WEATHER ANALYSIS PROGRAMS USING THE HP-41CV

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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.

1. INTRODUCTION

This paper describes four programs that can be programmed into the HP-41CV calculator. These programs deal 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 first problem, the estimation of surface wind at a point from a regional sea-level pressure analysis or forecast, 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 alternate solution: calculate 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 from a set of graphical tables. Using a tutorial program in a handheld 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 (3) graphical objective technique for forecasting 24-hr 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-hr 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 (4). 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. Entering values of surface temperature, surface pressure and specific humidity into 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.

2. 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 solving for the east-west (Ug) and north-south (Vg) components.
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:

$$\frac{\partial p}{\partial y} = \frac{P④ - P②}{222\ \text{km}} \; ; \; \frac{\partial p}{\partial x} = \frac{P① - P③}{222\ \text{km}}$$

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

$$|V_{gr}| = \frac{|V_g|}{.5 + \sqrt{.25 + V_g/fR}} \quad \text{where } R > 0 \text{ cyclonic}, \; R < 0 \text{ anticyclonic}$$

The user enters a radius of curvature (in kilometers) which is representative of the isobaric curvature in the forecast area. (See Fig. 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 (5) and the discussion of Petterssen (6) and Haltiner and Martin (7). Sheppard (5) and Mendenhall (8) 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. Examples

To illustrate the use of the program, the surface wind will be estimated for points A and B in Fig. 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, 1012 mb 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°).

3. DETERMINING THE PROBABILITY OF PRECIPITATION FOR MONTEREY, CALIFORNIA

a. Objective

This program will estimate the probability of 24-hr 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) nomogram method and statistics.

b. Principles

General Forecast Procedure. The probability of 24-hr 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 (ζm) and a point 8° latitude upstream from Monterey (ζ_8). Enter these values into a pre-established statistical table, which is stored in the calculator, to arrive at a forecast variable, Y_1. (See Fig. 4.)

A second forecast parameter, Y_2, is the value that results from taking the sea-level pressure difference between Monterey and Eureka (Δ Pm-Eureka) and Monterey and Las Vegas (Δ Pm-LV). (See Fig. 5). These two parameters, Y_1 and Y_2, are entered in a third table (Fig. 6) which results in a final value that corresponds to a probability of average rainfall for the Monterey Peninsula. Data to define the nomograms in Figs. 4, 5 and 6 are stored on HP-41 memory cards. The program asks for the appropriate card to determine Y_1, Y_2 and Y_3.

500 mb Geostrophic Relative Vorticity. To calculate the 500 mb geostrophic relative vorticity, five 500 mb heights are needed to use the finite differencing technique to solve ($\zeta m = g/f\nabla^2 z$) where ζm is the geostrophic relative vorticity at Monterey, and $\nabla^2 z$ is the Laplacian of the 500 mb height. For example, in Fig. 3 at Monterey (Zm = 558 dm) the four 500 mb heights are 552 dm (Zn: 500 mb height to the north), 566 dm (Zs), 560 dm (Ze), and 563 dm (Zw) with a grid spacing of 6° latitude. This results in a geostrophic relative vorticity of 1.8×10^{-5} sec^{-1}. The 500 mb geostrophic relative vorticity is computed for a point 8° latitude upstream (8° corresponds to a typical daily progression of shortwaves 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.

c. Example

The following example 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^{o} 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 Fig. 7.) Around Monterey, the 500 mb heights are 550.0 dm 6^{o} 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. These forecast variables result in a probability of precipitation of 90% as seen in Table 1. Rain did verify during the 24-hr period.

4. CONTRAIL FORMATION

a. Objective

This program will 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, 4).

b. Principles

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

$$Tcrit = a1 + a2 \ln p + a3(\ln P)^2 + a4\, RH + a5(RH)^2;$$

where:

p is the pressure level;
RH is the relative humidity;
$a1 = -90.4994$; $a2 = 3.4232$; $a3 = 0.5587$;
$a4 = -0.0372$; $a5 = 0.0012$.

This equation was determined from the curves in Fig. 8 of the Contrails Forecasting Manual (Chief of Naval Operations, 4).

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 (es) and relative humidity (R.H.) from the Clausius-Clapeyron equation.

