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NAVAL POSTGRADUATE SCHOOL

Monterey, California

Weather Analysis Programs Using
HP-41CV

by

Carlyle H. Wash

Laura A. Spray

November 1984

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Several synoptic problems, previously solved by graphical overlays, can be solved with a programmable calculator. The HP-41CV hand-held calculator is used to determine surface winds, the probability of average rainfall for a regional area (Monterey, California), contrail formation, and the lifting condensation level from surface data.

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Errata List for Weather Analysis Programs
Using the HP-41CV (NPS-63-84-008)

1. Page 1, Paragraph 3; Line 2 should read
   forecast from a set ......

2. Page 11, Paragraph 1; Line 4 should read
   Renard's (1972) nomogram method ......

3. Page 22, Paragraph 1; Line 7 should be
   $T_{amb} > T_{crit}$ rather than $T_{amb} < T_{crit}$ meaning 100% relative humidity.

TABLE OF CONTENTS

List of Figures

List of Tables

ABSTRACT

Several synoptic problems, previously solved by graphical overlays, can be solved with a programmable calculator. The HP-41CV hand-held calculator is used to determine surface winds, the probability of average rainfall for a regional area (Monterey, California), contrail formation, and the lifting condensation level from surface data.

I. Introduction

This report describes four programs that use the HP-41CV calculator's programming capability in dealing with interesting meteorological problems, including determining surface winds, the probability of average rainfall for a regional area (Monterey, California), contrail formation and the lifting condensation level from surface data.

The programs were prepared to use the hand-held calculator in solving synoptic problems. The first problem is the estimation of surface wind at a point from a regional sea-level pressure analysis or forecast. This problem arose in the synoptic laboratory where wind forecasts were prepared with numerical weather prediction guidance (facsimile sea-level pressure maps). The immediate solution is a geostrophic wind scale applied to the facsimile chart. The HP program provides an alternative solution. The program calculates the geostrophic and gradient wind, as well as the estimated surface wind, using Ekman boundary layer assumptions, by simply entering latitudes, longitudes and pressure readings from a sea-level pressure chart.

The second problem involves preparing a statistical precipitation forecast for a set of graphical tables. Using a tutorial program in a hand-held calculator, the need for the graphical tables is eliminated. The program determines the probability of average rainfall over the Monterey, California area for the period 0800 PST forecast day to 0800 PST of the following day, for the wet-season months, November through April. This procedure is based on the Renard (1972) graphical objective technique for forecasting 24-h rainfall at Monterey, California. From the data entries of 500 mb heights used to calculate geostrophic relative vorticity at Monterey and a point 8° latitude upstream from Monterey, as well as sea-level pressure data, the program uses a series of pre-established data tables to arrive at a probability of 24-h rainfall for Monterey, California.

The third problem involves forecasting contrails from upper-level sounding data. It was desired to have the HP make the decision from input sounding data as an alternative to plotting the entire sounding and using a graphical overlay. This program determines contrail formation at a given pressure level based on the curves found in the Contrails Forecasting Manual of Chief of Naval Operations (1964). A least squares approximation was made to the curves involving an expression for critical temperature which is a function of temperature, pressure and relative humidity. If the relative humidity is estimated (dew-point temperature is unknown), there is a series of criteria to determine whether or not contrails will occur.

The final problem is to determine the lifting condensation level (LCL) without using a thermodynamic diagram. Inputing values of surface temperature, surface pressure and specific humidity to the HP results in a lifting condensation level. The LCL is the height at which a parcel, when lifted dry-adiabatically, becomes saturated. The program uses the Clausius-Clapeyron equation to arrive at a final expression for the LCL that is determined by values of surface temperature, surface pressure and specific humidity.

II. Computation of Surface Winds

A. Objectives

This program will give the forecaster, either ship-board or at a regional center, an easy and accurate method of computing the geostrophic, gradient and estimated surface wind from a MSL pressure analysis or model forecast. This method is more complete than a graphical geostrophic wind scale overlay.

B. Principles

The geostrophic wind speed and direction are obtained from the east-west (u_g) and north-south (v_g) components.

$$u_g = -\frac{1}{f\rho}\frac{\partial p}{\partial y} \qquad |v_g| = \sqrt{u^2{}_g + v^2{}_g}$$

$$v_g = \frac{1}{f\rho}\frac{\partial p}{\partial x} \qquad \tan\theta_g = \frac{v_g}{u_g}$$

where u_g and v_g are geostrophic wind components,

$f = 2\,\Omega\sin\phi$; is latitude of forecast point,

$\rho = 1.3\ kg/m^3$; typical sea level density value,

$\partial x, \partial y = 1°$ lat $= 111$ km

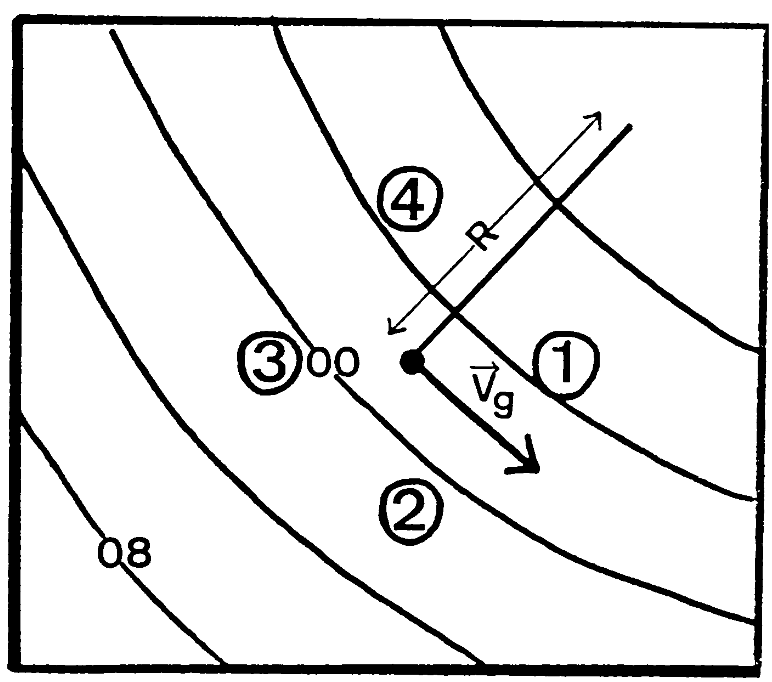


Figure 1

Geostrophic wind ($\vec{V}_g$) computed by the finite differencing scheme with 1° latitude grid spacing.

The user enters the latitude and longitude of the point (Northern Hemisphere) where a wind is desired. Next, the user enters four pressures that are 1° latitude north, south, east and west of the center point used in the finite differencing technique:

$$\frac{\partial p}{\partial y} = \frac{P④ - P②}{222\ \text{km}} \;;\; \frac{\partial P}{\partial x} = \frac{P① - P③}{222\ \text{km}} . \qquad \text{(See Figure 1.)}$$

The gradient wind speed is obtained from the geostrophic wind speed and the radius of curvature (R).

$$|V_{gr}| = \frac{|V_g|}{.5 + \sqrt{.25 + V_g/fR}} \qquad \begin{array}{ll} \text{where } R > 0 & \text{cyclonic} \\ R < 0 & \text{anticyclonic} \end{array}$$

The user enters a radius of curvature (in kilometers) which is representative of the isobaric curvature in the forecast area. (See Figure 1.)

In a cyclonic situation ($R > 0$), the magnitude of the gradient wind is less than the magnitude of the geostrophic wind (subgeostrophic); if $R < 0$ (anticyclonic), the gradient wind speed is greater than the geostrophic (supergeostrophic). If the curvature is zero ($R = \infty$) the magnitude of the gradient and geostrophic winds is the same. Regardless of the curvature, the gradient wind is from the same direction as the geostrophic wind.

The estimated surface wind speed and direction are obtained from the gradient speed and direction using Ekman layer assumptions. Over the land, the gradient wind speed is multiplied by a factor of 0.6 which is an approximate amount that the speed is reduced by friction. The resulting speed is an estimated surface wind speed. The actual direction is rotated counter-clockwise 20° from the original direction. Over the sea, the gradient wind speed is multiplied by .81 and direction is rotated by 10°. The oceanic and land frictional effects follow the observational summary of Sheppard (1969) and the discussion of Petterssen (1956) and Haltiner and Martin (1957). Sheppard (1969) and Mendenhall (1967) indicate 10° is a reasonable estimate of frictional veering over the ocean from weather ship data. Over land, the frictional effects are naturally heavily dependent upon surface roughness so the 20° veering is only a general estimate.

C. User's Guide

1) Make sure the calculator and printer (NOR mode) are on.

2) [XEQ] [alpha] SIZE [alpha]

will prompt SIZE __ __ __

3) Type 100.

4) Enter magnetic cards as labelled 1-9 - -

5) After the program (WIND) is "WORKING" and entered, it is ready to be executed.

6) [XEQ] [alpha] WIND [alpha]

7) The prompt CTR LAT? will appear.

8) Press the [R/S] button to continue.

(Do this each time you answer a prompt.)

9) The prompt CTR LON? will appear.

Enter the longitude of the center forecast point.

10) Press [R/S]

11) Answer the prompts for the four pressures (mb).

12) Press [R/S] . (Remember to do this each time.)

13) The geostrophic wind speed (m/s) and direction will be displayed.

14) Enter a radius of curvature (m) after prompt RADIUS?

15) The gradient wind speed will be displayed.

16) The prompt LAND or SEA? will appear.

If the forecast region is over land, enter "LAND"; otherwise, enter "SEA".

17) The estimated surface wind speed and direction will be displayed and the program is done.

18) To run the program again: [XEQ] [alpha] WIND [alpha]

D. Examples

To illustrate the use of the program the surface wind will be estimated for points A and B in Figure 2. The observed surface wind speed and direction for forecast point A at 0000Z on 26 November 1981 is 10 m/s from 315°. For point B, the surface wind speed is 20 m/s from 295°.

