NOAA Technical Memorandum NWS WR-128

HAND CALCULATOR PROGRAM TO COMPUTE PARCEL THERMAL DYNAMICS

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April 1978

UNITED STATES
DEPARTMENT OF COMMERCE
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ATMOSPHERIC ADMINISTRATION
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I. INTRODUCTION

This program computes the temperature of an air parcel raised dry adiabatically to the lifted condensation level, LCL, and then pseudo-adiabatically thereafter. The procedure is accomplished without aid of an energy diagram (Skew-T, Pseudo-adiabatic chart, etc.) using iterative computations on a Hewlett-Packard 67 hand computer. The iterative computations involve using finite difference to solve the energy balance equation for the ascending parcel. The program can be used in lieu of an energy diagram for computation of atmospheric stability indices (e.g., determination of a thunderstorm gust potential). A sample problem and a computer program are in Appendix I.

II. VARIABLE DEFINITION

t	=	temperature - °C
t_d	=	dew-point temperature - °C
D	=	dew-point depression - °C
T	=	temperature - °K
p	=	pressure - mb
L_v	=	latent heat of vaporization - j/g
e_s	=	saturation vapor pressure of water at a given temperature - mb
R_a	=	gas constant for dry air - .287 j/g°K
R_v	=	gas constant for moist air - .461 j/g°K
c_p	=	specific heat at constant pressure for dry air - 1.003 j/g°K
m_v	=	molecular weight of water - 18 g/g-mole
m_d	=	apparent molecular weight of dry air - 28.9 g/g-mole
γ_m	=	pseudo-adiabatic lapse rate - °K/mb
$dT/dp)_m$	=	pseudo-adiabatic lapse rate (finite difference) - °K/mb
ΔP	=	change in pressure - mb
w	=	saturation mixing ratio
c	=	specific heat of liquid water

III. EQUATIONS

1. Use simplified Haurwitz' equation [1] to obtain LCL temperature.

$$T_{LCL} = t_d - (0.212 + .001571\ t_d - .000436\ t)\ D$$

2. Use Poisson's equation to determine LCL pressure.

$$P_{LCL} = P\ (T_{LCL}/T_o)^{c_p/R_a} \qquad c_p/R_a = 7/2$$

T_o = initial temperature - °K

P = initial pressure - mb

3. Formula #184, p. 376 [2] is

$$c_p \frac{dT}{T} - R_a \frac{d(p-e_s)}{p-e_s} + d\left(\frac{wL}{T}\right) + cw\ \frac{dT}{T} = 0\ . \qquad (\#184)$$

Differentiating #184 and applying some simplifying assumptions yields the equation for a lapse rate in a saturated atmosphere, equation #190, p. 377 [2].

$$\gamma_m = \Delta T/\Delta P)_m = \left(\frac{R_a T}{c_p p}\right) \frac{P + \dfrac{0.622 L_v e_s}{R_a T}}{P + \dfrac{0.622 L_v^2 e_s}{c_p R_v T^2}} = °K/mb \qquad (\#190)$$

4. Teton's formula #63, p. 343 [2] is used to derive the saturation vapor pressure, e_s.

$$e_s = 6.11 \times 10^{at/b+t}$$

where a = 7.567 and b = 239.7 are based on the assumption that liquid water is present in the atmosphere below 0°C. This same assumption is used in the derivation of standard energy diagrams.

5. Since L_v changes with temperature, a linear interpolation is incorporated into the program to account for $\Delta L_v/\Delta T$. With L_v = 2358.12 j/g at 60°C., L_v = 2634.88 j/g at -50°C, the range of temperature = 110°K,

and the difference in L_v between the two temperatures being 276.76 j/g, the proportion for the linear interpolation is established.

$$(333°K - T_o) / 110°K = X/(276.76 \text{ j/g}) \qquad L_o = X + L_v$$

where T_o = temperature of the current iteration – °K

L_v = 2358.12 j/g

L_o = computed L_v for T_o

X = proportion resultant relating L_o and L_v.

6. Computational iterations are accomplished by finite differencing as follows:

a) $T_m^H - T_m^L + \Delta P\ (\chi)$

where χ = right hand side of equation #190, p. 377 [2].

b) $P_m^H = P_m^L + \Delta P$

where T_m^H = new computed temperature (higher atmospheric level)

T_m^L = old computed temperature (lower atmospheric level)

P_m^H = pressure level of new temperature (higher atmospheric level)

P_m^L = pressure level of old temperature (lower atmospheric level)

ΔP = $P_m^H - P_m^L$.

IV. LOGIC

1. As the program begins execution, the pressure and temperature of the LCL are computed and stored.

2. Computational iterations proceed adiabatically, checking the computed temperature and pressure against the LCL temperature and pressure.

3. At the LCL, the computer continues ascending parcel parameter computations but now accounts for diabatic effects.

4. The program stores temperature and pressure at the LCL as well as any other two levels as specified by the programmer.

5. The program terminates at the highest level at which temperature data are desired.

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