If the dewpoint temperature is unknown, the relative humidty is estimated and a $\pm$ 2^{o}C error margin is assumed when computing the critical temperature. If the ambient temperature is within $\pm 2^{o}$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:

Tamb < Tcrit → (RH = 0) → contrails
Tamb > Tcrit → (RH = 100) → no contrails
P < 225 →(stratosphere) → RH ≈ 0%
p > 300 →(not in upper troposphere) → RH ≈ 40%
225 < p < 300→(upper troposphere) →RH ≈ 40% UNLESS
cirrus are at this level → RH ≈ 60%
flow is known and from
moist region → RH ≈ 60%
dry region →RH ≈ 0%

c. Examples

Examples A-E in Table 2 illustrate the use of the program "TRAILS" in deciding whether contrails will form from upper-level sounding data. The user has the option of setting two different flags. Setting Flag 01 makes the user prompts shorter and less specific. Setting Flag 02 means that the program assumes that the dew-point temperature is known and skips the questions concerning relative humidity estimation. In example A, where no flags have been set, a pressure of 450 mb and temperature of -35^{o}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 in Fig. 8. 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^{o}C, and dew point of -62.0^{o}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.

5. DETERMINATION OF LIFTING CONDENSATION LEVEL

a. Objective

Given a surface temperature, surface pressure and dew point, 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); Rw is the gas constant for water vapor (462 J/kg ^{o}K); and T is the temperature (^{o}K), results in the following expression for the saturation vapor pressure:

$$e_s = 6.11 \exp\left(\frac{L}{Rw}\left(\frac{1}{273} - \frac{1}{T_{(Td)}}\right)\right).$$

Combining the hydrostatic equation and the ideal gas law and expressing the temperature as To - γ 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 is the dry adiabatic lapse rate, To is the standard atmospheric temperature, w is the specific humidity and Po is the standard atmospheric pressure. w is computed from the dew point (Td).

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 ≈ x-1 and several algebraic manipulations, the following equation is derived giving the lifting condensation level:

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

Only surface data values of temperature (To), pressure (Po) and dew point (Td) are required to find the LCL.

6. SUMMARY

This paper described four programs developed for the programable handheld HP-41CV calculator to solve meteorological problems. The programs determine surface winds from MSL pressure analyses, regional precipitation probability from synoptic data, contrail decisions from sounding data and LCL from surface reports. For more details and program listings, the reader is directed to Wash and Spray (9).

ACKNOWLEDGEMENTS

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FOOTNOTES AND REFERENCES

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3. Renard, R. J., 1972: An objective method of forecasting precipitation for Monterey, California, unpublished manuscript, Dept. of Meteorology, Naval Postgraduate School, Monterey, CA, 13 pp.

4. Chief of Naval Operations, 1964: Contrails Forecasting Manual. NAVWEPS 50-IP-522. (available from C. Wash, Naval Postgraduate School, Monterey, CA.)

5. Sheppard, P. A., 1969: Atmospheric boundary layer. The Global Circulation of the Atmosphere, ed., G. Corby, Royal Meteorological Society, London, England, 91-112.

6. Petterssen, S., 1956: Weather Analysis and Forecasting, Vol I, Motion and Motion Systems. McGraw-Hill, New York.

7. Haltiner, G. J. and F. L. Martin, 1957: Dynamical and Physical Meteorology. McGraw-Hill, New York.

8. Mendenhall, B. R., 1967: A statistical study of frictional wind veering in the planetary boundary layer. Colorado State Univ Atmos Sci Paper, No. 116.

9. Wash, C. H. and L. A. Spray, 1984: Weather Analyses Programs using HP-41CV. Technical Report NPS63-84-008. Department of Meteorology, Naval Postgraduate School, Monterey, CA, 40 pp.

Table 1

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

ENTER ZN:8		
	541.	
ENTER ZE:8		
	543.	ENTER PRES MONT
ENTER ZS:8		1,018.8
	562.5	ENTER PRES LVGS
ENTER ZW:8		1,006,2000
	563.	ENTER PRES ERKA
ENTER Z0:8		1,017,3000
	555.	X1= 1,018.0000
ENTER ZN:M		X2=-33.0000
	548.	X3= 2.0000
ENTER ZE:M		X4= 14.0000
	554.	INSERT CRD 13
ENTER ZS:M		Y1=-20.0000
	569.5	INSERT CRD 3
ENTER Z0:M		Y2= 25.0000
	570.5	90.0000
ENTER Z0:M		
	555.	

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

Table 2
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
Td 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, Td 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
Td unknown

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 Td

E

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

Flag 02 set
Td known

c. Examples

Examples A, B and C in Table 3 illustrate the use of the program "LCL" in estimating the lifting condensation level from a surface temperature, pressure and dew point. In example A, a surface temperature of 9°C, a surface pressure of 1010 mb, and a dew point of 6.6°C are entered in the "LCL" program. The data result in a lifting condensation level of 318.9 m which is verified by a thermodynamic diagram in Fig. 9. In example B, the lifting condensation level occurs at the surface and in example C, the LCL is at 637.4 m.

