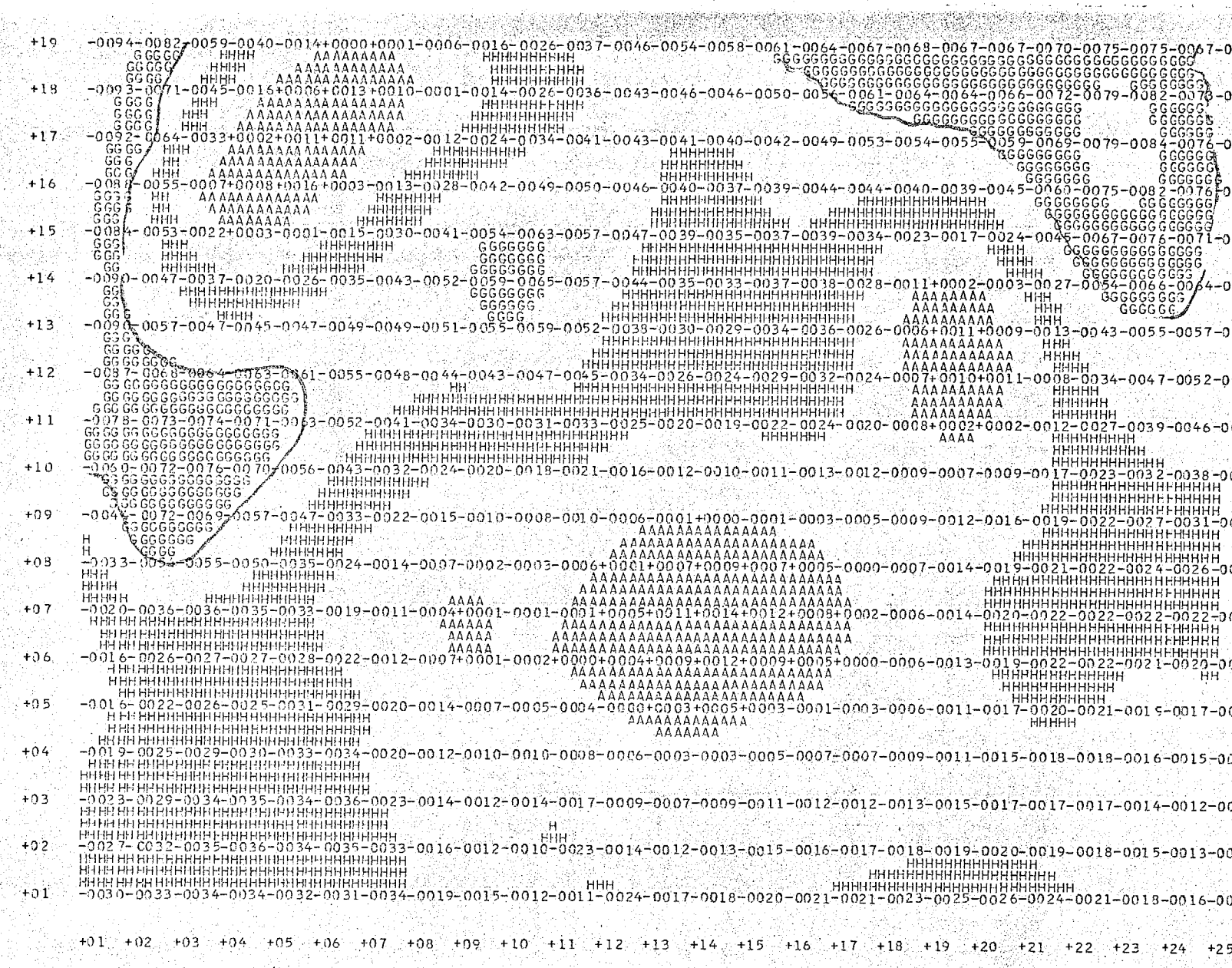
+01 +02 +03 +04 +05 +06 +07 +08 +09 +10 +11 +12 +13 +14 +15 +16 +17 +18 +19 +20 +21 +22 +23 +24 +25
THE ERROR OF 700MB HIGHT BETWEEN THE 36HR FCST ANDANALYSIS AT 0 Z ~~APRIL~~ March 12 1982
+01 +02 +03 +04 +05 +06 +07 +08 +09 +10 +11 +12 +13 +14 +15 +16 +17 +18 +19 +20 +21 +22 +23 +24 +25
+19 +5386+5385+5382+5382+5390+5414+5452+5498+5540+5571