Execution of the "WIND" program on the HP-41CV calculator results in a surface wind speed of 14 m/s from a northwest direction of 319° for forecast point A. Entering the latitude/longitude position (43N 130 W) along with four pressures 1° latitude north, south, east and west (1007 mb, 1012 mb, 1009 mb, 1012mb respectively) results in a geostrophic wind of 20 m/s from 329°. A radius of curvature of 1,100 km allows a gradient wind to be computed (18 m/s). Finally, since forecast point A is an ocean location, the oceanic Ekman layer boundary assumptions are applied. The resulting estimated surface wind is 14 m/s from 319°. This estimated wind is in agreement with the observed real wind speed (10 m/s) and direction (315°).

For forecast point B (46N 135W) the four pressures (1008 mb, 1011 mb, 1006.5 mb and 1013 mb) result in a geostrophic wind of 24 m/s from 295°. From the radius of curvature (1,300 km), a gradient wind of 21 m/s is calculated. The final estimated wind speed for this ocean location is 17 m/s from 285° which compares with the observed real wind speed (20 m/s) and direction (295°).

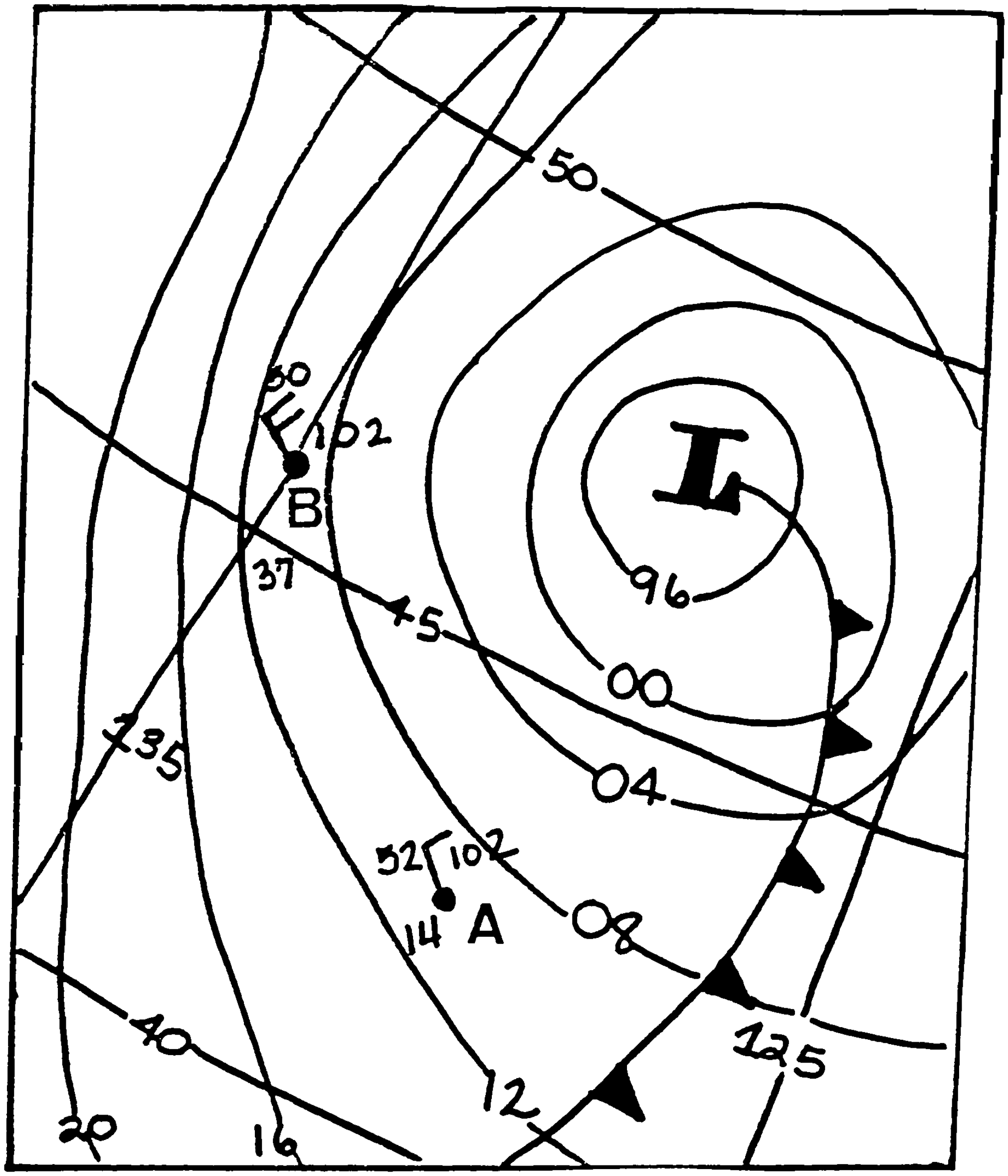


Figure 2

Surface conditions observed at 0000Z 26 November, 1981 for illustration of surface wind program.

A

```
            XEQ "WIND"   GEO. SPEED:
CTR LAT?                               20.
            43.          GEO. DIR FROM:
CTR LON?                               329.
            130.         RADIUS?
PRS NO LAT?                   1,100,000.
          1,007.         GRAD. SPEED:
PRS SO LAT?                            18.
          1,012.         LAND OR SEA?
PRS EAST LAT?            SEA
          1,009.         SFC SPEED:
PRS WEST LAT?                          14.
          1,012.         SFC DIR FROM:
                                       319.
```

B

```
            XEQ "WIND"   GEO. SPEED:
CTR LAT?
            46.          GEO. DIR FROM:
CTR LON?
            135.         RADIUS?
PRS NO LAT?                   1,300,000.
          1,008.         GRAD. SPEED:
PRS SO LAT?
          1,011.         LAND OR SEA?
PRS EAST LAT?            SEA
          1,006.5        SFC SPEED
PRS WEST LAT?
          1,013.         SFC DIR FROM:
```

E. Program

Table I
Surface Winds Program.

```
01♦LBL "WIND"
02 FIX 0
03 "CTR LAT?"
04 PROMPT
05 STO 01
06 "CTR LON?"
07 PROMPT
08 STO 02
09 "PRS NO. LAT?"
10 PROMPT
11 STO 03
12 "PRS SO. LAT?"
13 PROMPT
14 STO 04
15 "PRS EAST LAT?"
16 PROMPT
17 STO 05
18 "PRS WEST LAT?"
19 PROMPT
20 STO 06
21 RCL 03
22 ENTER↑
23 RCL 04
24 -
25 100
26 *
27 2.22 E05
28 /
29 1.3
30 /
31 CHS
32 STO 07
33 RCL 01
34 ENTER↑
35 SIN
36 1.4584 E-04
37 *
38 STO 08
39 RCL 07
40 ENTER↑
41 RCL 08
42 /
43 STO 09
44 RCL 05
45 ENTER↑
46 RCL 06
47 -
48 100
49 *
50 2.22 E05
51 /
52 1.3
53 /
54 RCL 08
55 /
56 STO 10
57 RCL 09
58 ENTER↑
59 X↑2
60 RCL 10
61 X↑2
62 +
63 SQRT
64 STO 11
65 "GEO. SPEED:"
66 AVIEW
67 PSE
68 RCL 11
69 VIEW 11
70 PSE
71 0
72 ENTER↑
73 RCL 09
74 X=Y?
75 GTO "CHK"
76 0
77 ENTER↑
78 RCL 10
79 X=Y?
80 GTO "CHKS"
81 0
82 ENTER↑
83 RCL 09
84 X>Y?
85 GTO "WSH"
86 0
87 ENTER↑
88 RCL 10
89 X>Y?
90 GTO "TWO"
91 1/X
92 RCL 09
93 *
94 ATAN
95 STO 18
96 GTO "GRAD"
97♦LBL "TWO"
98 1/X
99 RCL 09
100 *
101 ATAN
102 180
103 +
104 STO 18
105 GTO "GRAD"
106♦LBL "WSH"
107 0
108 ENTER↑
109 RCL 10
110 X>Y?
111 GTO "TRE"
112 1/X
113 RCL 09
114 *
115 ATAN
116 CHS
117 270
118 +
119 STO 18
120 GTO "GRAD"
121♦LBL "TRE"
122 1/X
123 RCL 09
124 *
125 ATAN
126 CHS
127 270
128 +
129 STO 18
130 GTO "GRAD"
131♦LBL "CHK"
132 0
133 ENTER↑
134 RCL 10
135 X<=Y?
136 GTO "NOR"
137 180.0
138 STO 18
139 GTO "GRAD"
140♦LBL "NOR"
141 360.0
142 STO 18
143 GTO "GRAD"
144♦LBL "CHKS"
145 0
146 ENTER↑
147 RCL 09
148 X<=Y?
149 GTO "EAST"
150 270.0
151 STO 18
152 GTO "GRAD"
153♦LBL "EAST"
154 90.0
155 STO 18
156 GTO "GRAD"
157♦LBL "GRAD"
158 "GEO. DIR FROM:"
159 AVIEW
160 PSE
161 RCL 18
162 VIEW 18
163 PSE
164 "RADIUS?"
165 PROMPT
166 STO 25
167 0
168 ENTER↑
169 RCL 25
170 X<=Y?
171 GTO "ANTI"
172 RCL 11
173 RCL 25
174 /
175 RCL 08
176 /
177 .25
178 +
179 SQRT
180 .5
181 +
182 STO 26
183 RCL 11
184 RCL 26
185 /
186 STO 27
187 GTO "ACT"
188♦LBL "ANTI"
189 RCL 11
190 RCL 25
191 /
192 RCL 08
193 /
194 STO 28
195 RCL 28
196 ENTER↑
197 .25
198 +
199 STO 28
200 0
```

```
201 ENTER↑
202 RCL 29
203 X>Y?
204 GTO "OK"
205 "BAD RAD"
206 AVIEW
207 GTO "END"
208♦LBL "OK"
209 SQRT
210 .5
211 +
212 STO 29
213 RCL 11
214 RCL 29
215 /
216 STO 27
217♦LBL "ACT"
218 "GRAD. SPEED:"
219 AVIEW
220 PSE
221 RCL 27
222 VIEW 27
223 PSE
224 "LAND OR SEA?"
225 AON
226 PROMPT
227 AOFF
228 ASTO Y
229 "LAND"
230 ASTO IND X
231 X=Y?
232 GTO "LAND"
233 RCL 27
234 ENTER↑
235 .81
236 *
237 STO 32
238 "SFC SPEED:"
239 AVIEW
240 PSE
241 RCL 32
242 VIEW 32
243 RCL 18
244 ENTER↑
245 10
246 -
247 STO 33
248 "SFC DIR FROM:"
249 AVIEW
250 PSE
251 RCL 33
252 VIEW 33
253 GTO "END"
254♦LBL "LAND"
255 RCL 27
256 ENTER↑
257 .6
258 *
259 STO 30
260 "SFC SPEED:"
261 AVIEW
262 PSE
263 RCL 30
264 VIEW 30
265 RCL 18
266 ENTER↑
267 20
268 -
269 STO 31
270 "SFC DIR FROM:"
271 AVIEW
272 PSE
273 RCL 31
274 VIEW 31
275♦LBL "END"
276 "END"
277 .END.
```

