What is Convective Parameterization?

A technique used in NWP to predict the collective effects of (many) convective clouds that may exist within a single grid element

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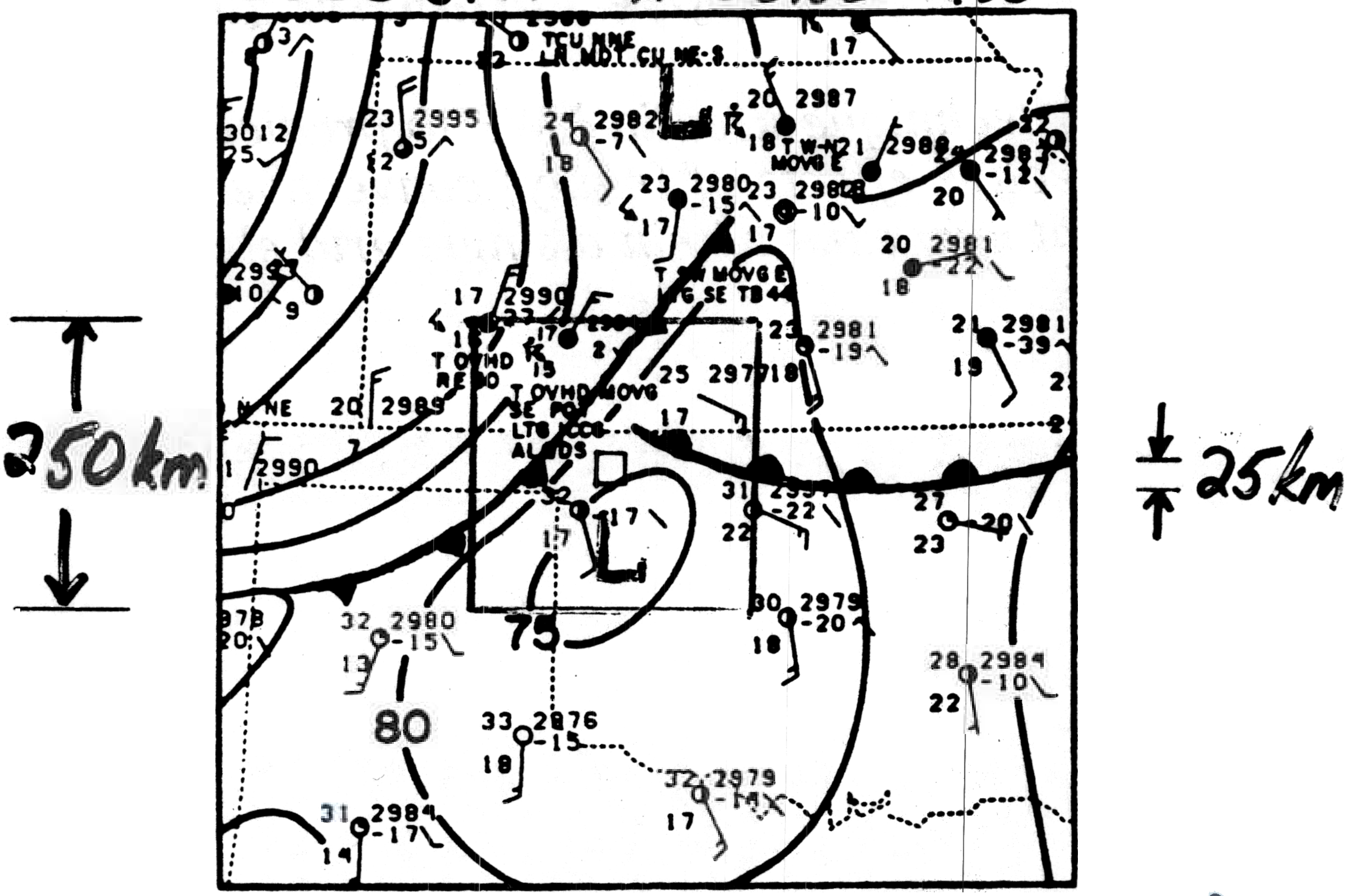
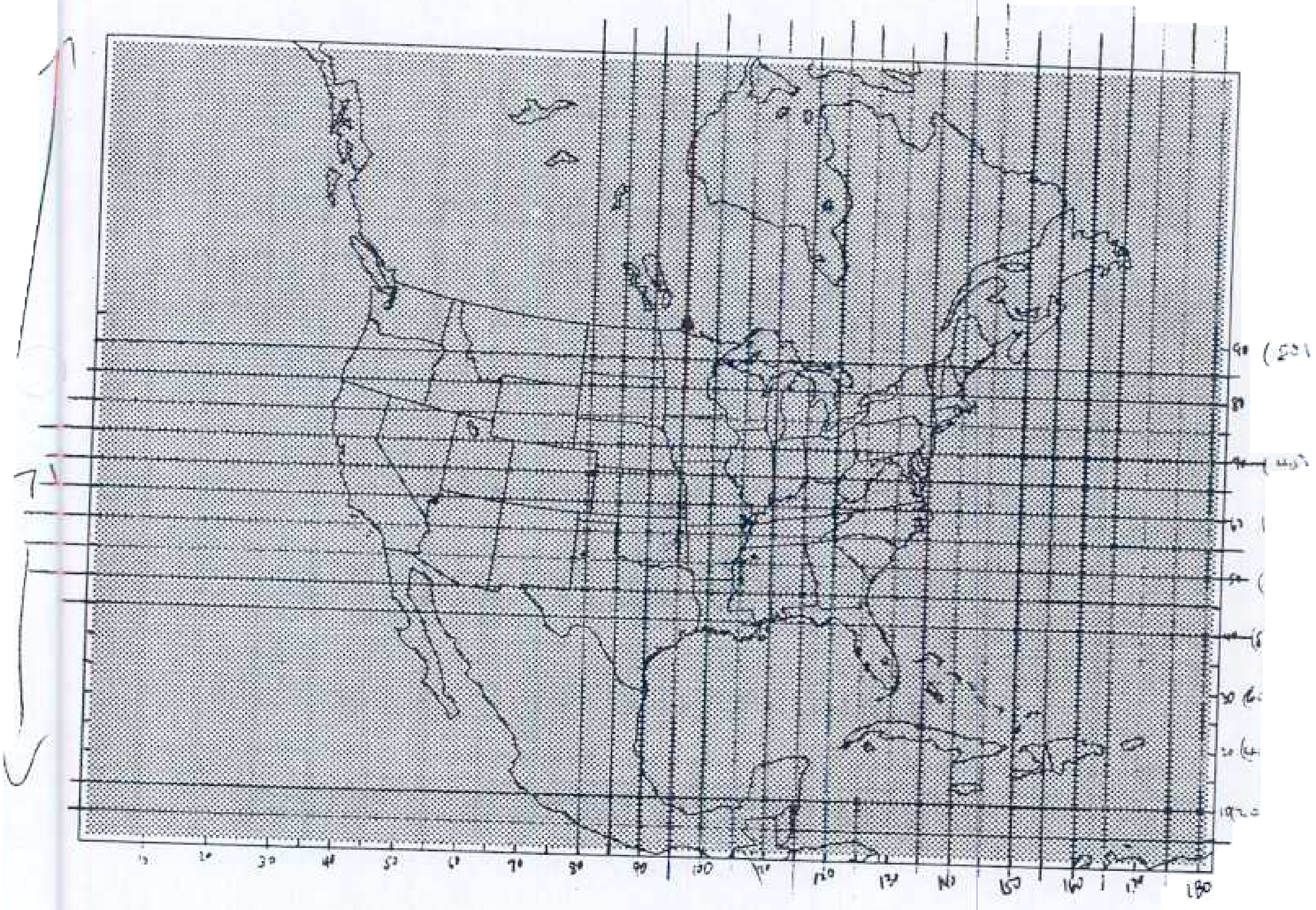