Fig 8



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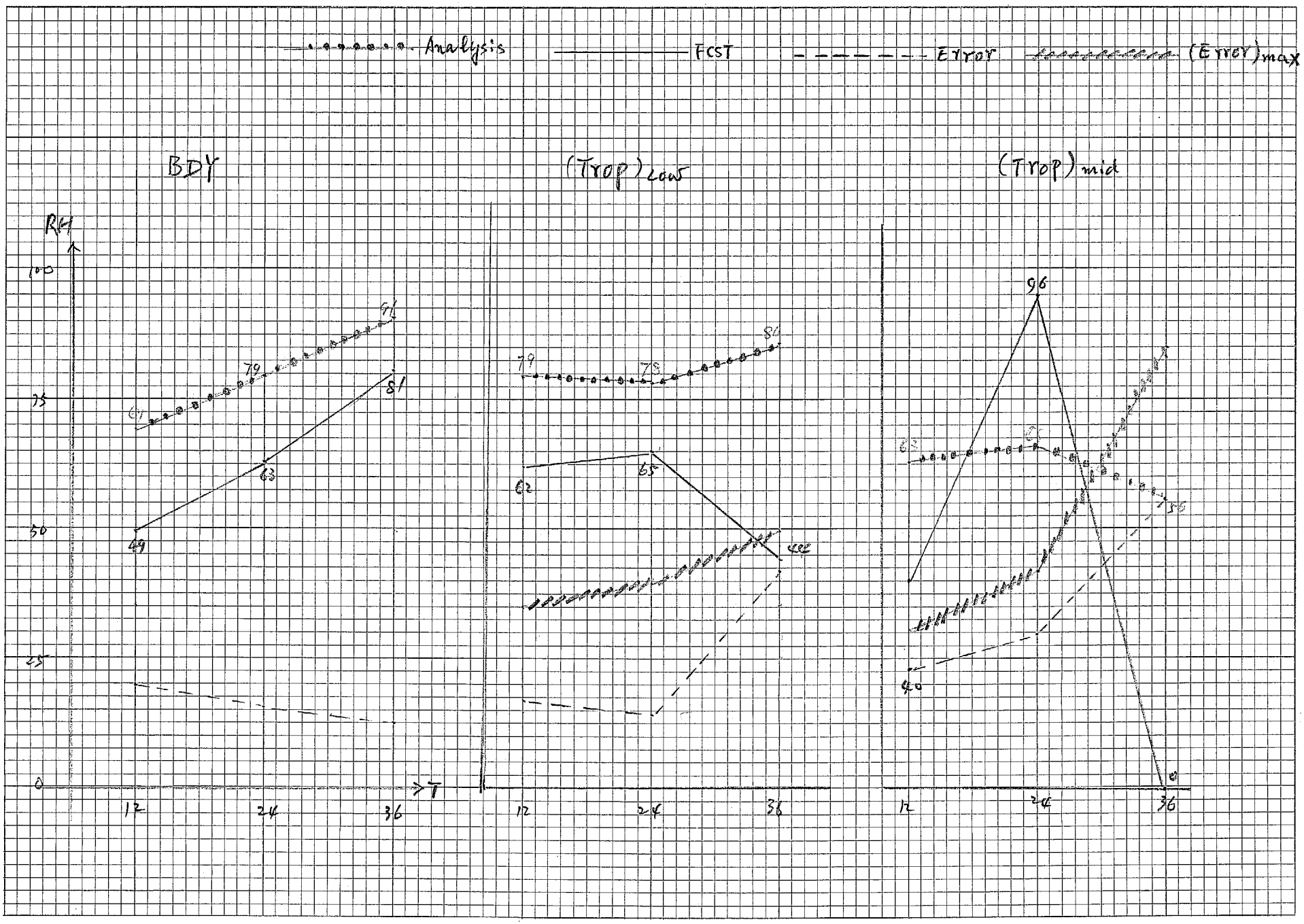
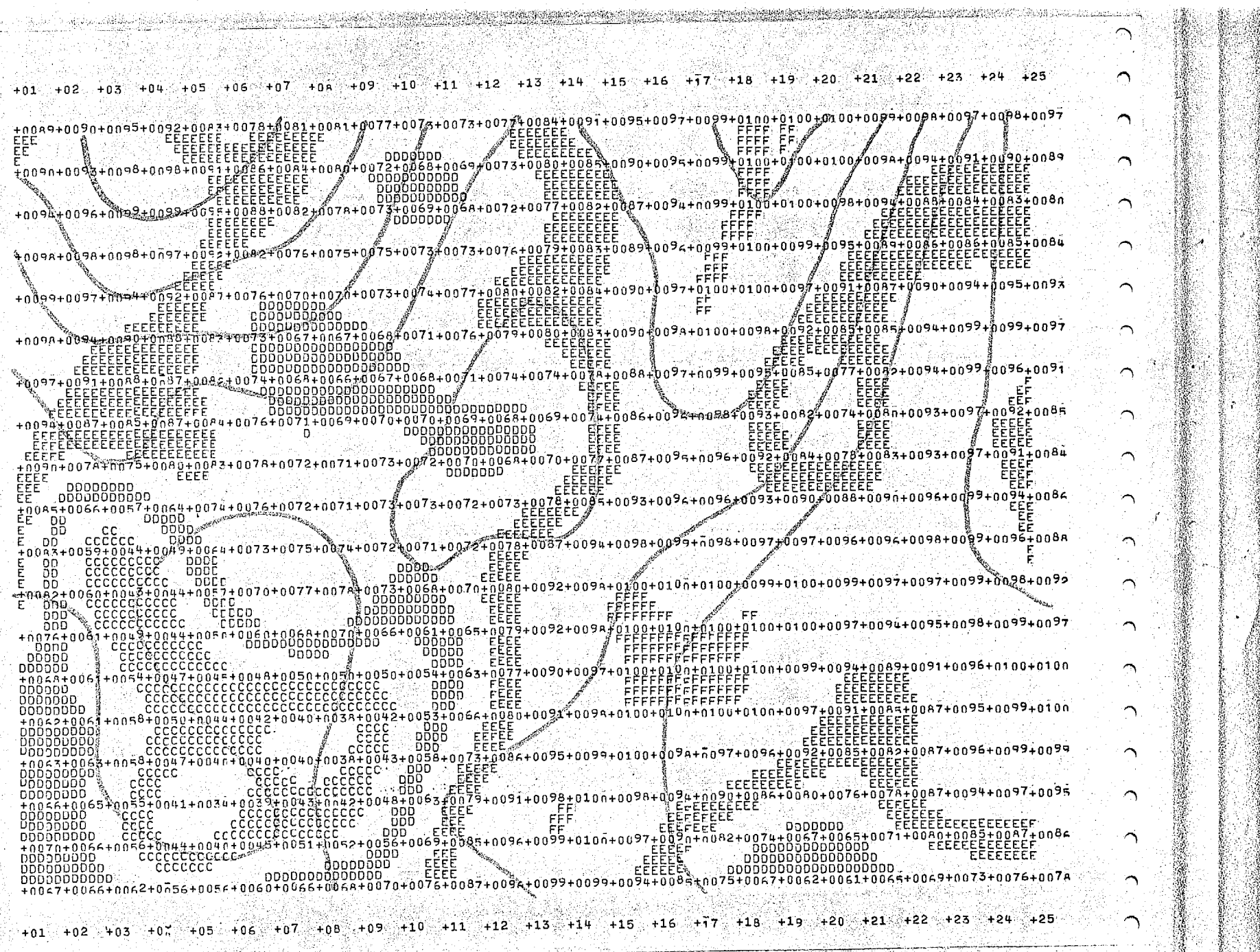

Analysis
FCST
ERROR
(ERROR)max
BDY
(Trop)low
(Trop)mid
RH
100
75
50
25
0
T
12
24
36
71
79
81
61
63
49
79
78
84
62
65
96
62
40

Fig 9

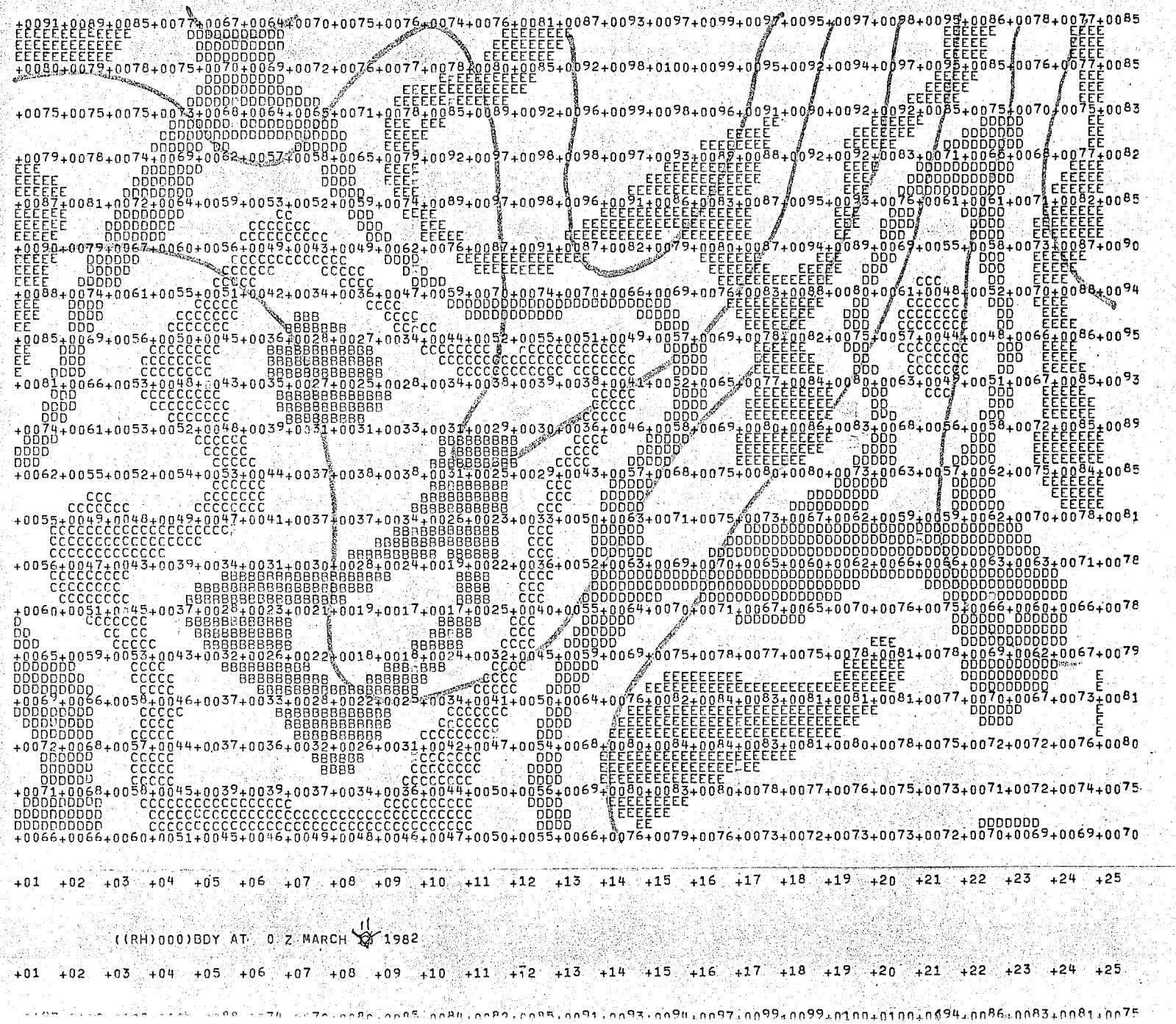
Fig 10 —— BDY ; —— The Second Layer ; —— The third Layer