Table 3
Examples of the Lifting Condensation Level Program.

A

```
SFC TEMP C?
        9.0000
SFC PRES MB?
    1,010.0000
SFC DEWPT?
        6.6000
LCL, M=318.8959
```

B

```
SFC TEMP C?
         .5000
SFC PRES MB?
    1,000.0000
SFC DEWPT?
         .5000
SURFACE
```

C

```
SFC TEMP C?
        6.0000
SFC PRES MB?
    1,020.0000
SFC DEWPT?
        1.0000
LCL, M=637.3732
```

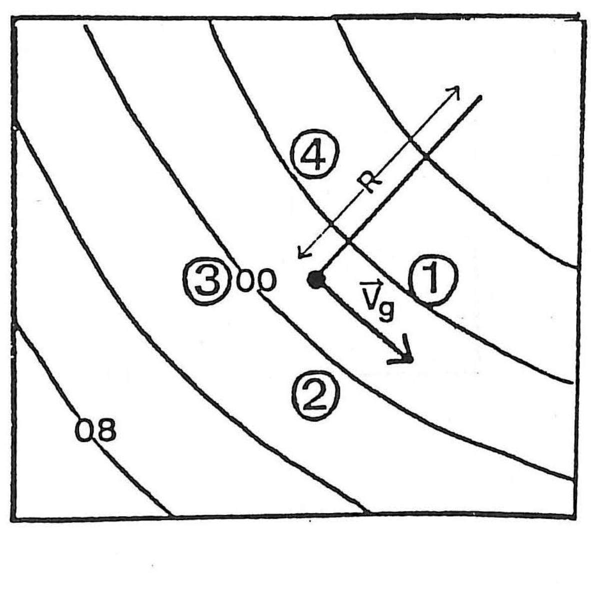

Fig. 1— Geostrophic wind ($\vec{V_g}$) computed by the finite differencing scheme with 1° latitude grid spacing.

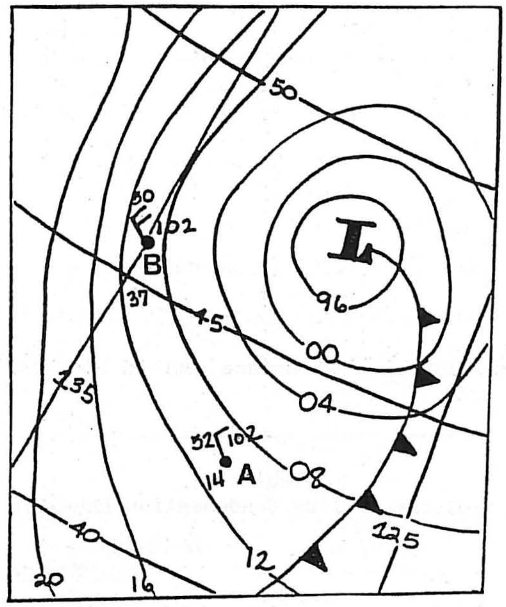

Figure 2. Surface conditions observed at 0000Z 26 November, 1981 for illustration of surface wind program.