(JOHNSON & HAMILTON, 1988)

ETA GRID H POINTS



181 (mass)

I

I=54
J=108

I=93
J=120

I=106
J=115

I=80
J=104

Why do NWP models need to worry about it?

- ***Direct Concern:*** *To predict convective precipitation*

- ***Feedback to Larger Scales:*** *Deep convection "overturns" the atmosphere, strongly affecting mesoscale and larger scale dynamics:*

  Changes vertical stability

  - redistributes and generates heat

  - redistributes and removes moisture

  - Makes clouds, strongly affecting surface heating and atmospheric radiation

How Does the Feedback Occur in a Model?

...At every model grid point, predictive variables change each time step as a function of a number of processes, including convection...

temperature

$$\frac{d\theta}{dt} = \boldsymbol{P}_{\text{rad}} + \boldsymbol{P}_{\text{conv}} + \boldsymbol{P}_{\text{cond/evap}} + \boldsymbol{P}_{\text{hdiff}} + \boldsymbol{P}_{\text{vdiff}} + \boldsymbol{P}_{\text{sfc}}$$

where

$$\frac{d\theta}{dt} = \frac{\partial\theta}{\partial t} + u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y} + \omega\frac{\partial\theta}{\partial p}$$

water vapor

$$\frac{dq_v}{dt} = + \boldsymbol{P}_{\text{conv}} + \boldsymbol{P}_{\text{cond/evap}} + \boldsymbol{P}_{\text{hdiff}} + \boldsymbol{P}_{\text{vdiff}} + \boldsymbol{P}_{\text{sfc}}$$

u (and v)-momentum

$$\frac{du}{dt} + \frac{1}{\rho}\frac{\partial p}{\partial x} - fv = (\boldsymbol{P}_{conv}) + \boldsymbol{P}_{hdiff} + \boldsymbol{P}_{vdiff} + \boldsymbol{P}_{sfc}$$

...When activated, a convective parameterization computes the changes in Temperature and Moisture (possibly cloud water, momentum, etc.) that would occur at each vertical level if convection developed in the given grid-point environment...

for example,

$$\left.\frac{\partial \theta}{\partial t}\right|_{conv} = \frac{\theta_{final} - \theta_{initial}}{\tau_c} = P_{conv}$$

where τ_c is a convective time scale, typically 30 mins. to 1 hr.

How to Parameterize...

- Relate unresolved effects (convection) to grid-scale properties using statistical or empirical techniques

- What properties of convection do we need to predict?

  - *convective triggering* (YES/NO)

  - *convective intensity (how much rainfall/heating?)*

  - *vertical distribution of heating*

  - *vertical distribution of drying*

When, Where, and How much...

- ***Triggering*** *(always requires positive area on a thermodynamic [e.g., Skew-T, Log-P] diagram)*

Different approaches; **either**

- *Mass or moisture convergence threshold exceeded at a grid point,* ***or***

- *Positive destabilization rate,* ***or***

- *Perturbed parcels can reach their level of free convection*

- CLOUD-LAYER MOISTURE IS SUFFICIENT

- ***Convective Intensity*** *(net heating)*

either

- *Proportional to mass or moisture convergence,* ***or***

- *Sufficient to offset large-scale destabilization rate,* ***or***

✓ - *Sufficient to eliminate CAPE* (CONSTRAINED BY AVAILABLE MOISTURE)

- ***Vertical distribution of heating and drying***

  either

  determined by nudging to empirical reference profiles, ***or***

  - estimated using a simple 1-d cloud model to satisy the constraints on intensity

Schemes based on mass, moisture convergence (e.g., Kuo-type schemes)

IF:

1.) Atmosphere is conditionally unstable;

2.) Horizontal moisture (or maybe mass) convergence is positive

THEN:

3.) Converged moisture is assumed to go up in deep convective clouds (rather than broadscale ascent)

4.) Convective heating is distributed vertically according to the distribution of T′ - T, where T′ is the temperature on the moist adiabat of most-unstable air.

5.) Moisture is all condensed out (or a specified fraction is condensed out.

Quasi-Equilibrium Schemes (i.e., Arakawa-Schubert)

- Large-Scale destabilization rate ≈ Convective Stabilization Rate
- Convective Stabilization is Achieved by an Ensemble of Clouds

Current EMC Operational Models all use Different Approaches to Convective Parameterization...

RUC II: *Grell scheme**

Eta: *Betts-Miller-Janjic scheme**
(Kain-Fritsch used on an experimental basis)*

MRF/AVN: *Grell-Pan scheme**

The Grell, Grell-Pan, and Kain-Fritsch schemes are* ***Mass-Flux schemes**, meaning that they use simple cloud models to simulate rearrangements of mass in a vertical column.*

**The Betts-Miller-Janjic scheme adjusts to "mean post-convective profiles" based on widespread observations.*

Grell and Grell-Pan Schemes:
(basic operating principles)

1.) Initiation (on/off switch)

- Find highest θe air in column below ~ 400 mb level...does CAPE exist for this air?

- Is CAP too strong? How far does parcel have to be lifted to reach LFC?
  Is P(source) - P(LFC) less than 150 mb?