III. Determining the Probability of Precipitation for Monterey, California

A. Objective

To determine the probability of 24-h rainfall for a regional area (Monterey, California) for the period 0800 PST forecast day to 0800 PST of the following day, for the wet-season months, November through April. This procedure is based on Renard's (1972) honogram method and statistics.

B. Principles

General Forecast Procedure. The probability of 24-h rainfall is determined by values of geostrophic relative vorticity and sea-level pressures at different locations.

A first forecast parameter is obtained by taking the sea-level pressure at Eureka, CA (P_{Eureka}) and the difference between the 500 mb geostrophic relative vorticity at Monterey (ζ_M) and a point 8° latitude upstream from Monterey (ζ_8). Enter these values into a pre-established statistical table, which is stored on the calculator, to arrive at a forecast variable, Y_1. (See Figure 4.)

A second forecast parameter, Y_2, is the value that results from taking the sea-level pressure difference between Monterey and Eureka ($\Delta P_{M-Eureka}$) and Monterey and Las Vegas (ΔP_{M-LV}). (See Figure 5). These two parameters, Y_1 and Y_2, are entered in a third table (Figure 6) which results in a final value that corresponds to a probability of average rainfall for the Monterey Peninsula.

500 mb Geostrophic Relative Vorticity. To calculate the 500 mb geostrophic relative vorticity, five 500 mb heights are needed to use finite differencing technique to solve ($\zeta_M = g/f \nabla^2 Z$) where $_M$ is the geostrophic relative vorticity at Monterey, $\nabla^2 Z$ is the Laplacian of the 500 mb height. For example, in Figure 3 at Monterey (Z_M = 558 dm) the four 500 mb heights

are 552 dm (Z_n: 500 mb height to the north), 566 dm (Z_s), 560 dm (Z_e), and 563 dm (Z_w) with a grid spacing of 6° latitude. This results in a geostrophic relative vorticity of 1.8×10^{-5} sec^{-1}.

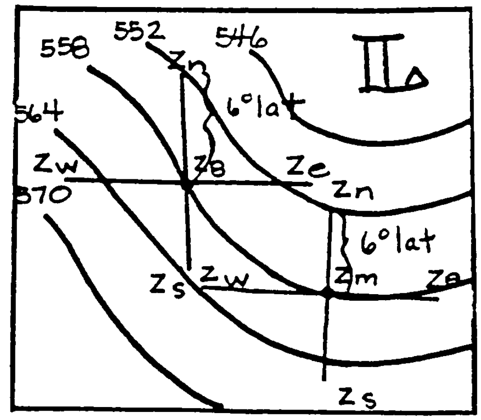


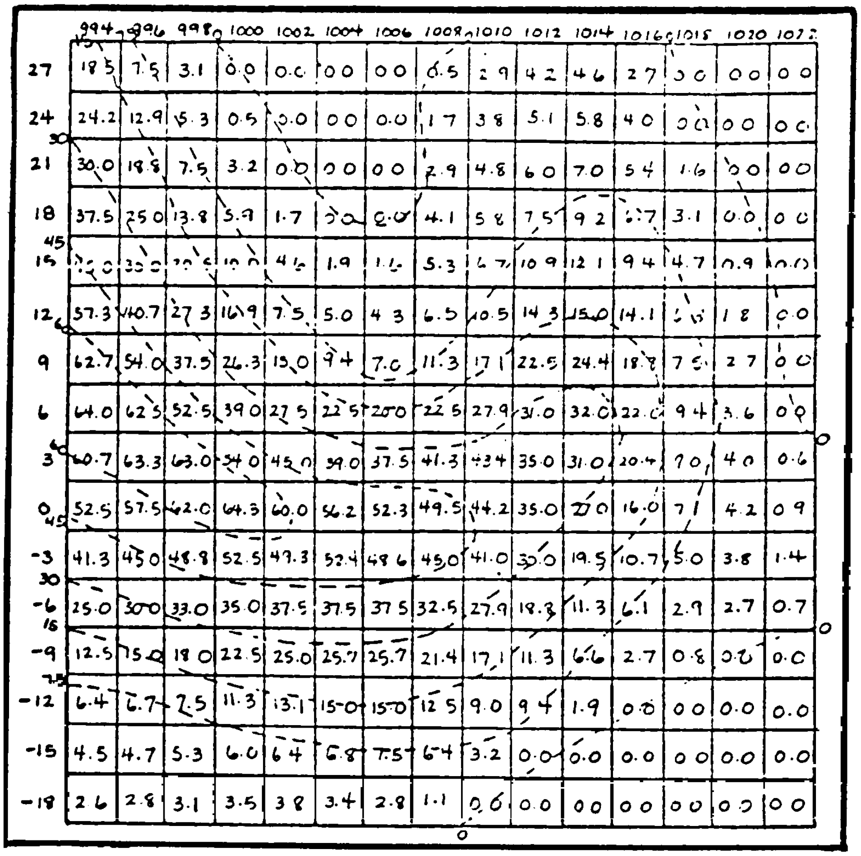
Figure 3

Computation of geostrophic relative vorticity for Monterey (ζ_M) and a point 8° latitude upstream (ζ_8).

The 500 mb geostrophic relative vorticity is computed for a point 8° latitude upstream (8° corresponds to a typical daily progression of short-waves in the westerlies of 22 kt during the winter season) from Monterey in the same way. The difference between the two vorticities ($\zeta_{8°} - \zeta_M$) is used as a forecast factor.

<u>Sea-Level Pressure</u>. Y_1, a first forecast parameter, is obtained from the computed vorticity difference and a sea-level pressure at Eureka, California (Figure 4). Y_2, a second forecast parameter, is obtained from the difference between the sea-level pressure at Monterey minus the sea-level pressure at Eureka ($\Delta P_{M-Eureka}$) and the sea-level pressure at Monterey minus the sea-level pressure at Las Vegas (ΔP_{M-LV}) (Figure 5).

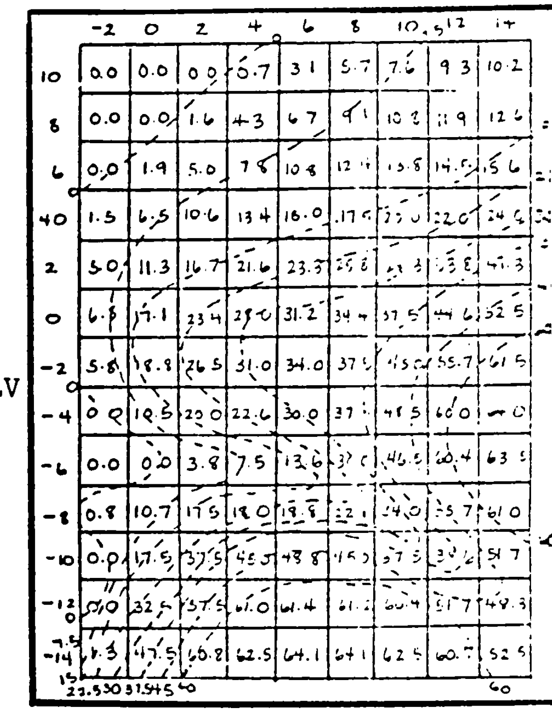
<u>Probability of Rainfall</u>. From the two forecast parameters, Y_1 and Y_2, a value Y_3 is obtained which corresponds to a probability of rainfall for the Monterey, CA area for the period 0800 PST forecast day to 0800 PST of the following day, for the wet-season months, November through April. (Figure 6.) The corresponding values between Y_3 and a probability of average rainfall are on data cards that are entered during the program execution.



P_{Eureka}

Figure 4

$Y_1 = f(P_{Eureka}, \zeta_8 - \zeta_M)$: first forecast factor of the raincaster.