Fig 11



((RH)000)BDY AT 12 4 MARCH 11 1982

Fig 12



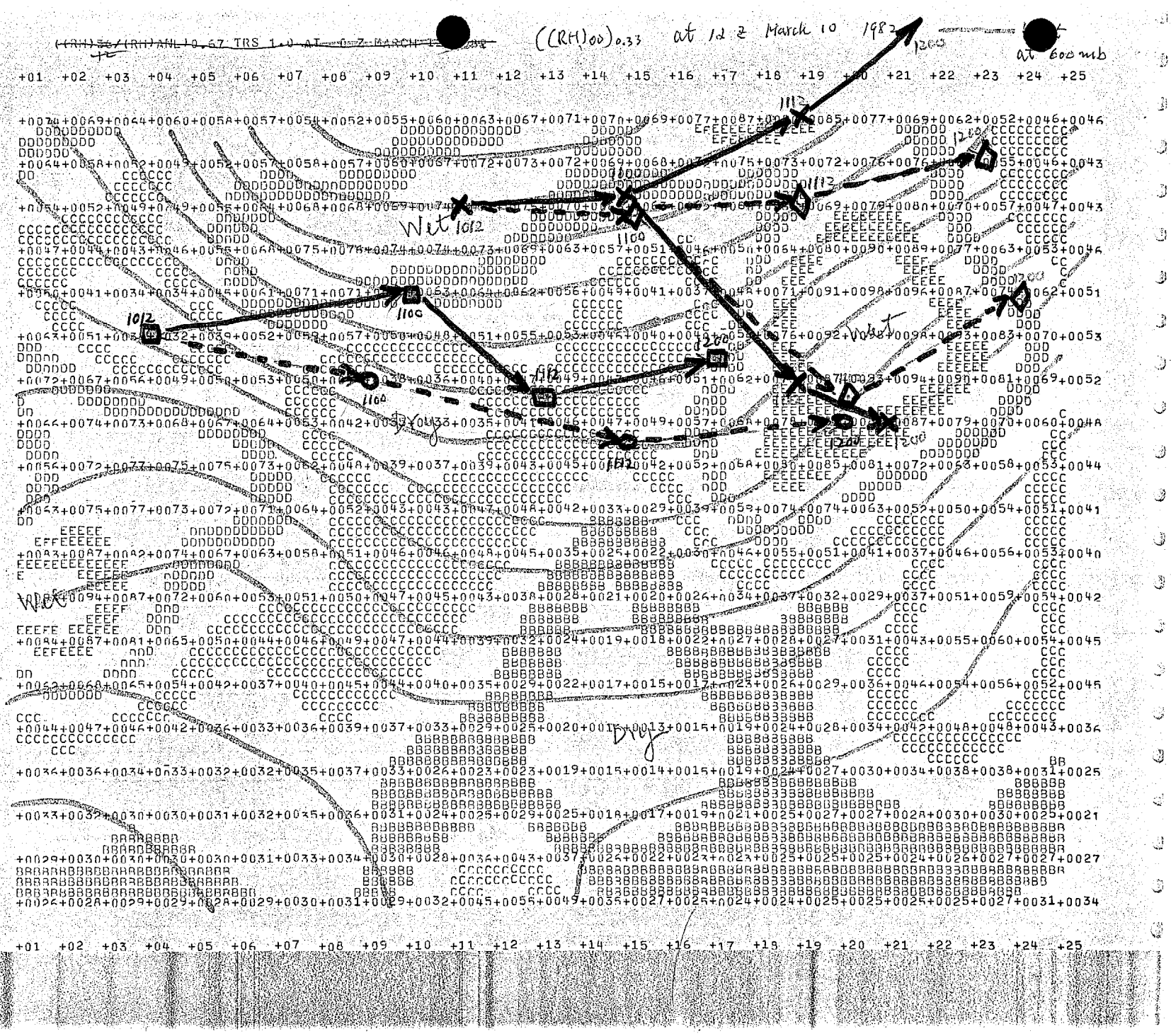


Fig 13

wet center (Analysis)

Wet Center (FCST)

dry Center (Analysis)

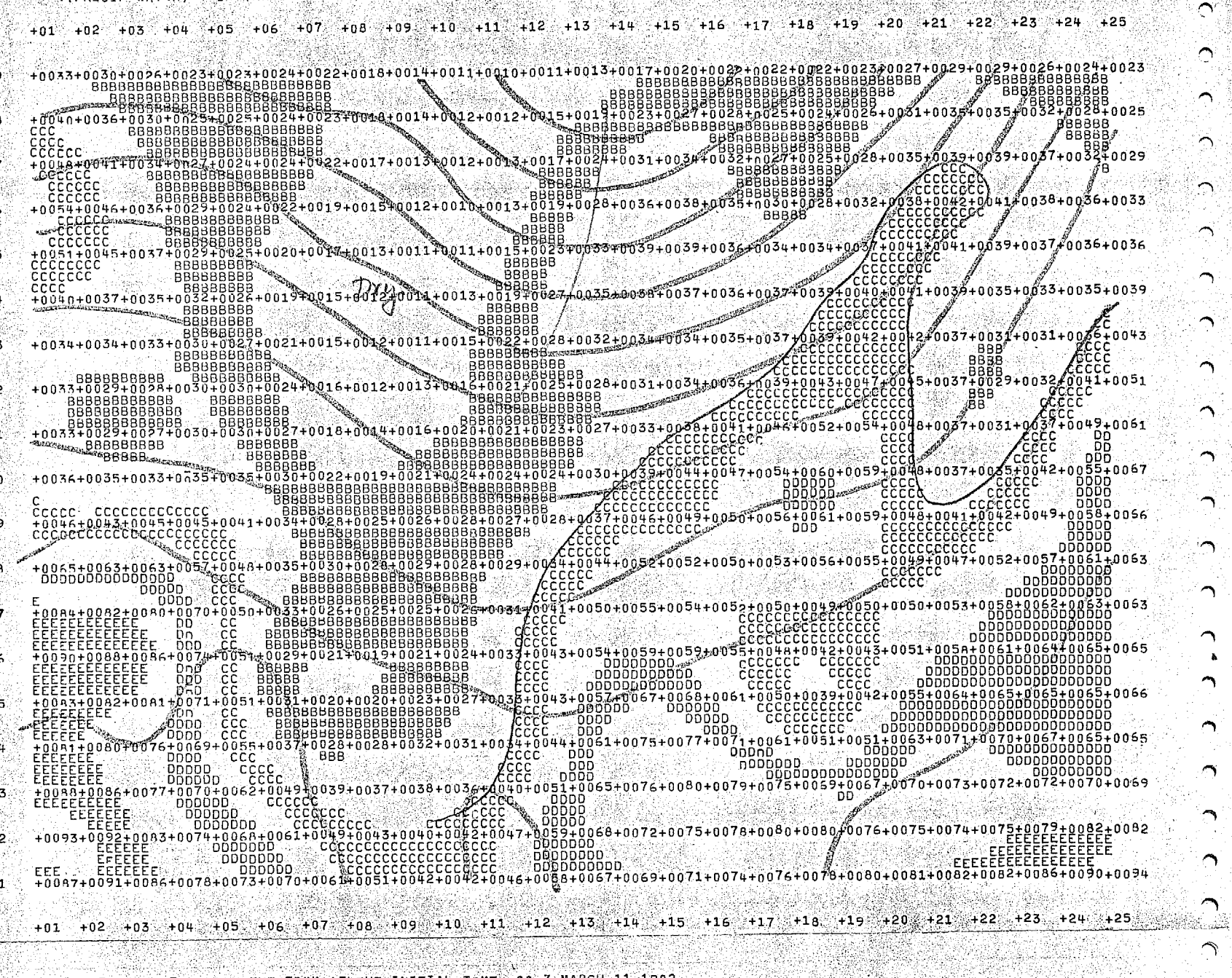
dry center (FCST)