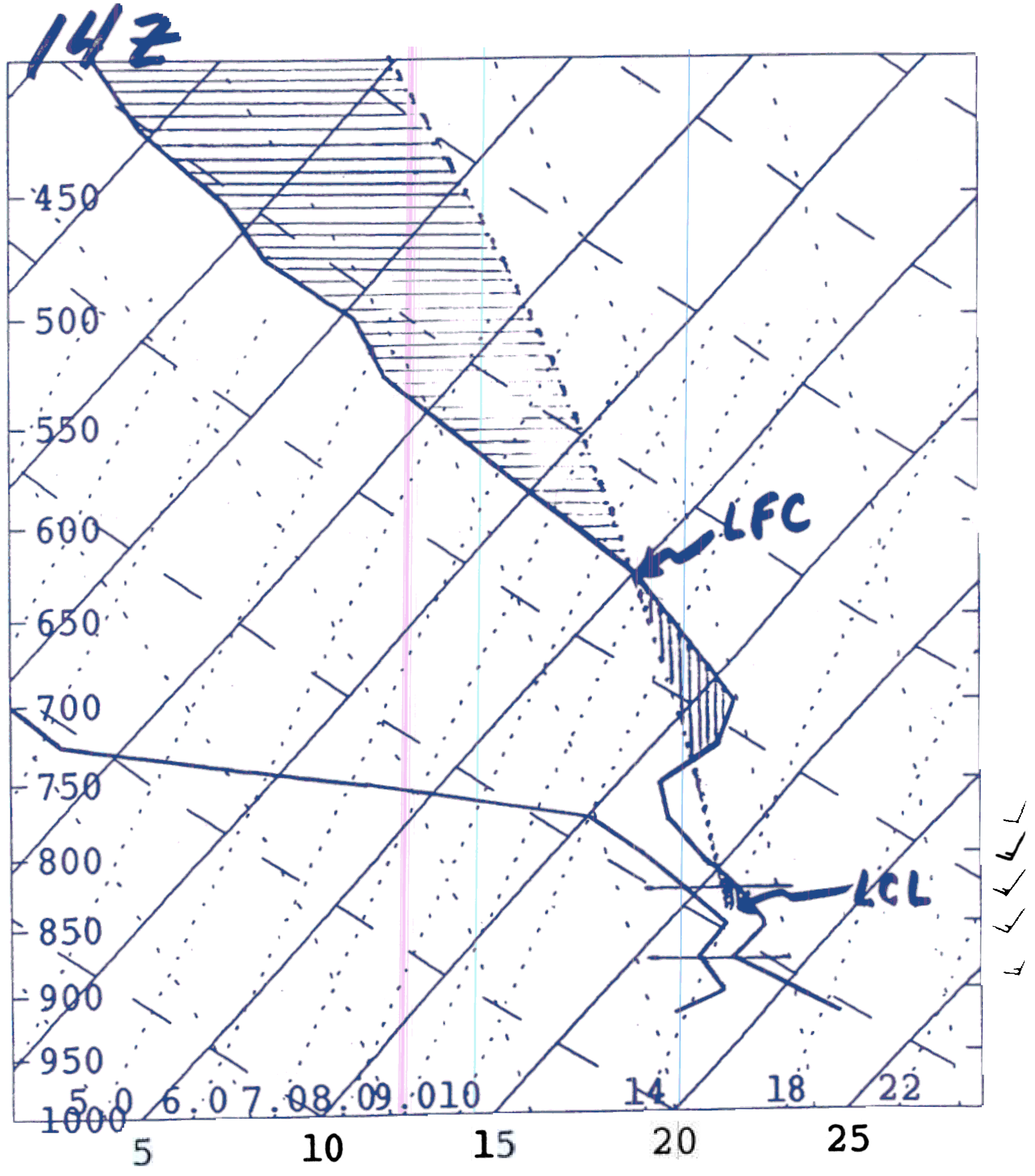
  Is large-scale destabilization rate positive?
  i.e., is d(CAPE)/dt > 0?

  If yes to all 3, initiate convection..

2.) Characteristics of Convection

- use simple models of an updraft and downdraft to simulate mass rearrangements by convection

- make updraft and downdraft mass fluxes strong enough that their stabilizing effect approximately balances rate of large-scale destabilization:



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20
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LFC
LCL

Grell and Grell-Pan Schemes: (basic operating principles) (cont.)

$$\left[\frac{d(\mathrm{CAPE})}{dt}\right]_{\mathrm{convection}} \approx -\left[\frac{d(\mathrm{CAPE})}{dt}\right]_{\mathrm{large-scale}}$$

3.) Feeding back the effects of convection

- Introduce introduce tendency terms in the prognostic equations for temperature and moisture:

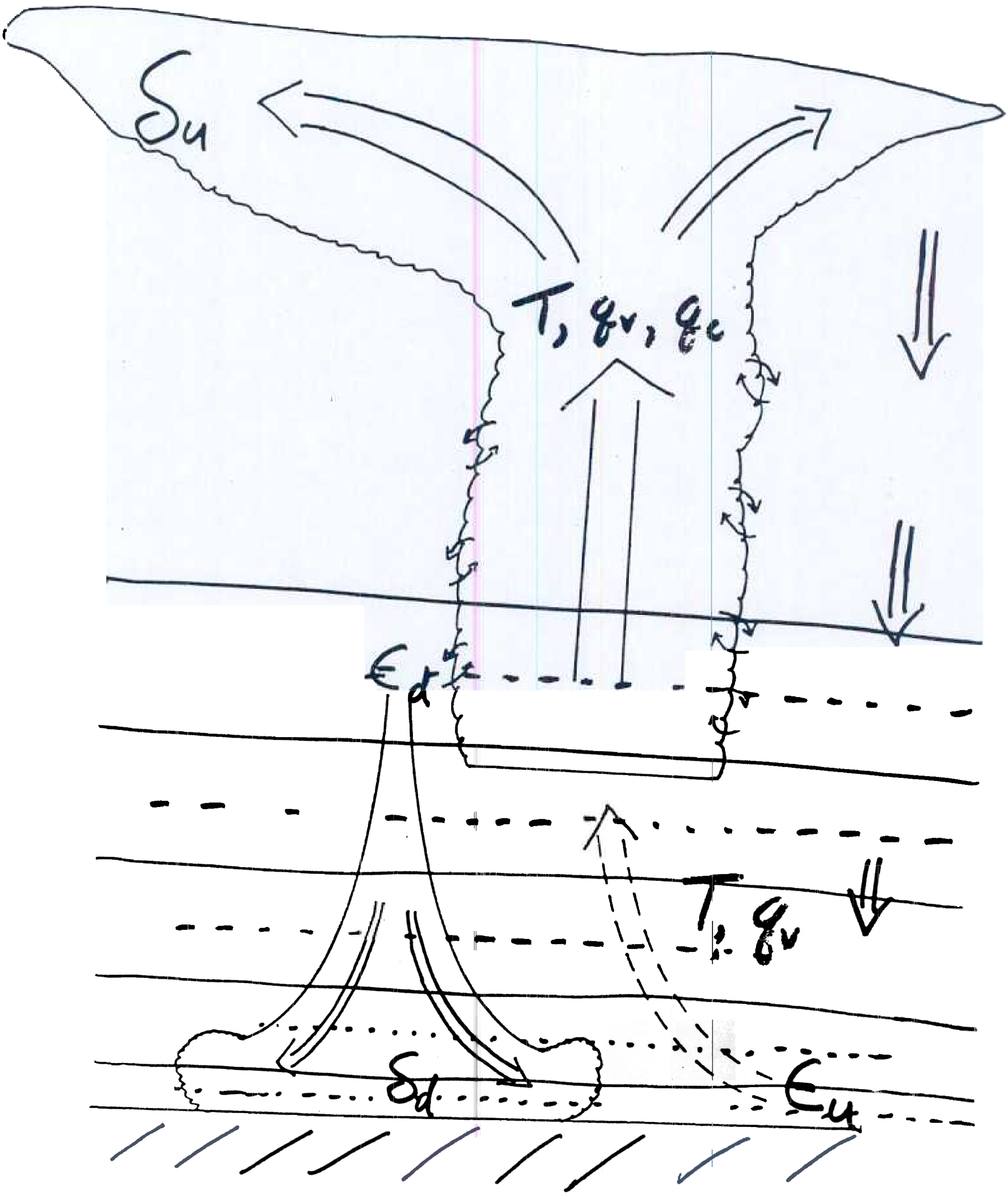
$$\left.\frac{\partial \alpha}{\partial t}\right|_{\mathrm{conv}} = \frac{\alpha_{\mathrm{final}} - \alpha_{\mathrm{initial}}}{\tau_c},$$

where α represents T or q_v

Kain-Fritsch Scheme...

basic operating principles are similar to Grell-type schemes, except...