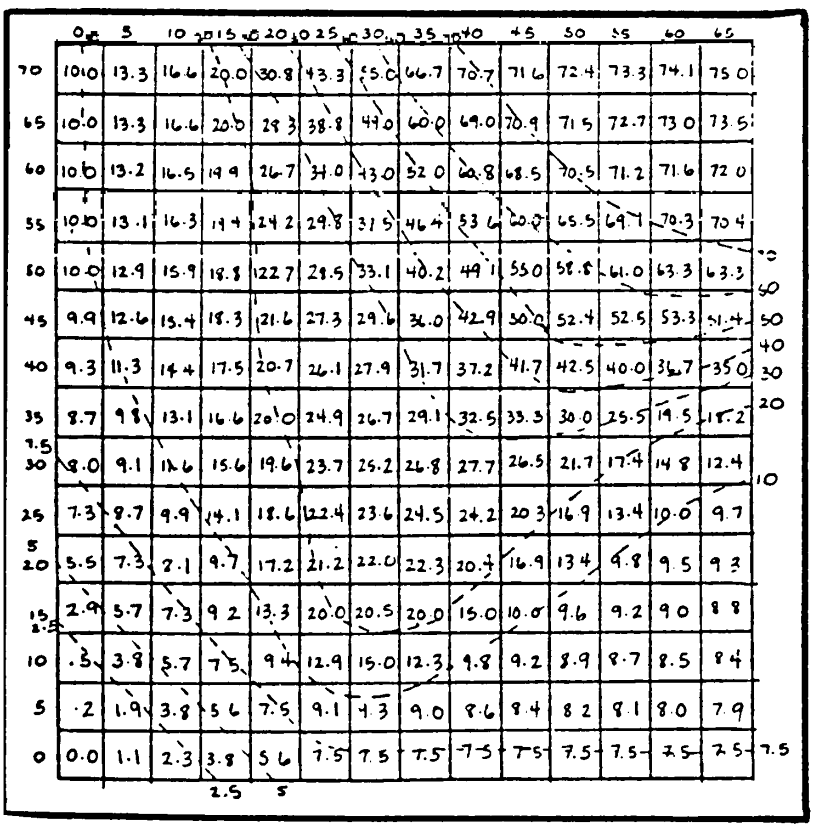


ΔP_{M-LV}

$\Delta P_{M-Eureka}$

Figure 5

$Y_2 = f(\Delta P_{M-Eureka}, \Delta P_{M-LV})$: second forecast factor of the raincaster.



Y_1

Figure 6

$Y_3 = f(Y_1, Y_2)$: third forecast factor of the raincaster.

C. User's Guide

1) Make sure the printer is attached and in the NOR mode. Both printer and calculator should be on and the calculator's memory cleared.

2) [XEQ] [alpha] SIZE [alpha]

   will prompt SIZE __ __ __

3) Type 035.

4) Load the program cards (1-18). Continue after the prompt "WORKING."

5) [XEQ] [alpha] RAIN [alpha]

6) Enter 500 mb heights (dm) for each prompt. (For example, ZN: 8° means height at north position at a point 8° latitude upstream from Monterey.)

7) Hit [R/S] after each entry.

8) Enter pressure values for Monterey, Las Vegas, and Eureka.

9) Hit [R/S] after each entry.

10) A data card prompt will occur after all the information has been entered. For the first time, use data set #1; the second time, use data set #2, etc.

11) The final number that appears after all data card insertion instructions is the probability of average rainfall for the Monterey Peninsula.

    NOTE: If the program ends with "OUT OF RANGE", then the values used are either too small or too large. Try another set of values that will fit in the stored data sets.

D. Examples

Example A illustrates the use of the program "RAIN" in determining the probability of precipitation at Monterey, CA. At 1200Z 25 November 1981 for a point 8° latitude upstream from Monterey, the 500 mb heights (in decameters) 6° latitude to the north, east, south, west and at the center point are 541.0, 543.0, 562.5, 563.0 and 555.0 respectively. (See Figure 7.) Around Monterey, the 500 mb heights are 550.0 dm 6° latitude to the north, 555.0 dm at the eastern location, 573.0 dm to the south, 576.0 dm to the west, and 567.0 dm at Monterey. These heights are used to obtain the 500 mb relative geostrophic vorticity values used in generating forecast variables. The 1200Z sea-level pressures at Monterey, Las Vegas and Eureka (1018.8 mb, 1006.2 mb, 1017.3 mb) are also required to compute forecast variables. (See Figure 8a.) These forecast variables result in a probability of precipitation of 90%. Rain did verify during the 24-h period, as noted from the 1200Z 26 November 1981 observation (Figure 8b.)

A

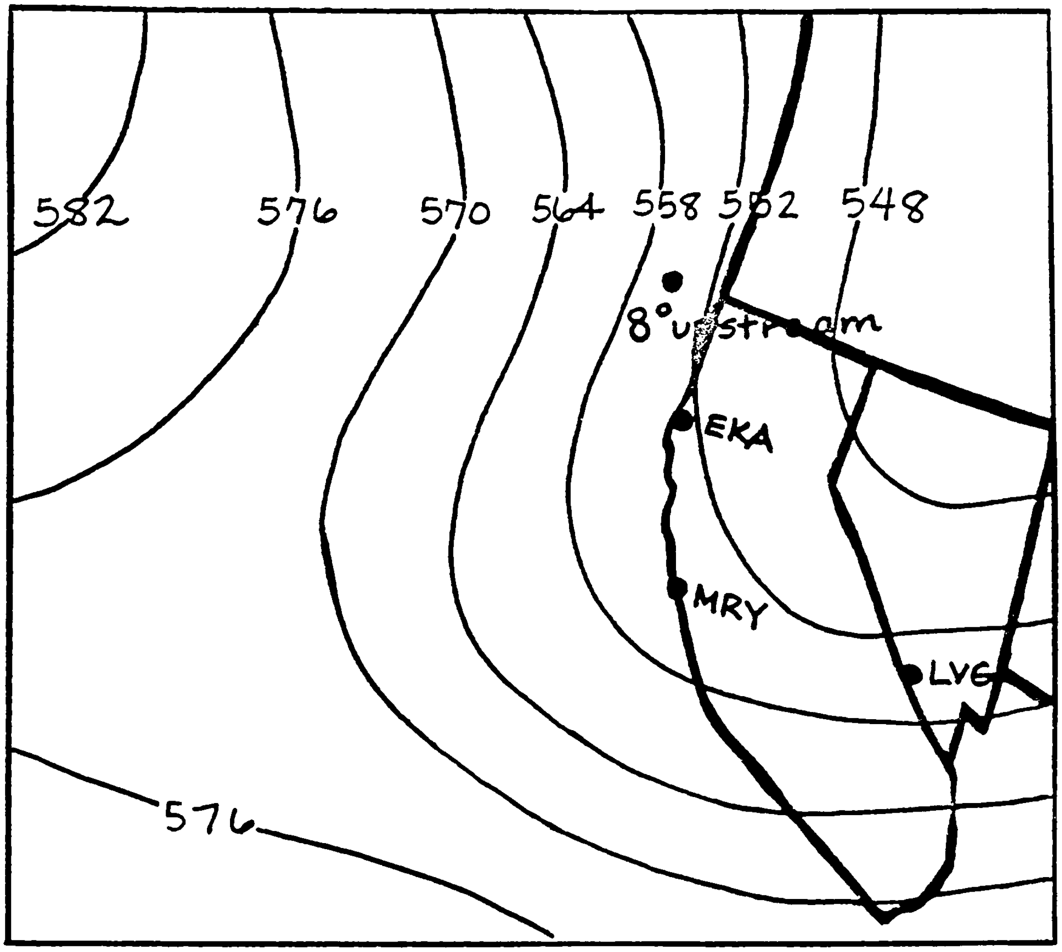


Figure 7
500 mb analysis for
1200Z 25 November 1981

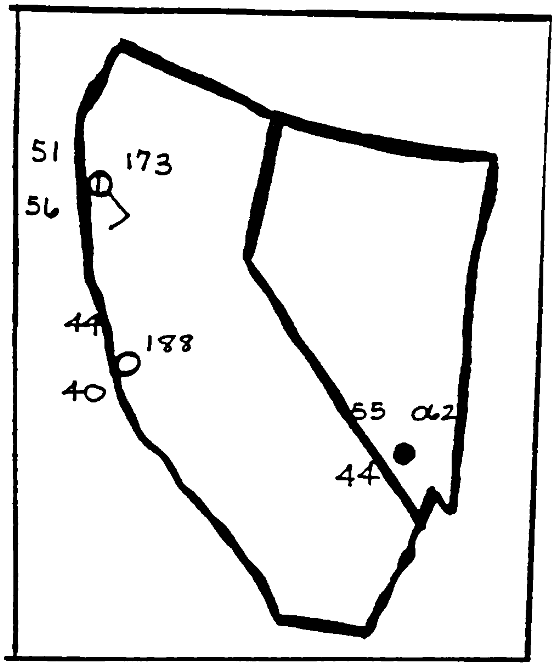


Figure 8a
Surface observations
for 1200Z 25 November 1981

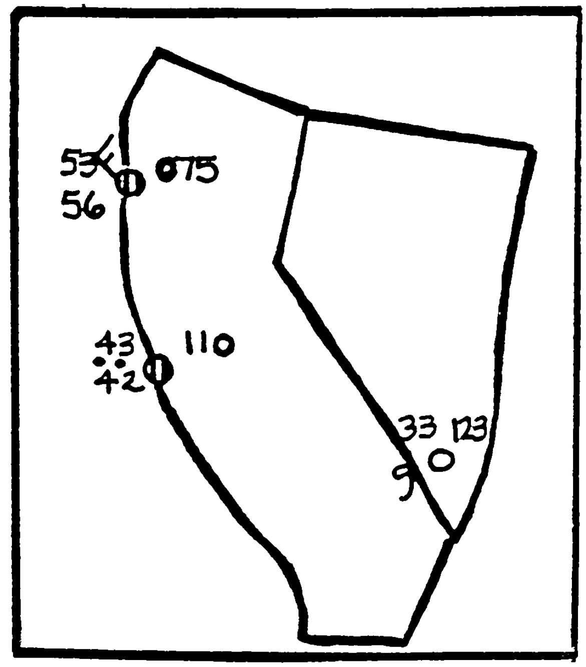


Figure 8b
Surface observations
for 1200Z 26 November 1981

Table II
Example of the Probability of Precipitation for Monterey, California Program.

```
ENTER ZN:S
           541.
ENTER ZE:S
           543.
ENTER ZS:S
          562.5
ENTER ZW:S
           563.
ENTER Z0:S
           555.
ENTER ZN:M
           548.
ENTER ZE:M
           554.
ENTER ZS:M
          569.5
ENTER ZW:M
          570.5
ENTER Z0:M
           555.
```

```
ENTER PRES MONT
          1,018.8
ENTER PRES LVGS
        1,006.2000
ENTER PRES ERKA
        1,017.3000
           X1= 1,018.0000
              X2=-33.0000
               X3= 2.0000
              X4= 14.0000
INSERT CRD 13
              Y1=-20.0000
INSERT CRD 3
              Y2= 25.0000
                  90.0000
```

Probability of
Precipitation is 90%.
Data verified from
observed case at
1200Z 26 November 1981.