every 12 hrs FCST

Fig 14

Hight at 700 mb

~~(PRECIP WATER)*4 IN THE DRY AT THE INITIAL TIME 00 Z MARCH 11 1982~~



(PRECIP WATER)*4 IN THE TROP AT THE INITIAL TIME 00 Z MARCH 11 1982

Fig 15

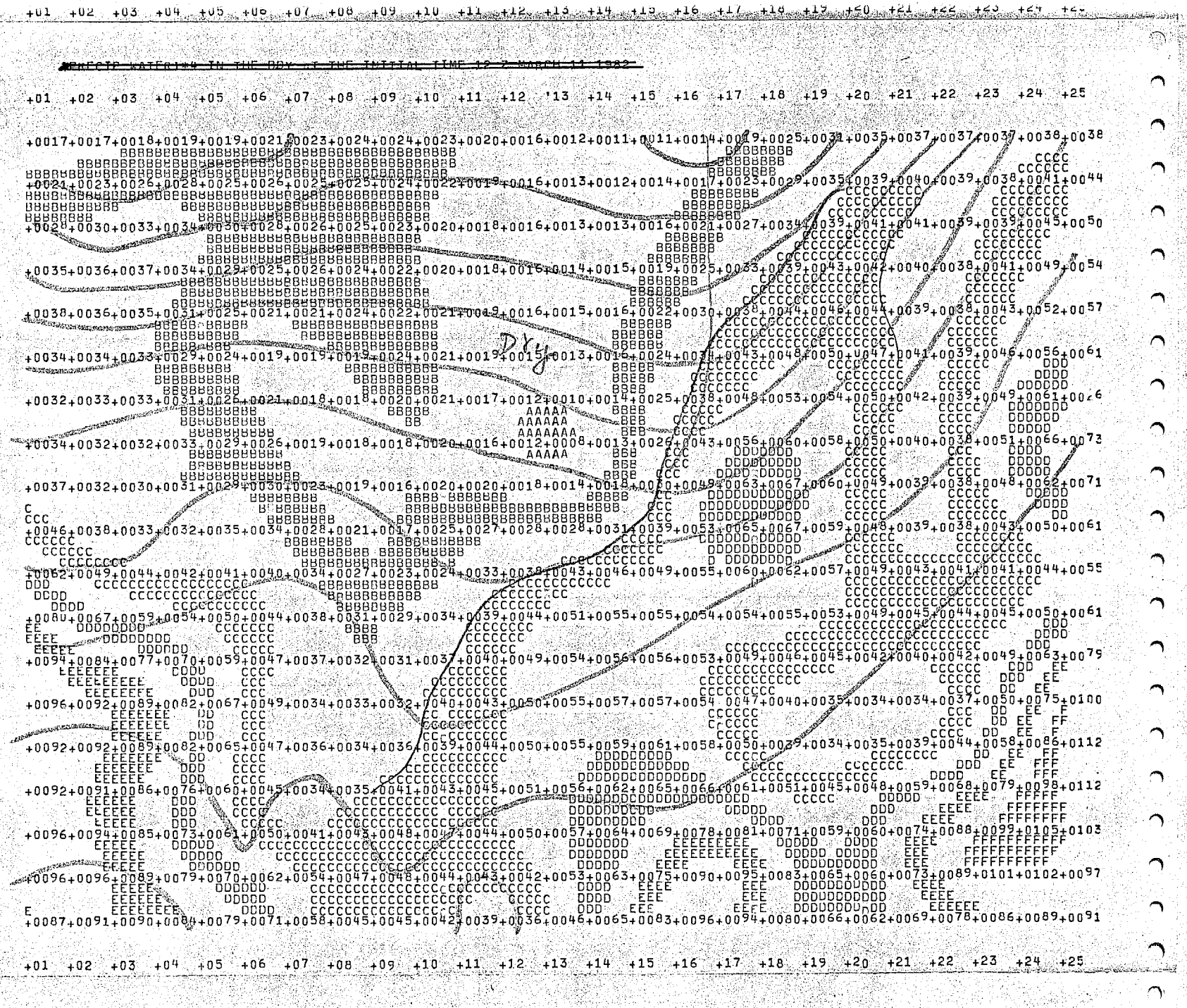
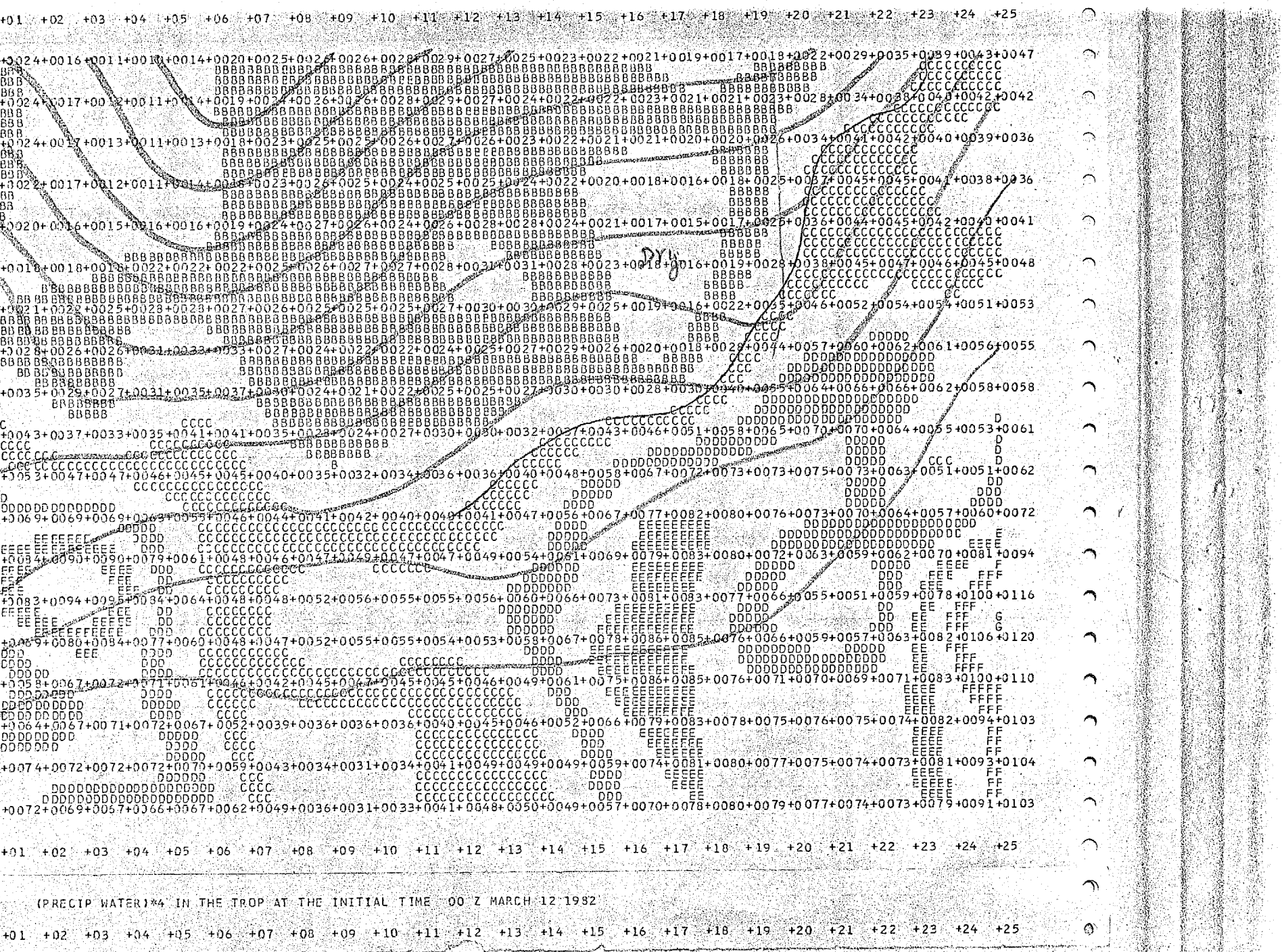