- Convective inhibition evaluated in terms of negative area, not just pressure depth
- Large-scale destabilization not required, only CAPE
- Updraft and downdraft formulations more sophisticated
- Convective intensity based on instantaneous CAPE value rather than d(CAPE)/dt



δ_u
T, q_v, q_c
ϵ_d
T, q_v
δ_d
ϵ_u

Kain-Fritsch convective initiation check

• *Beginning at the surface, mix in model layers overhead until a mixture 50-100 mb deep is found. This comprises a* ***potential*** *updraft source layer. Find mean* θ, q_v *of this layer.*

• *Lift a parcel with these characteristics to its LCL. At the LCL, Compute a temperature perturbation,* ΔT_p *based on grid-point vertical velocity:*

$$> \quad \Delta T_p = \left(w_g - w_c\right)^{1/3} + \Delta T_p(RH)$$

where w_g is the grid point vertical velocity (cm/s)
w_c is a correction factor:

$$w_c = 2. * Z(LCL)/2 \text{ km}$$

For Example:

$w_g - w_c$		ΔT_p
1 cm/s	>>>	1.0 K
10 cm/s	>>>	2.15 K

In the Eta model, an additional perturbation, $\Delta T_p(RH)$, of magnitude ~ 0.5 K is given to account for low RHs in the model

So...In a typical convective environment with some larger-scale forcing , ΔT_p *~ 1 - 2 K*

Kain-Fritsch convective initiation check
(cont.)

- Is $(T_p(LCL) + \Delta T_p) > T_g$????

  > If no, move up one model level and repeat the process above

- If yes, then compute a vertical velocity perturbation, W_p, based on magnitude of ΔT_p.
  For $\Delta T_p = 1.5K$, $W_p \approx 4 - 5$ m/s

- Release a parcel at the LCL with temperature given by $T_p(LCL)$ and vertical velocity given by W_p, begin solving "parcel buoyancy equation" at sequential model levels overhead

- Determine cloud top as the highest model level at which $W_p > 0$.

- Is Z(top) - Z(LCL) > 3 km?

  > If yes, initiate deep convection from this source layer

  > If no, remember this layer as a possible source for shallow convection, move up to next potential source layer and repeat all above steps.

- If no potential source layer in lowest 300 mb can generate a convective cloud, move on to the next grid point...

The stabilizing mechanisms of the Kain-Fritsch scheme

- Convective Updraft

> Removes high θ_e air from lower troposphere, transports it aloft.
> Generates condensation

- Convective Downdraft

> Draws mass from layer beginning at cloud base and extending up 150 - 200 mb.

> Deposits low θ_e air in subcloud layer

> Assumed to be saturated above cloud base, RH decreasing at ~ 10%/km below cloud base.

> Continues until it either 1.) reaches the surface, or 2.) becomes warmer than the environment.

> Mass flux ≈ updraft mass flux at cloud base.

- Return flow, i.e., "compensating subsidence"

> Compensates for any mass surplus or deficit created by Updraft and Downdraft...Typically, the updraft creates a mass surplus aloft and deficit below so that this return flow is downward

KF Scheme: How much precip is generated?

It depends...

> ***> Updraft generates condensate***
>
> ***> Updraft dumps condensate into environment***
>
> ***> Downdraft evaporates condensate at a rate that depends on:***
>
> - RH of downdraft source air
> - Depth of downdraft
>
> ***> Leftover condensate accumulates at surface as Precipitation***

KF scheme: How does it affect resolved flow?

> Heating, Drying, and precipitation tendencies are fed back to resolved-scale equations over a time period of 30 mins to 1 hour.

)

Betts-Miller scheme:
(basic operating principles)

- Checks for CAPE - highest θ_e air in the lowest ~~500~~ 130 mb

- makes a first guess at an "adjusted" temperature profile based on a moist adiabat

- makes a corresponding first guess at a reference *moisture* profile, based on an imposed *sub*saturation (~ relative humidity)

imposes enthalpy conservation:

$$\int_{sfc}^{top} L_v dq_v = \int_{sfc}^{top} C_p dT$$

This usually requires an adjustment ("sliding over" on a skew-T) of both temperature and moisture.