E. Program

Table III
Probability of 24-h Precipitation for Monterey, California Program.

```
01♦LBL "RAIN"
02 "ENTER ZN:8"
03 PROMPT
04 STO 00
05 "ENTER ZE:8"
06 PROMPT
07 RCL 00
08 +
09 STO 00
10 "ENTER ZS:8"
11 PROMPT
12 RCL 00
13 +
14 STO 00
15 "ENTER ZW:8"
16 PROMPT
17 RCL 00
18 +
19 STO 00
20 "ENTER Z0:8"
21 PROMPT
22 4
23 *
24 CHS
25 RCL 00
26 +
27 STO 00
28 "ENTER ZN:M"
29 PROMPT
30 STO 01
31 "ENTER ZE:M"
32 PROMPT
33 RCL 01
34 +
35 STO 01
36 "ENTER ZS:M"
37 PROMPT
38 RCL 01
39 +
40 STO 01
41 "ENTER ZW:M"
42 PROMPT
43 RCL 01
44 +
45 STO 01
46 "ENTER Z0:M"
47 PROMPT
48 4
49 *
50 CHS
51 RCL 01
52 +
53 CHS
54 RCL 00
55 +
56 STO 02
57 "ENTER PRES MONT"
58 PROMPT
59 XEQ "ROUND"
60 STO 03
61 "ENTER PRES LVGS"
62 PROMPT
63 XEQ "ROUND"
64 STO 04
65 "ENTER PRES ERKA"
66 PROMPT
67 XEQ "ROUND"
68 STO 01
69 RCL 01
70 2
71 MOD
72 X=0?
73 GTO 85
74 RCL 01
75 1
76 +
77 STO 01
78 GTO 85
79♦LBL 85
80 RCL 01
81 "X1="
82 ACA
83 ACX
84 ADV
85 RCL 02
86 XEQ "ROUND"
87 STO 02
88♦LBL 77
89 RCL 02
90 3
91 MOD
92 X=0?
93 GTO 86
94 1
95 X=Y?
96 GTO 88
97 GTO 87
98♦LBL 88
99 RCL 02
100 1
101 -
102 STO 02
103 GTO 77
104♦LBL 87
105 RCL 02
106 1
107 +
108 STO 02
109 GTO 77
110♦LBL 86
111 RCL 02
112 "X2="
113 ACA
114 ACX
115 ADV
116 RCL 03
117 RCL 01
118 -
119 XEQ "FIXEVEN"
120 RCL 05
121 STO 00
122 "X3="
123 ACA
124 ACX
125 ADV
126 RCL 03
127 RCL 04
128 -
129 XEQ "FIXEVEN"
130 RCL 05
131 STO 04
132 "X4="
133 ACA
134 ACX
135 ADV
136 994
137 STO 07
138 27
139 STO 08
140 2
141 STO 09
142 RCL 00
143 STO 03
144 RCL 01
145 GTO 40
146♦LBL 40
147 RCL 07
148 X>Y?
149 GTO 27
150 X=Y?
151 GTO 08
152 XEQ 00
153 X=Y?
154 GTO 09
155 XEQ 00
156 X=Y?
157 GTO 10
158 XEQ 00
159 X=Y?
160 GTO 11
161 XEQ 00
162 X=Y?
163 GTO 12
164 XEQ 00
165 X=Y?
166 GTO 13
167 XEQ 00
168 X=Y?
169 GTO 14
170 XEQ 00
171 X=Y?
172 GTO 15
173 XEQ 00
174 X=Y?
175 GTO 16
176 FS? 00
177 GTO 23
178 XEQ 00
179 X=Y?
180 GTO 17
181 XEQ 00
182 X=Y?
183 GTO 18
184 XEQ 00
185 X=Y?
186 GTO 19
187 XEQ 00
188 X=Y?
189 GTO 20
190 XEQ 00
191 X=Y?
192 GTO 21
193 XEQ 00
194 X=Y?
195 GTO 22
196 GTO 23
197♦LBL 00
198 RCL 09
199 +
200 RTN
201♦LBL 08
202 20.035
203 "INSERT CRD 1"
204 AVIEW
205 RDTAX
206 FS? 00
207 GTO 33
208 FS? 01
209 GTO 44
210 GTO 24
211♦LBL 09
212 20.035
213 "INSERT CRD 2"
214 AVIEW
215 RDTAX
216 FS? 00
217 GTO 33
218 FS? 01
219 GTO 44
220 GTO 24
221♦LBL 10
222 20.035
223 "INSERT CRD 3"
224 AVIEW
225 RDTAX
226 FS? 00
227 GTO 33
228 FS? 01
229 GTO 44
230 GTO 24
231♦LBL 11
232 20.035
233 "INSERT CRD 4"
234 AVIEW
235 RDTAX
236 FS? 00
237 GTO 33
238 FS? 01
239 GTO 44
240 GTO 24
241♦LBL 12
242 20.035
243 "INSERT CRD 5"
244 AVIEW
245 RDTAX
246 XROM 28,33
247 RCL 01
248 FS? 01
249 GTO 44
250 GTO 24
```

```
251♦LBL 13
252 20.035
253 "INSERT CRD 6"
254 AVIEW
255 RDTAX
256 AVIEW
257 XROM 28,33
258 GTO 33
259 FS? 01
260 GTO 44
261 GTO 24
262♦LBL 14
263 20.035
264 "INSERT CRD 7"
265 AVIEW
266 RDTAX
267 XROM 28,33
268 GTO 33
269 FS? 01
270 GTO 44
271 GTO 24
272♦LBL 15
273 20.035
274 "INSERT CRD 8"
275 AVIEW
276 RDTAX
277 GTO 33
278 FS? 33
279♦LBL 00
280 GTO 44
281 GTO 24
282♦LBL 16
283 20.035
284 "INSERT CRD 9"
285 AVIEW
286 RDTAX
287 XROM 28,33
288 RCL 01
289 FS? 01
290 GTO 44
291 GTO 24
292♦LBL 17
293 20.035
294 "INSERT CRD 10"
295 AVIEW
296 RDTAX
297 XROM 28,33
298♦LBL 00
299 GTO 44
300 GTO 24
301♦LBL 18
302 20.035
303 "INSERT CRD 11"
304 AVIEW
305 RDTAX
306 XROM 28,33
307 X>0?
308 RCL 12
309 GTO 24
310♦LBL 19
311 20.035
312 "INSERT CRD 12"
313 AVIEW
314 RDTAX
315 GTO 44
316 XROM 28,33
317 GTO 24
318♦LBL 20
319 20.035
320 "INSERT CRD 13"
321 AVIEW
322 RDTAX
323 FS? 01
324 GTO 44
325 GTO 24
326♦LBL 21
327 20.035
328 "INSERT CRD 14"
329 AVIEW
330 RDTAX
331 AVIEW
332 XROM 28,33
333 GTO 44
334 GTO 24
335♦LBL 22
336 20.035
337 "INSERT CRD 15"
338 AVIEW
339 RDTAX
340 GTO d
341 XROM 28,33
342 RCL 12
343 GTO 24
344♦LBL 24
345 RCL 02
346 RCL 08
347 X=Y?
348 GTO 50
349 XEQ 25
350 X=Y?
351 GTO 51
352 XEQ 25
353 X=Y?
354 GTO 52
355 XEQ 25
356 X=Y?
357 GTO 53
358 XEQ 25
359 X=Y?
360 GTO 54
361 XEQ 25
362 X=Y?
363 GTO 55
364 XEQ 25
365 X=Y?
366 GTO 56
367 XEQ 25
368 X=Y?
369 GTO 57
370 XEQ 25
371 X=Y?
372 GTO 58
373 XEQ 25
374 X=Y?
375 GTO 59
376 XEQ 25
377 X=Y?
378 GTO 60
379 XEQ 25
380 X=Y?
381 GTO 61
382 XEQ 25
383 X=Y?
384 GTO 62
385 XEQ 25
386 X=Y?
387 GTO 63
388 XEQ 25
389 X=Y?
390 GTO 64
391 XEQ 25
392 X=Y?
393 GTO 65
394 GTO 26
395♦LBL 25
396 3
397 -
398 RTN
399♦LBL 26
400 XEQ "ROUND"
401 STO 06
402 5
403 MOD
404 STO 13
405 X=0?
406 GTO 31
407 RCL 13
408 1
409 X=Y?
410 GTO 30
411 RCL 13
412 2
413 X=Y?
414 GTO 29
415 RCL 13
416 3
417 X=Y?
418 GTO 28
419 RCL 13
420 4
421 X=Y?
422 GTO 27
423♦LBL 27
424 RCL 06
425 1
426 +
427 STO 06
428 GTO 31
429♦LBL 28
430 RCL 06
431 2
432 +
433 STO 06
434 GTO 31
435♦LBL 29
436 RCL 06
437 2
438 -
439 STO 06
440 GTO 31
441♦LBL 30
442 RCL 06
443 1
444 -
445 STO 06
446 GTO 31
447♦LBL 31
448 FS? 00
449 GTO 32
450 FS? 01
451 GTO 35
452 RCL 06
453 STO 10
454 "Y1="
455 ACA
456 ACX
457 ADV
458 -2
459 STO 07
460 10
461 STO 08
462 2
463 STO 09
464 SF 00
465 RCL 03
466 GTO 40
467♦LBL 32
468 RCL 06
469 STO 12
470 "Y2="
471 ACA
472 ACX
473 ADV
474 0
475 STO 07
476 70
477 STO 08
478 5
479 STO 09
480 SF 01
481 CF 00
482 RCL 10
483 GTO 40
484♦LBL 23
485 FS? 01
486 GTO "END"
487 "OUT OF RANGE"
488 AVIEW
489 RTN
490♦LBL "END"
491 FS? 02
492 GTO 99
493 SF 02
494 RCL 06
495 1
496 STO 09
497 XEQ 00
498 X>Y?
499 GTO 66
500 XEQ 00
```

```
501 X>Y?
502 GTO 67
503 XEQ 00
504 X>Y?
505 GTO 68
506 XEQ 00
507 X>Y?
508 GTO 69
509 XEQ 00
510 X>Y?
511 GTO 70
512 XEQ 00
513 X>Y?
514 GTO 71
515 XEQ 00
516 X>Y?
517 GTO 72
518 XEQ 00
519 X>Y?
520 GTO 73
521 XEQ 00
522 X>Y?
523 GTO 74
524 XEQ 00
525 X>Y?
526 GTO 75
527 XEQ 00
528 X>Y?
529 GTO 76
530 XEQ 00
531 XEQ 00
532 X>Y?
533 GTO 78
534 XEQ 00
535 XEQ 00
536 X>Y?
537 GTO 79
538 XEQ 00
539 XEQ 00
540 X>Y?
541 GTO 80
542 XEQ 00
543 XEQ 00
544 X>Y?
545 GTO 81
546 CLX
547 29
548 X>Y?
549 GTO 82
550 CLX
551 40
552 X>Y?
553 GTO 83
554 GTO 84
555 RTN
556♦LBL 99
557 ACX
558 ADV
559 CF 01
560 CF 02
561 RTN
562♦LBL 33
563 -2
564 STO 09
565 RCL 04
566 RCL 08
567 X=Y?
568 GTO 50
569 XEQ 00
570 X=Y?
571 GTO 51
572 XEQ 00
573 X=Y?
574 GTO 52
575 XEQ 00
576 X=Y?
577 GTO 53
578 XEQ 00
579 X=Y?
580 GTO 54
581 XEQ 00
582 X=Y?
583 GTO 55
584 XEQ 00
585 X=Y?
586 RCL 26
587 GTO 56
588 XEQ 00
589 X=Y?
590 GTO 57
591 XEQ 00
592 X=Y?
593 GTO 58
594 XEQ 00
595 X=Y?
596 GTO 59
597 XEQ 00
598 X=Y?
599 GTO 60
600 XEQ 00
601 X=Y?
602 GTO 61
603 XEQ 00
604 X=Y?
605 GTO 62
606 GTO 63
607 GTO 26
608♦LBL 35
609 RCL 06
610 "Y3="
611 ACA
612 ACX
613 ADV
614 GTO 23
615♦LBL 44
616 -5
617 STO 09
618 RCL 12
619 RCL 08
620 X=Y?
621 GTO 50
622 XEQ 00
623 X=Y?
624 GTO 51
625 XEQ 00
626 X=Y?
627 GTO 52
628 XEQ 00
629 X=Y?
630 GTO 53
631 XEQ 00
632 X=Y?
633 GTO 54
634 XEQ 00
635 X=Y?
636 GTO 55
637 XEQ 00
638 X=Y?
639 GTO 56
640 XEQ 00
641 X=Y?
642 GTO 57
643 XEQ 00
644 X=Y?
645 GTO 58
646 XEQ 00
647 X=Y?
648 GTO 59
649 XEQ 00
650 X=Y?
651 GTO 60
652 XEQ 00
653 X=Y?
654 GTO 61
655 XEQ 00
656 X=Y?
657 GTO 62
658 XEQ 00
659 X=Y?
660 GTO 63
661 XEQ 00
662 X=Y?
663 GTO 64
664 GTO 65
665 GTO 26
666♦LBL 50
667 RCL 20
668 GTO 26
669♦LBL 51
670 RCL 21
671 GTO 26
672♦LBL 52
673 RCL 22
674 GTO 26
675♦LBL 53
676 RCL 23
677 GTO 26
678♦LBL 54
679 RCL 24
680 GTO 26
681♦LBL 55
682 RCL 25
683 GTO 26
684♦LBL 56
685 RCL 26
686 GTO 26
687♦LBL 57
688 RCL 27
689 GTO 26
690♦LBL 58
691 RCL 28
692 GTO 26
693♦LBL 59
694 RCL 29
695 GTO 26
696♦LBL 60
697 RCL 30
698 GTO 26
699♦LBL 61
700 RCL 31
701 GTO 26
702♦LBL 62
703 RCL 32
704 GTO 26
705♦LBL 63
706 RCL 33
707 GTO 26
708♦LBL 64
709 RCL 34
710 GTO 26
711♦LBL 65
712 RCL 35
713 GTO 26
714♦LBL 66
715 10
716 GTO 23
717♦LBL 67
718 15
719 GTO 23
720♦LBL 68
721 25
722 GTO 23
723♦LBL 69
724 30
725 GTO 23
726♦LBL 70
727 35
728 GTO 23
729♦LBL 71
730 40
731 GTO 23
732♦LBL 72
733 45
734 GTO 23
735♦LBL 73
736 50
737 GTO 23
738♦LBL 74
739 55
740 GTO 23
741♦LBL 75
742 60
743 GTO 23
744♦LBL 76
745 65
746 GTO 23
747♦LBL 78
748 70
749 GTO 23
750♦LBL 79
751 75
752 GTO 23
753♦LBL 80
754 80
755 GTO 23
756♦LBL 81
757 85
758 GTO 23
759♦LBL 82
760 90
761 GTO 23
762♦LBL 83
763 95
764 GTO 23
765♦LBL 84
766 100
767 GTO 23
768♦LBL "ROUND"
769 FIX 0
770 RND
771 FIX 4
772 RTN
773♦LBL "FIXEVEN"
774 STO 05
775 2
776 MOD
777 X=0?
778 RTN
779 RCL 05
780 1
781 +
782 STO 05
783 RTN
784 .END.
```