(PRECIP WATER)*4 IN THE TROP AT THE INITIAL TIME 12 Z MARCH 11 1982
Dry

Fig 16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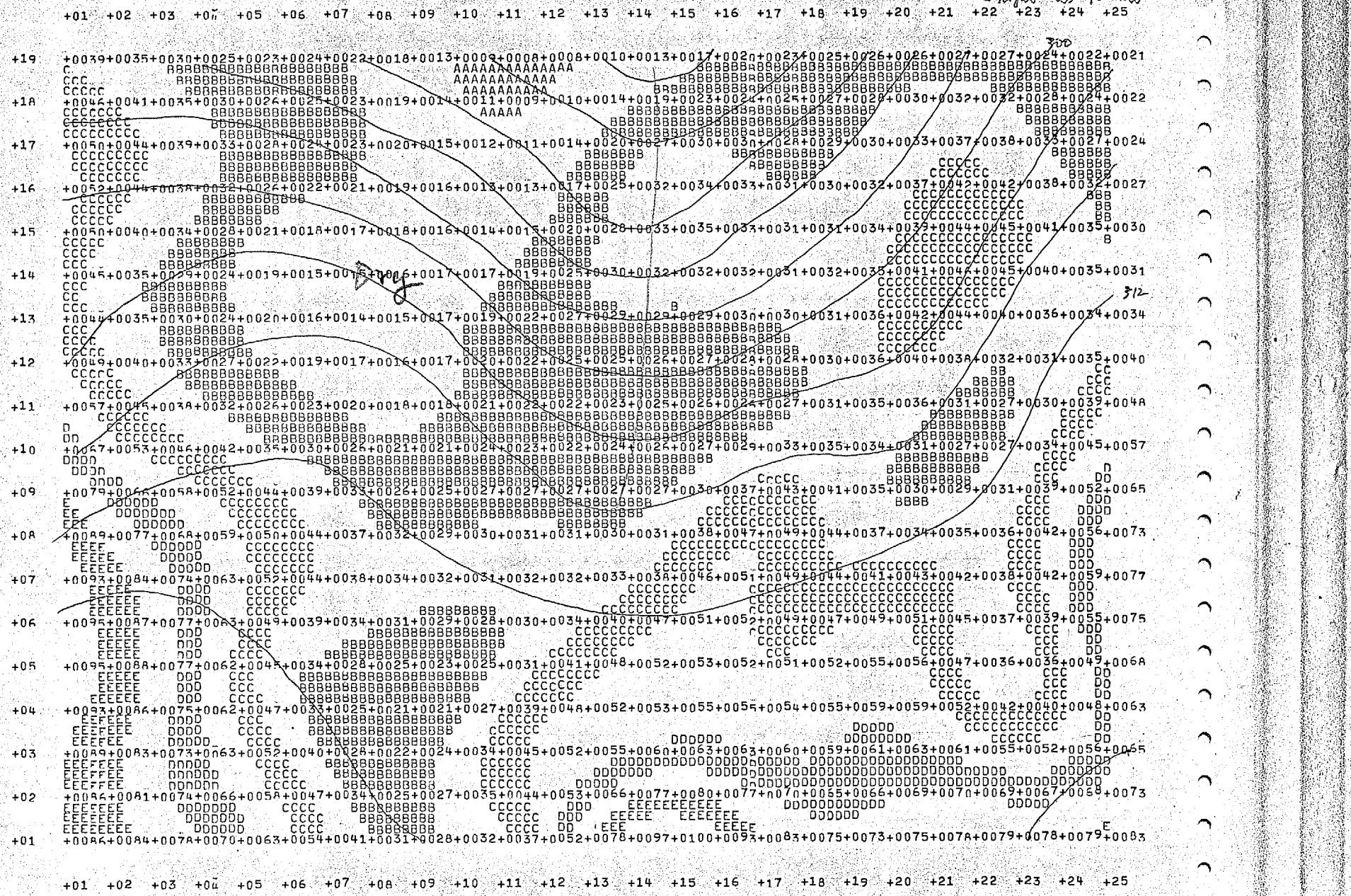
+10 +0043+0037+0033+0035+0041+0041+0035+0028+0024+0027+0030+0030+0032+0027+0043+0046+0051+0058+0065+0070+0070+0064+0055+0053+0061
+09 +0053+0047+0047+0046+0045+0045+0040+0035+0032+0036+0036+0040+0048+0058+0067+0072+0073+0073+0075+0073+0063+0051+0051+0062
+08 +0069+0069+0069+0063+0055+0046+0044+0041+0042+0040+0040+0041+0047+0056+0067+0077+0082+0080+0076+0073+0070+0064+0057+0060+0072
+07 +0084+0090+0090+0079+0061+0048+0046+0047+0049+0047+0047+0049+0054+0061+0069+0079+0083+0080+0072+0063+0059+0062+0070+0081+0094
+06 +0083+0094+0095+0084+0064+0048+0048+0052+0056+0055+0055+0056+0060+0066+0073+0081+0083+0077+0066+0055+0051+0059+0078+0100+0116
+05 +0069+0080+0084+0077+0060+0048+0047+0052+0055+0055+0054+0053+0058+0067+0078+0086+0085+0076+0066+0059+0057+0063+0082+0106+0120
+04 +0058+0067+0072+0071+0061+0046+0042+0045+0046+0045+0045+0046+0049+0061+0075+0086+0085+0076+0071+0070+0069+0071+0083+0100+0110
+03 +0064+0067+0071+0072+0067+0052+0039+0036+0036+0036+0040+0045+0046+0052+0066+0079+0083+0078+0075+0076+0075+0074+0082+0094+0103
+02 +0074+0072+0072+0072+0070+0059+0043+0034+0031+0034+0041+0049+0049+0049+0059+0074+0081+0080+0077+0075+0074+0073+0081+0093+0104
+01 +0072+0069+0057+0066+0067+0062+0049+0036+0031+0033+0041+0048+0050+0049+0057+0070+0078+0080+0079+0077+0074+0073+0079+0091+0103
+01 +02 +03 +04 +05 +06 +07 +08 +09 +10 +11 +12 +13 +14 +15 +16 +17 +18 +19 +20 +21 +22 +23 +24 +25
(PRECIP WATER)*4 IN THE TROP AT THE INITIAL TIME 00 Z MARCH 12 1982
+01 +02 +03 +04 +05 +06 +07 +08 +09 +10 +11 +12 +13 +14 +15 +16 +17 +18 +19 +20 +21 +22 +23 +24 +25
+19 +0004+0003+0004+0005+0005+0005+0006+0006+0006+0005+0004+0002+0002+0001+0001+0001+0002+0002+0003+0005+0006+0007+0008+0009+0010