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?                              24.
                46.     GEO. DIR FROM:
CTR LON?                             295.
               135.     RADIUS?
PRS NO LAT?                    1,300,000.
             1,008.     GRAD. SPEED:
PRS SO LAT?                           21.
             1,011.     LAND OR SEA?
PRS EAST LAT?                         SEA
           1.006.5      SFC SPEED:
PRS WEST LAT?                         17.
             1,013.     SFC DIR FROM:
                                     285.
```

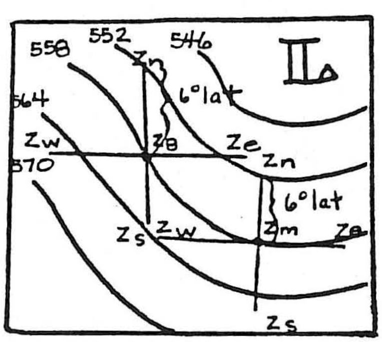

Figure 3. Computation of geostrophic relative vorticity for Monterey (ζ_m) and a point 8^{o} latitude upstream (ζ_8).

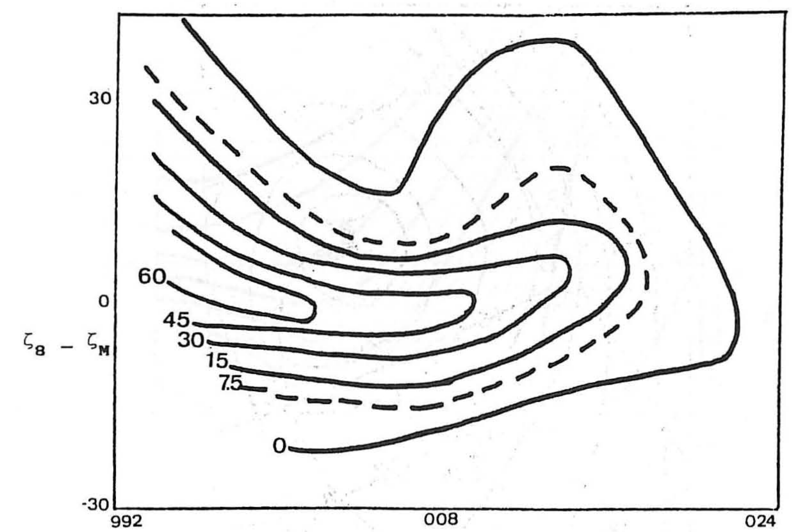

Figure 4. Y_1 = f(Peureka, $\zeta_8 - \zeta m$): first forecast factor of the raincaster.

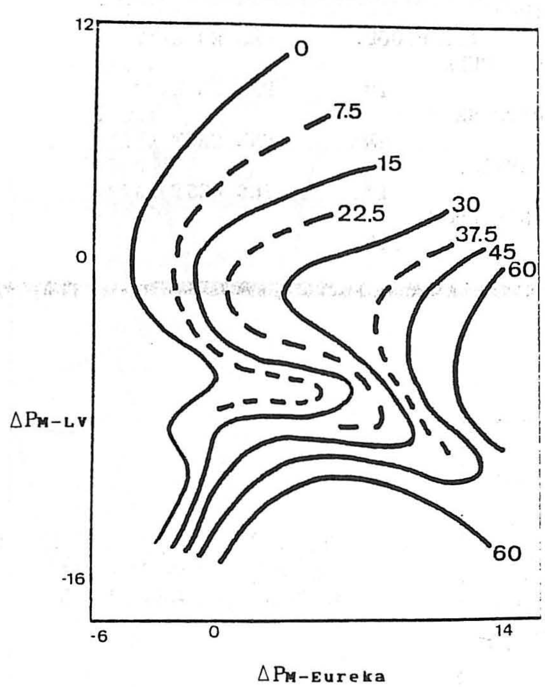

Figure 5. Y_2 = f(Δ Pm-Eureka, Δ Pm-LV): second forecast factor of the raincaster.

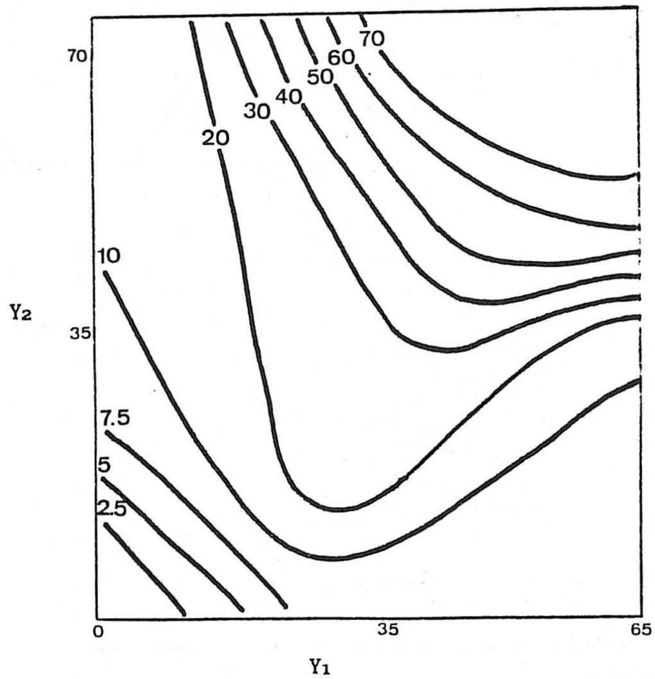

Figure 6. $Y_3 = f(Y_1,Y_2)$: third forecast factor of the raincaster.

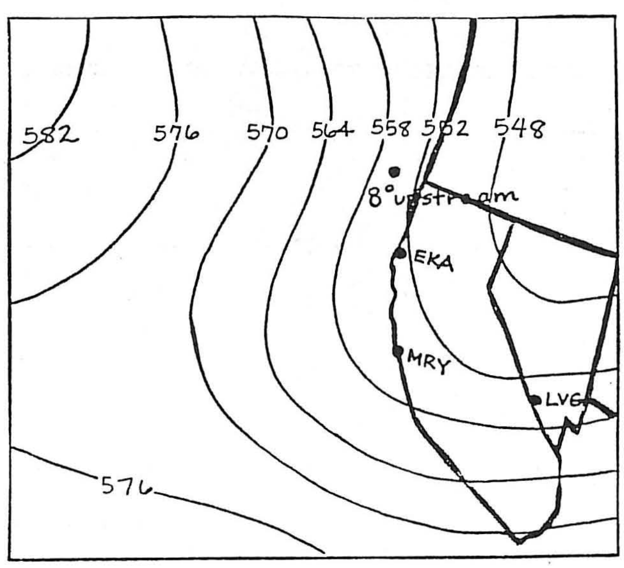

Figure 7. 500 mb analysis for 1200Z 25 November 1981.

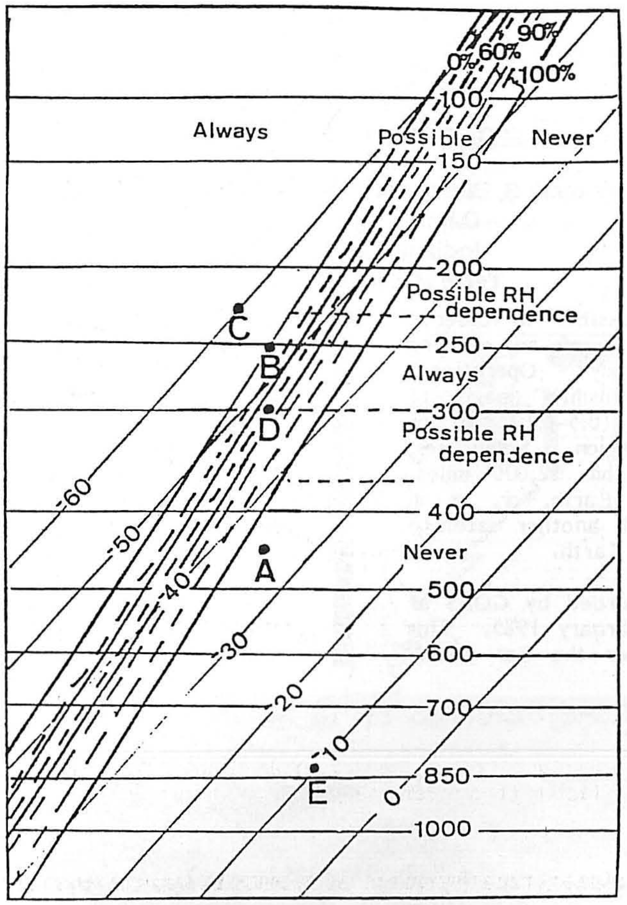

Figure 8. Illustration of contrail decisions; curves taken from the Chief of Naval Operations (1964).

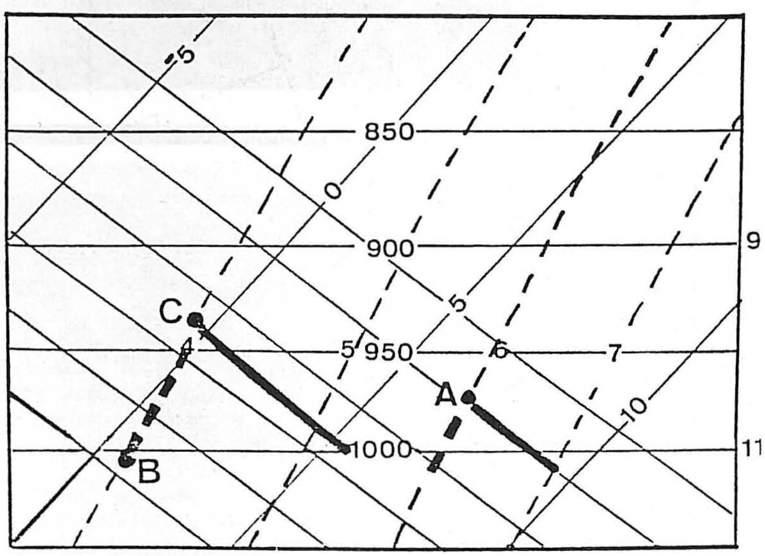

Figure 9. Lifting condensation levels determined by surface temperature, pressure and dew point.