IV. Contrail Formation

A. Objective

To determine whether or not contrails will form at a certain level in the atmosphere based on the curves from the Contrail Forecasting Manual (Chief of Naval Operations, 1964).

B. Principles

The critical temperature determines if contrails will form at a level. A least squares approximation is given for the critical temperature:

$$T_{crit} = a_1 + a_2 \ln p + a_3 (\ln p)^2 + a_4 RH + a_5 (RH)^2;$$

where:

p is the pressure level;

RH is the relative humidity;

$a_1 = -90.4994$; $a_2 = 3.4232$; $a_3 = 0.5587$; $a_4 = -0.0372$; $a_5 = 0.0012$.

This equation was determined from the curves in Figure 9 of the Contrails Forecasting Manual (Chief of Naval Operations, 1964).

If the ambient temperature is less than the critical temperature, then contrails will form. If the ambient temperature is greater than the critical temperature, then contrails will not form.

There is a narrow range of temperatures where the relative humidity is important. If the dew point is known, the relative humidity can be calculated by using the definitions of saturation vapor pressure (e_s) and relative humidity (R.H.).

$$e_s(T) = 6.11 \exp (L/R_w (1/273 - 1/T))$$

$$R.H. = 100 * (e/e_s)$$

where $e_s(T)$ is the saturation vapor pressure

e is the actual vapor pressure

T is the temperature (°K)

L is the latent heat of evaporation (J/kg)

R_w is the specific gas constant for pure water vapor (J/kg °K)

If the dew-point temperature is unknown, the relative humidity is estimated and a ±2°C error margin is assumed when computing the critical temperature. If the ambient temperature is within ±2°C of the critical temperature, a "probably" will precede the "contrails" or "no contrails" message. The following criteria are used to estimate the relative humidity:

$T_{amb} < T_{crit}$ --> (RH = 0) --> contrails

$T_{amb} < T_{crit}$ --> (RH = 100) --> no contrails

p < 225 --> (stratosphere) --> RH $\simeq$ 0%

p > 300 --> (not in upper troposphere) --> RH $\simeq$ 40%

225 < p < 300 --> (upper troposphere) --> RH $\simeq$ 40% UNLESS

cirrus are at this level --> RH $\simeq$ 60%

flow is known and from

moist region --> RH $\simeq$ 60%

dry region --> RH $\simeq$ 0%

C. User's Guide

1) Make sure both the calculator and printer are on and that the printer is set to the MAN mode.

2) [XEQ] [alpha] SIZE [alpha]

3) Prompts SIZE __ __ __; Type 100.

4) Load all three cards, sides 1-6.

5) After "WORKING" signal, program is ready for execution.

6) [XEQ] [alpha] TRAILS [alpha]

7) Program asks about CHANGING FLAGS. For the first run through, leave the flags as they are and continue by hitting the [R/S] key.

8) Enter a pressure level in mb.

9) Press [R/S] key. (Hit [R/S] after each entry.)

10) Enter a temperature in °C.

11) A prompt for a dew-point temperature will be displayed. If T_d is known, type a 1; if T_d is unknown, type a 0.

12) The program will then decide whether or not contrails can be formed at that particular level depending upon the criteria discussed on the preceding pages. If the dew-point temperature is unknown, there might be more "yes" or "no" questions depending upon the pressure level and ambient temperature. Answer "1" for "yes" and "0" for "no."

13) The program will determine whether or not contrails will form at a certain pre-established pressure level.

14) After the answer is displayed, execution can continue for another level by pressing [R/S].