Fig 17

~~(PRECIP WATER)*4 IN THE TROP AT 12 HR FCST~~ (valid time 00Z March 11 1982)

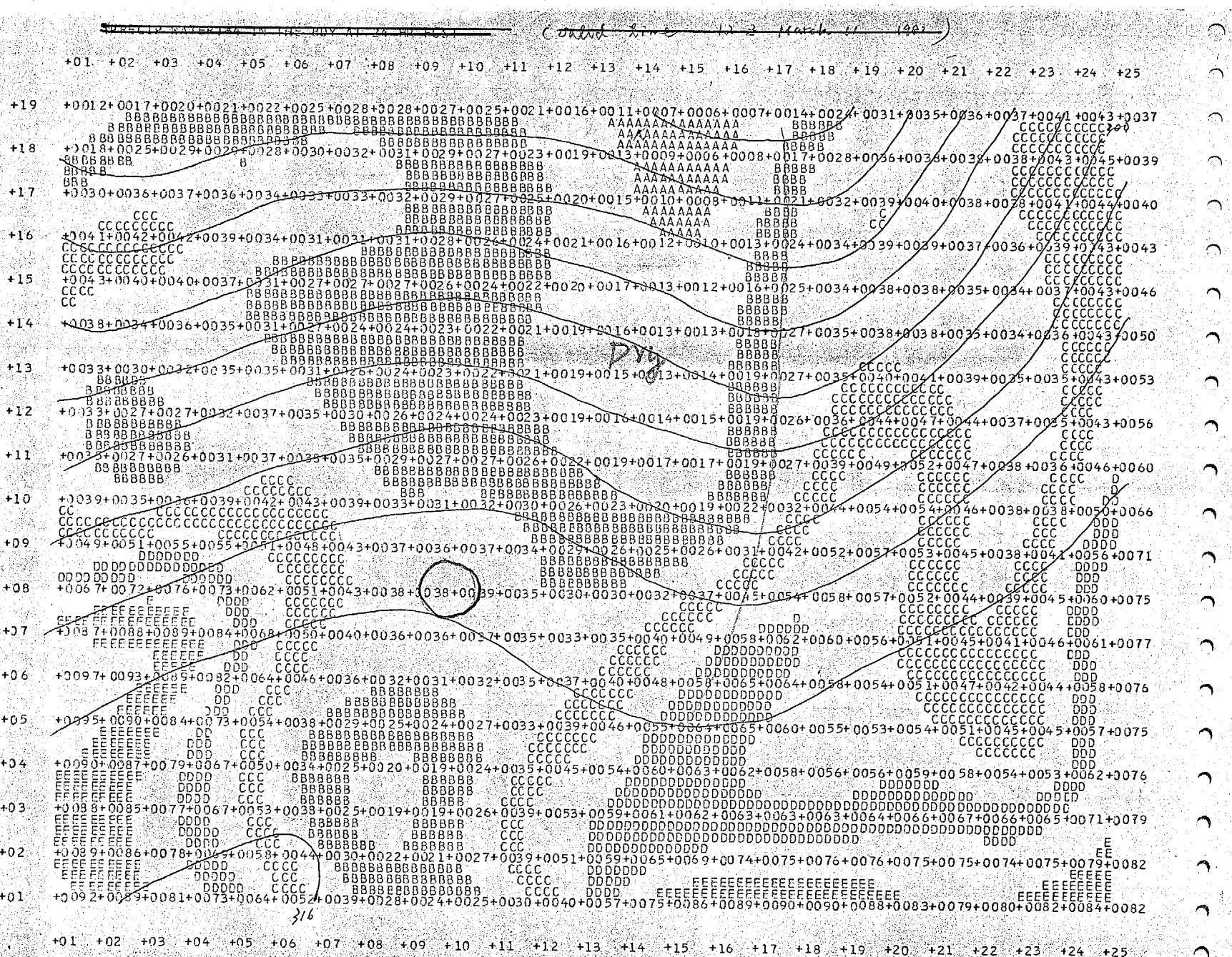
hight at 700 mb



~~(PRECIP WATER)*4 IN THE TROP AT 12 HR FCST~~ (Valid time 00Z March 11 1982)