Implications of this adjustment:

- *Betts convection will be weak (or non-existent) when column-mean relative humidity is low even if CAPE is present, will increase in intensity as column moistens.*

- Nudges grid-scale T, q_v to convectively adjusted values over a specified time period (~ 1 hour)

BETTS M ER - JANJIC

ETA MODEL ONVECTIVE PARAMETERIZAT N

Equilibrium assumption

Convective precipitation acts to move a convectively unstable atmosphere toward some equilibrium state (such as a moist adiabatic lapse rate)

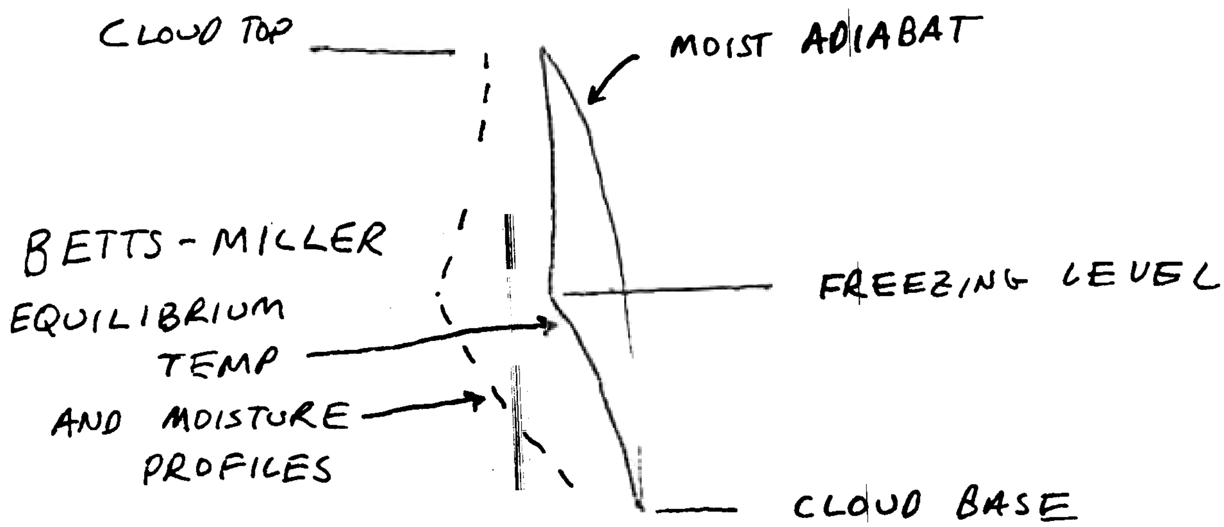
Different schemes define the equilibrium state in different ways

- moist adiabat
- modification of a moist adiabat
- results from a cloud model

Convective - equilibrium type

Betts-Miller scheme

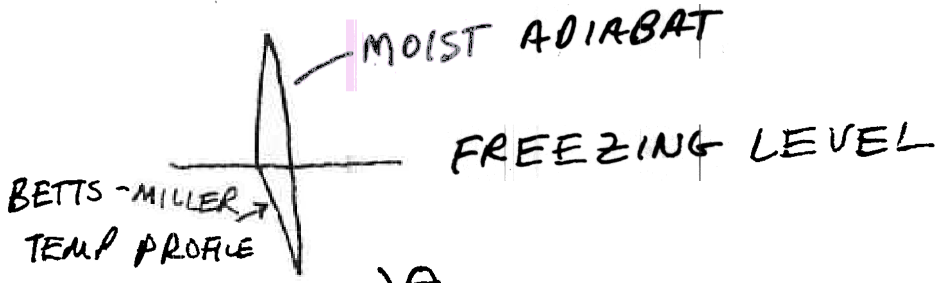
the equilibrium profile is a modified moist adiabat



moisture profile is determined by saturation point deficits (DSP's)

How the equilibrium (reference) profile is computed.

Temperature



slope of profile is 0.85 $\frac{\partial \theta_e}{\partial p}$ below the freezing level

profile is connected to original θ_e at cloud top, making it more stable than a moist adiabat above freezing level

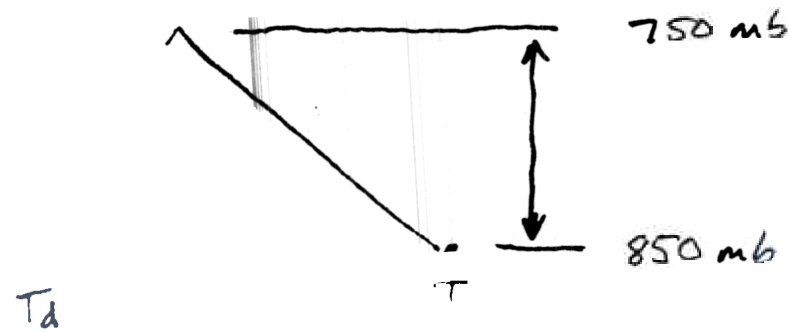
profiles based upon observational evidence