By changing the flags, two options are possible. Setting Flag 1 will make the prompts shorter and less specific. Setting Flag 2 means that the program assumes that the dew-point temperature is known and skips the questions concerning relative humidity estimation.

To change a flag:

a) Press gold button and SF key.

b) Program prompts SF __ __.

c) Enter either (or both): 01 - short prompt
02 - known T_d

d) To clear flags, press gold button and CF key.

e) Program prompts CF __ __.

f) Enter 01 or 02 to clear any flag that was set.

The program assumes all flags are clear each time it is first executed.

D. Examples

Examples A-E in Table IV illustrate the use of the program "TRAILS" in deciding whether contrails will form from upper-level sounding data. In example A, where no flags have been set, a pressure of 450 mb and temperature of -35°C are entered in the "TRAILS" program. The dew-point is unknown in this case so a "0" is entered. The program decides that contrails will not be possible with these conditions which agrees with the contrail curve diagram. (See Figure 9.) Example B is similar to A (no flags set and dew point unknown), but contrails will probably form with the particular upper-level sounding data. In example C, no flags are set, but the dew point is known. With a pressure of 250 mb, a temperature of -60.0°C, and dew point of -62.0°C, contrails will form. Examples D and E have flags set, which result in shortened prompts for both cases, and for example E, the dew point is assumed to be known. Both examples D and E illustrate that contrails will not form in these environmental conditions.

Table IV
Examples of the Contrail Formation Program.

A

```
P=? MB
         450.0000    ***
T=? C
         -35.0000    ***
DO YOU KNOW
DEWPOINT, TD?
YES=ONE
NO=ZERO
KNOW TD?
           0.0000    ***
NO CONTRAILS
```

No flags set
T_d unknown

B

```
P=? MB
         250.0000    ***
T=? C
         -54.0000    ***
DO YOU KNOW
DEWPOINT, TD?
YES=ONE
NO=ZERO
KNOW TD?
           0.0000    ***
ARE THERE
CIRRUS AT
THIS LEVEL?
YES=ONE
NO=ZERO
CIRRUS?
           1.0000    ***
PROBABLY
CONTRAILS
```

No flags set, T_d unknown

C

```
P=? MB
         225.0000    ***
T=? C
         -60.0000    ***
DO YOU KNOW
DEWPOINT, TD?
YES=ONE
NO=ZERO
KNOW TD?
           1.0000    ***
TD=? C
         -62.0000    ***
CONTRAILS
```

No flags set
T_d known

D

```
P=? MB
         300.0000    ***
T=? C
         -48.0000    ***
KNOW TD?
           0.0000    ***
CIRRUS?
           0.0000    ***
KNOW FLOW?
           1.0000    ***
MST OR DRY?
           1.0000    ***
NO CONTRAILS
```

Flag 01 set
Unknown T_d

E

```
P=? MB
         850.0000    ***
T=? C
         -10.0000    ***
TD=? C
         -20.0000    ***
NO CONTRAILS
```

Flag 02 set
T_d known

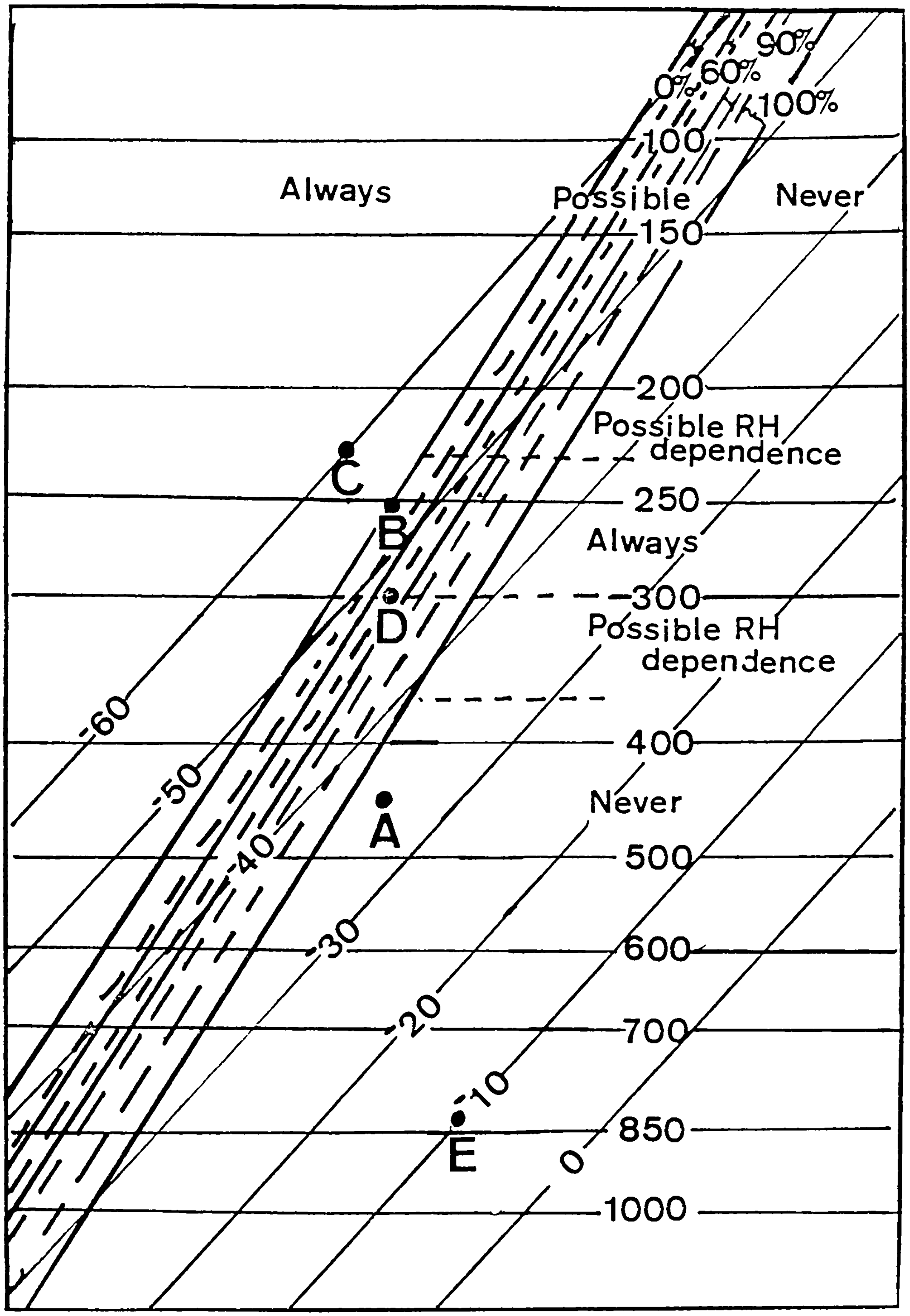


Figure 9

Illustration of contrail decisions: curves taken from the Chief of Naval Operations (1964).

E. Program

Table V Contrail Formation Program.

```
♦LBL "TRAILS"
CF 01
CF 02
"CHANGE FLAGS?"
PROMPT
♦LBL 10
TONE 1
"P=? MB"
FS? 21
PRA
PROMPT
FS? 21
PRX
STO 00
LN
STO 01
TONE 2
"T=? C"
FS? 21
PRA
PROMPT
FS? 21
PRX
STO 04
FC? 02
GTO 03
♦LBL 01
XEQ "RH"
XEQ "TC"
♦LBL 02
RCL 04
RCL 03
X>Y?
GTO C
♦LBL D
"NO CONTRAILS"
TONE 5
AVIEW
ADV
STOP
GTO 10
♦LBL C
"CONTRAILS"
TONE 8
AVIEW
ADV
STOP
GTO 10
♦LBL 03
FS? 01
GTO 11
"DO YOU KNOW"
AVIEW
PSE
"DEWPOINT, TD?"
AVIEW
PSE
"YES=ONE"
AVIEW
PSE
"NO=ZERO"
AVIEW
PSE
♦LBL 11
"KNOW TD?"
FS? 21
PRA
XROM 28,21
XROM 28,33
CHS
!
X=Y?
GTO 01
0
STO 02
XEQ "TC"
RCL 04
RCL 03
X>Y?
GTO C
100
STO 02
XEQ "TC"
RCL 03
RCL 04
X>Y?
GTO D
0
STO 02
RCL 00
225
X>Y?
GTO A
40
STO 02
300
RCL 00
X>Y?
GTO A
60
STO 02
FS? 01
GTO 12
"ARE THERE"
AVIEW
PSE
"CIRRUS AT"
AVIEW
PSE
"THIS LEVEL?"
AVIEW
PSE
"YES=ONE"
AVIEW
PSE
"NO=ZERO"
AVIEW
PSE
♦LBL 12
"CIRRUS?"
FS? 21
PRA
FS? 21
XROM 28,33
PRX
X=Y?
GTO A
XROM 28,33
40
STO 02
FS? 01
GTO 13
"DO YOU"
AVIEW
PSE
"KNOW FLOW?"
AVIEW
PSE
"YES=ONE"
AVIEW
PSE
"NO=ZERO"
AVIEW
PSE
♦LBL 13
"KNOW FLOW?"
FS? 21
PRA
FS? 21
PRX
XROM 28,33
X=0?
GTO A
FS? 01
GTO 14
"FROM MOIST"
AVIEW
PSE
"REGION"
AVIEW
PSE
"= ONE"
AVIEW
PSE
"FROM DRY"
AVIEW
PSE
"= ZERO"
AVIEW
PSE
♦LBL 14
"MST OR DRY?"
FS? 21
PRA
XROM 28,33
5
PRX
*
GTO 39
RCL 01
X<0?
♦LBL A
XEQ "TC"
RCL 03
RCL 04
-
ABS
2
X<=Y?
GTO 02
"PROBABLY"
AVIEW
PSE
GTO 02
♦LBL "RH"
RCL 04
273
+
XEQ "ES"
STO 02
TONE 3
"TD=? C"
FS? 21
PRA
FS? 21
PRX
XROM 28,33
273
+
XEQ "ES"
RCL 02
/
100
*
STO 02
RTN
♦LBL "ES"
1/X
CHS
273
1/X
+
2500
*
0.461
/
E↑X
6
*
RTN
♦LBL "TC"
-90.4994
STO 03
.5587
RCL 01
*
3.4232
+
RCL 01
*
ST+ 03
.0012
RCL 02
*
-.0372
+
RCL 02
*
ST+ 03
RTN
.END.
```

V. Determination of Lifting Condensation Level

A. Objective

Given a surface temperature, surface pressure and specific humidity, this program calculates the lifting condensation level.