Fig 18

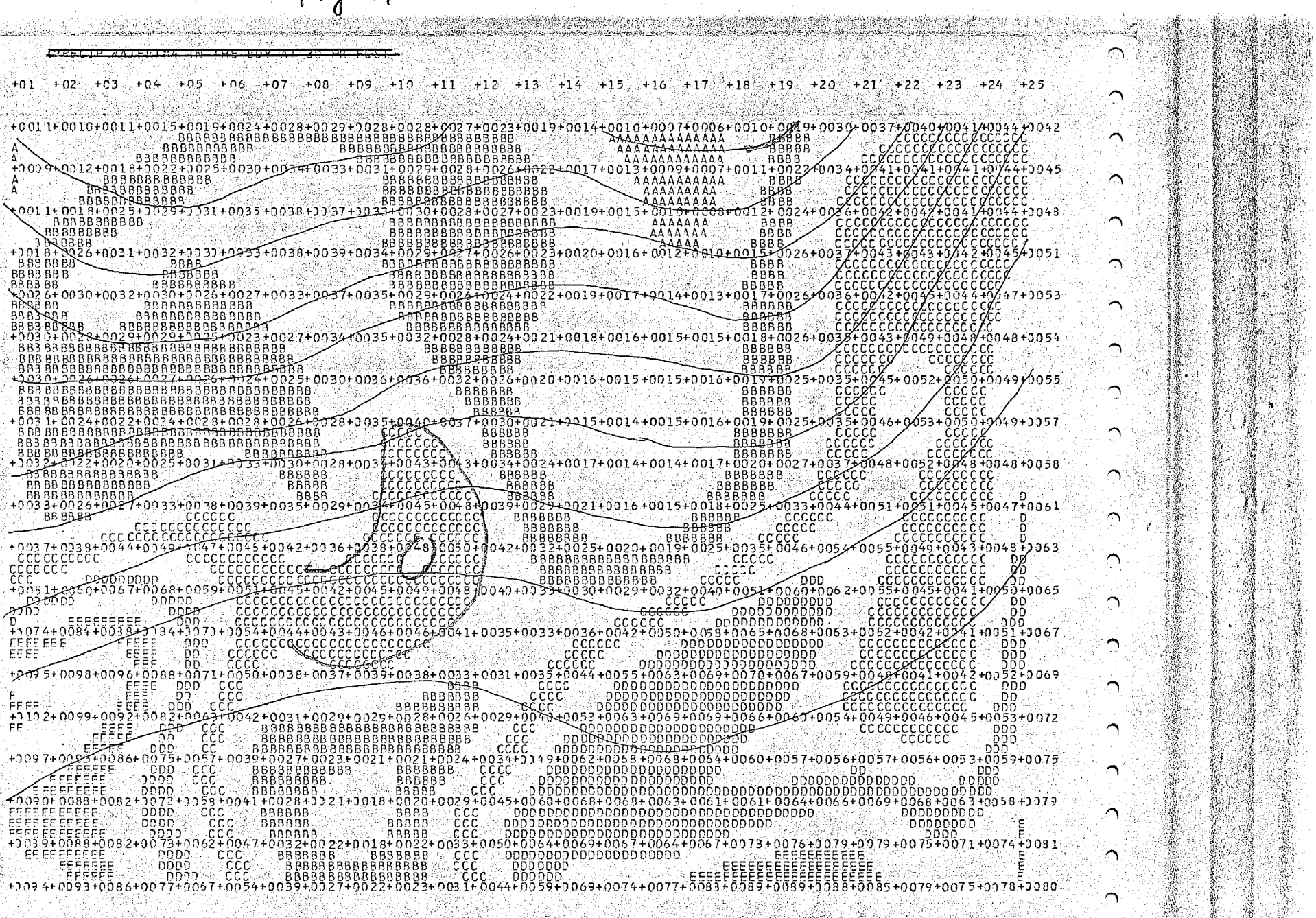
~~PRECIP WATER*4 IN THE TROP AT 24 HR FCST~~ (Valid time 12 Z March 11 1982)



(PRECIP WATER)*4 IN THE TROP AT 24 HR FCST (Valid time 12 Z March 11 1982)

Fig 19

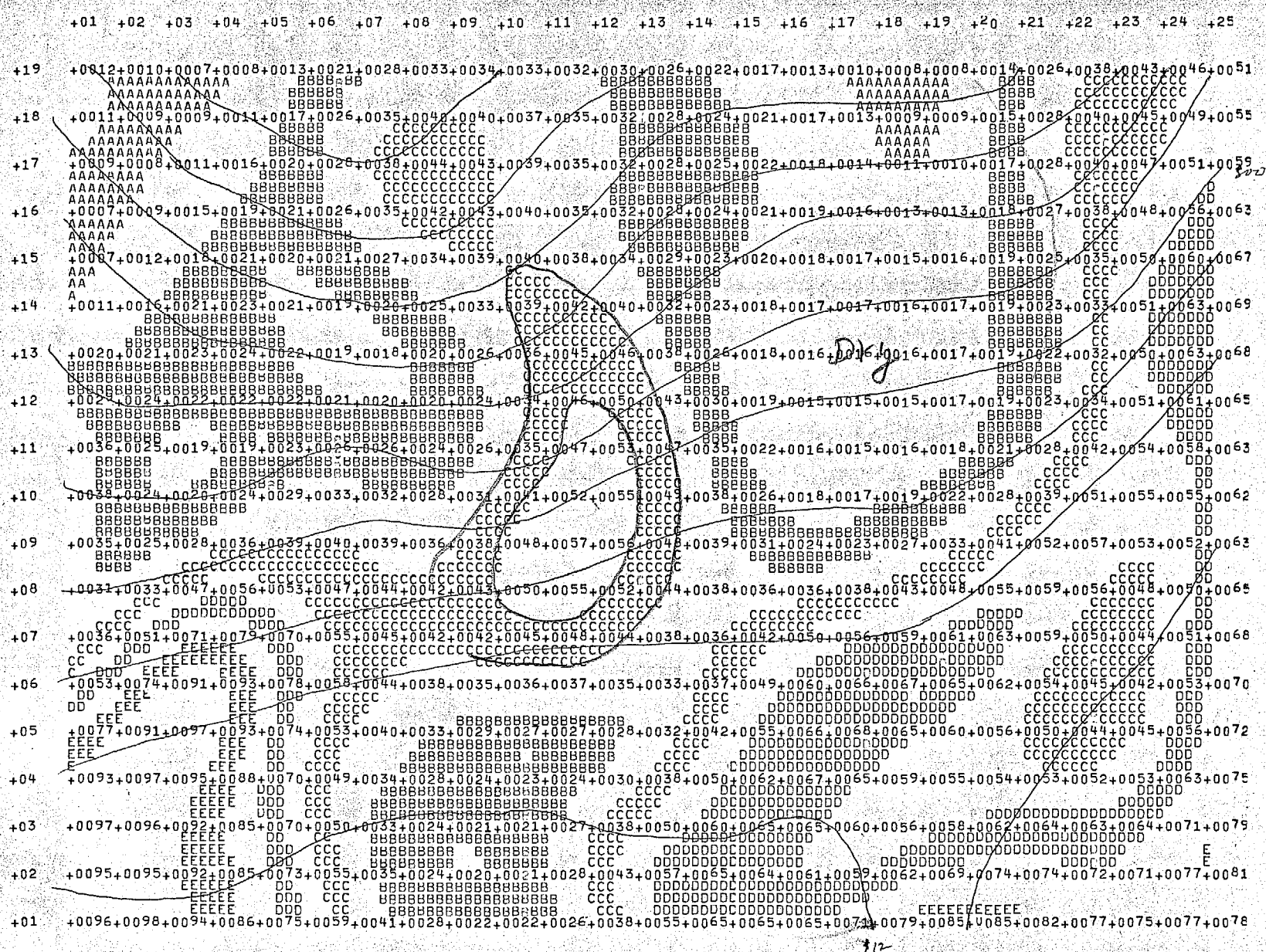
~~PRECIP WATER IN THE TROP AT 30 HR FCST~~



(PRECIP WATER)*4 IN THE TROP AT 30 HR FCST

Fig 20

~~(PRECIP WATER)*4 IN THE TROP AT 36 HR FCST~~ (Valid time 00 Z March 12 1982)



(PRECIP WATER)*4 IN THE TROP AT 36 HR FCST (Valid time 00 Z March 12 1982)

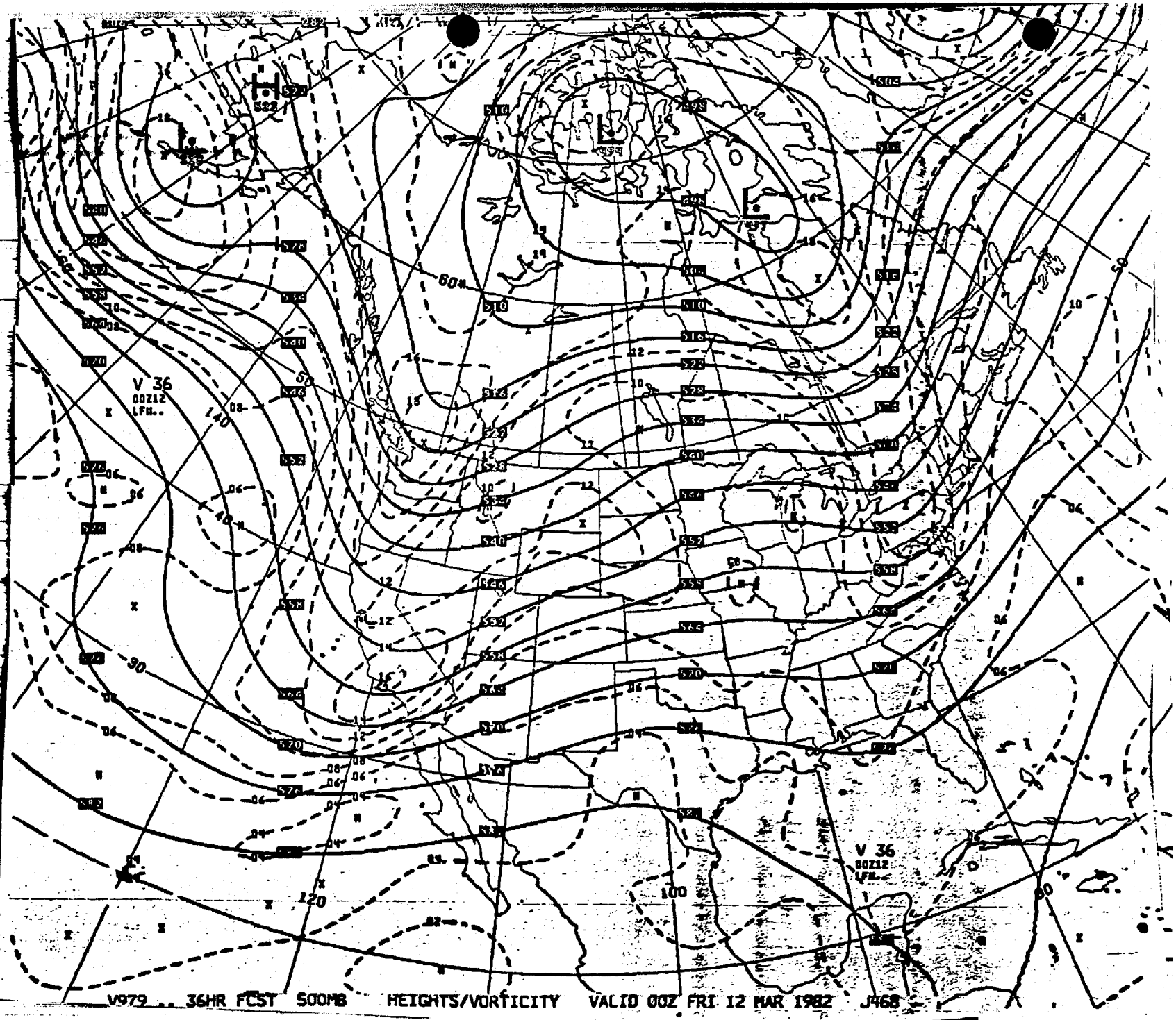

V 36
00Z12
LFM..
V 36
00Z12
LFM..
V979 .. 36HR FCST 500MB HEIGHTS/VORTICITY VALID 00Z FRI 12 MAR 1982 J468

Fig 21

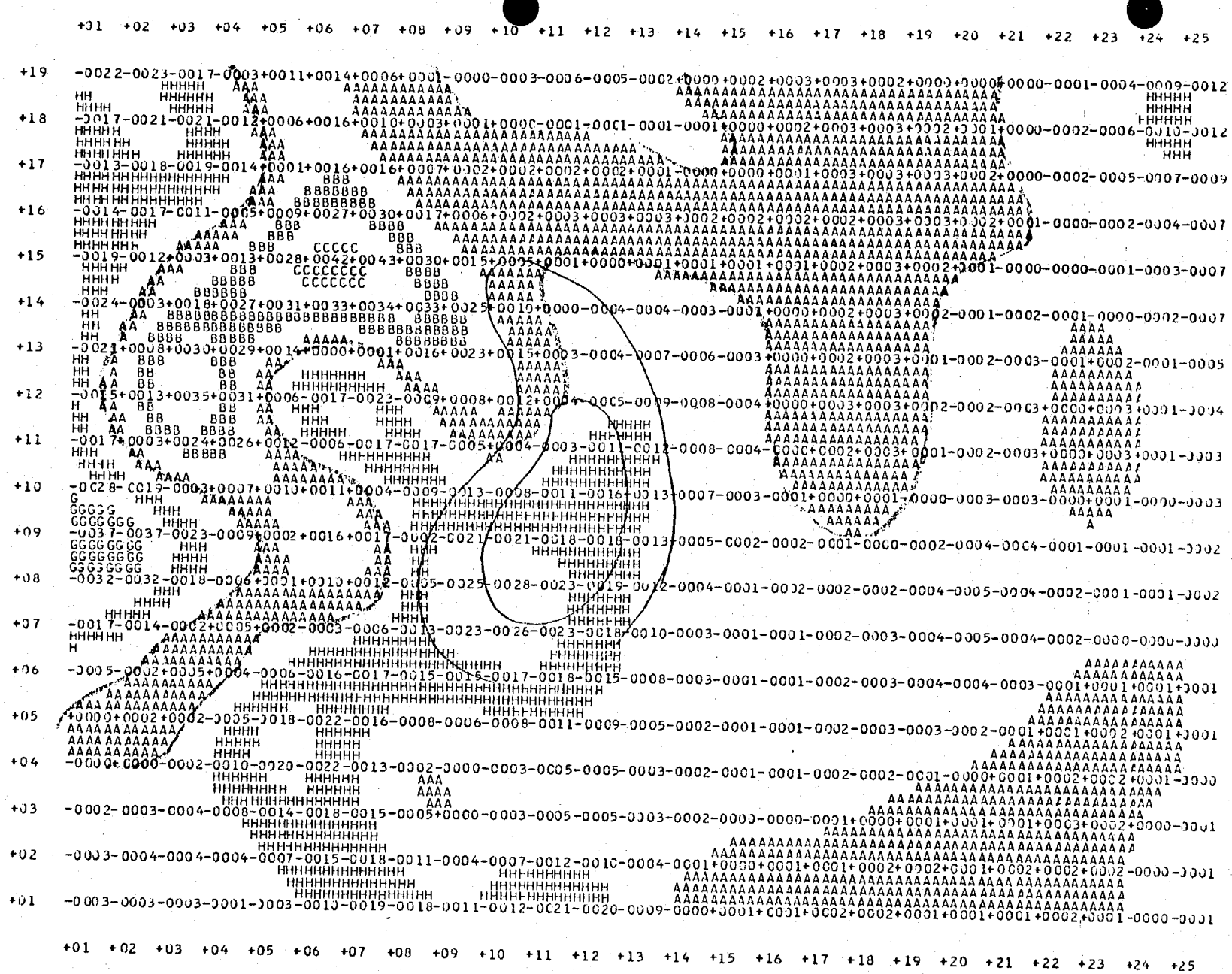


Fig 22 THE VERTICAL VELOCITY (DP/DT)*10000 AT 950 MB AT 36 HOUR FCST

Solid line is the Wtrop line ———