B. Principles

The lifting condensation level (LCL) is the level to which a parcel of air can be lifted dry adiabatically before it becomes saturated. During the lifting process, the potential temperature of the air parcel and the saturation mixing ratio remain constant. The actual mixing ratio decreases and eventually equals the saturation mixing ratio. The lifting condensation level is obtained when the actual vapor pressure equals the saturation vapor pressure ($e = e_s$). Integrating the Clausius-Clapeyron equation from 273 K to air temperature (T)

$$\int_{273}^{T} \frac{de_s}{e_s} = \int_{273}^{T} \frac{L}{R_w} \frac{dT}{T^2}$$

where e_s is the saturation vapor pressure; L is the latent heat of condensation (2.5×10^6 J/kg); R_w is the gas constant for water vapor (462 J/kg °K); and T is the temperature (°K), results in the following expression for the saturation vapor pressure:

$$e_s = 6.11 \exp\left(\frac{L}{R_w}\left(\frac{1}{273} - \frac{1}{T}\right)\right).$$

Combining the hydrostatic equation and the ideal gas law and expressing the temperature as $T_o - \gamma z$ results in the following expression relating pressure (P) to height (z):

$$P = P_o \frac{(T_o - z)^{\frac{g}{R}\gamma}}{T_o}$$

where γ is the dry adiabatic lapse rate, T_o is the standard atmospheric temperature, w is the specific humidity and P_o is the standard atmospheric pressure. (w = .622 (e/P) ==> P = .622 e/w)

An expression for the actual vapor pressure (e) is obtained by using the definition of specific humidity and substituting the above expression in for P. The lifting condensation level is obtained when the following two equations are equal to each other:

$$e = \frac{wP_o}{.622} \frac{(T_o - \gamma z)^{\frac{g}{R}\gamma}}{T_o}$$

$$e_s = 6.11 \exp \left[\frac{L}{R_w} \left(\frac{1}{273} - \frac{1}{T_o - \gamma z}\right)\right]$$

After a series of substitutions, using Taylor series expansion of $\ln x \approx x-1$ and several algebraic manipulations, the following equation is derived giving the lifting condensation level:

$$z_{LCL} = T_o \left(102.041 - 14.6429 \left(23.3058 - \ln\left(\frac{wP_o}{3.80042}\right) - \left[\ln\left(\frac{wP_o}{3.80042}\right) - 23.3058^2 - \frac{75418.2}{T_o}\right]^{\frac{1}{2}}\right)\right)$$

Only surface data values of temperature (T_o), pressure (P_o) and specific humidity (w) are required to find the LCL.

C. User's Guide

1) Turn on calculator and set printer to the NOR mode.

2) [XEQ] LCL

3) Prompt reads, SFC TEMP °C?

4) Type in a surface temperature.

5) Press [R/S] to enter the temperature.

6) Prompt is SFC PRES MB?

7) Enter a surface pressure.

8) [R/S]

9) Prompt reads, SP HUMID G/G?

10) Enter a specific humidity value.

11) [R/S]

The lifting condensation level will appear with its value in meters. If the LCL occurs at the surface, the word SURFACE will be displayed.

D. Examples

Examples A, B and C in Table VI illustrate the use of the program "LCL" in estimating the lifting condensation level from a surface temperature, pressure and specific humidity. In example A, a surface temperature of 9°C, a surface pressure of 1010 mb, and a specific humidity of .006 g/g are entered in the "LCL" program. The data result in a lifting condensation level of 318.9m which is verified by a thermodynamic diagram. (See Figure 10.) In example B, the lifting condensation level occurs at the surface and in example C, the LCL is at 637.4 m.

Table VI
Examples of the Lifting Condensation Level Program.

A

```
SFC TEMP C?
         9.0000
SFC PRES MB?
     1,010.0000
SP HUMID G/G?
          .0060
LCL, M,=318.8959
```

B

```
SFC TEMP C?
          .5000
SFC PRES MB?
     1,000.0000
SP HUMID G/G?
          .0040
SURFACE
```

C

```
SFC TEMP C?
         6.0000
SFC PRES MB?
     1,020.0000
SP HUMID G/G?
          .0040
LCL, M,=637.3732
```

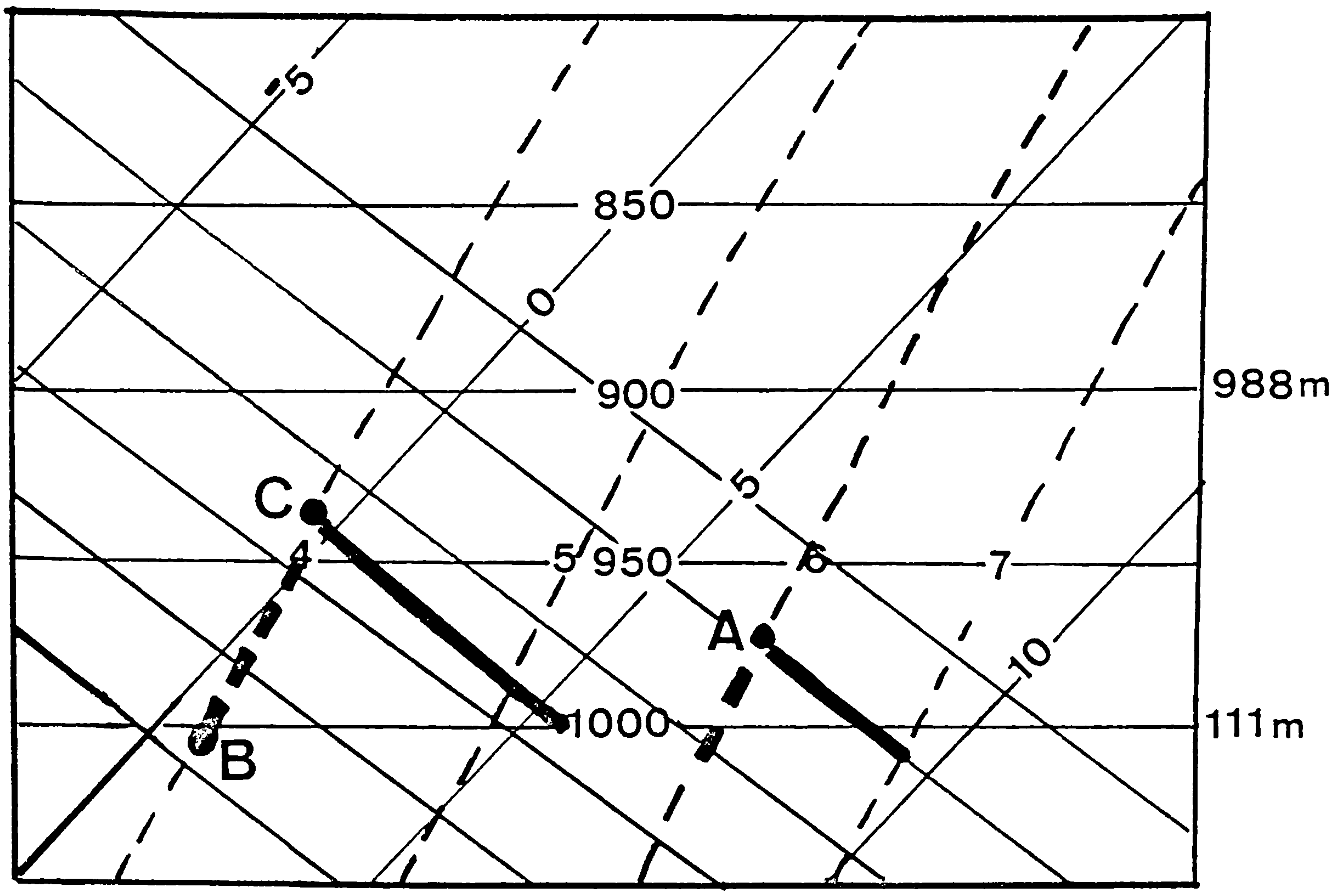


Figure 10

Lifting condensation levels determined by surface temperature, pressure and specific humidity.

E. Program

Table VII
Lifting Condensation Level Program.

```
01♦LBL "LCL"
02 23.3858
03 STO 25
04 "SFC TEMP C?"
05 PROMPT
06 273.15
07 +
08 STO 21
09 "SFC PRES MB?"
10 PROMPT
11 STO 22
12 "SP HUMID G/G?"
13 PROMPT
14 STO 23
15 RCL 22
16 *
17 3.80042
18 /
19 LN
20 STO 24
21 RCL 25
22 -
23 X↑2
24 75418.2
25 RCL 21
26 /
27 -
28 SQRT
29 STO 26
30 CHS
31 RCL 24
32 CHS
33 +
34 RCL 25
35 +
36 14.6429
37 *
38 102.041
39 X<>Y
40 -
41 RCL 21
42 *
43 STO 30
44 0
45 X<>Y
46 X<=Y?
47 GTO "SFC"
48 "LCL, M,="
49 ARCL 30
50 AVIEW
51 GTO "END"
52♦LBL "SFC"
53 "SURFACE"
54 AVIEW
55♦LBL "END"
56 .END.
```

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