Saturation point deficit (DSP) is similar to dewpoint depression

It is the pressure change that a parcel must undergo in adiabatic expansion to reach saturation

For example

a parcel at 850 mb with a temperature of 10°C and a RH of 60%



would have a DSP of -100 mb

Moisture

critical DSP's are specified

		TYPICAL RH
cloud ~~base~~ TOP	-22.5	40-50%
freezing level	-70.5	60-70%
cloud ~~top~~ BASE	-48.5	~80%

different sets are used over land and sea

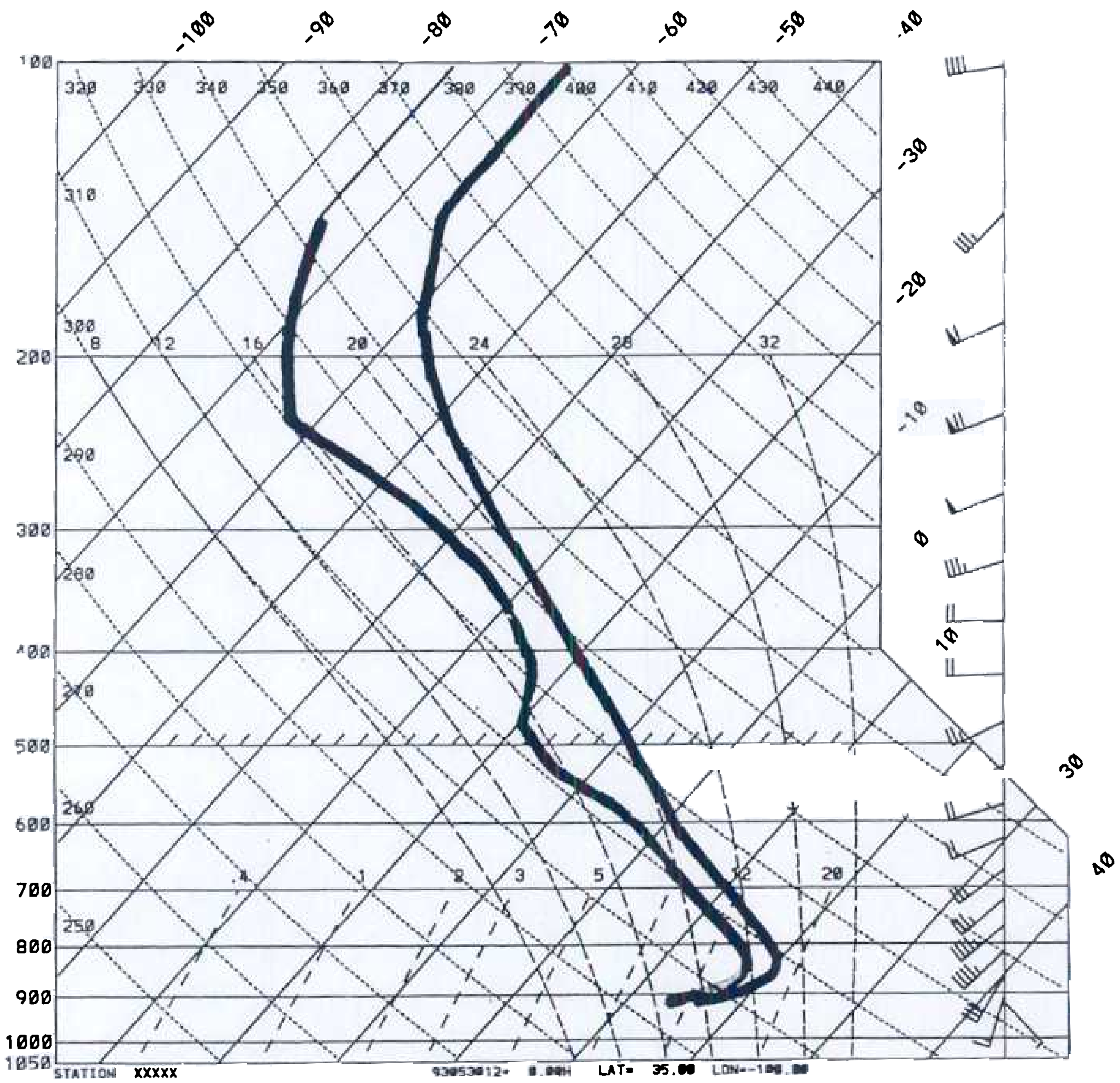
land

drier (larger)
easier to
to produce
precipitation

sea

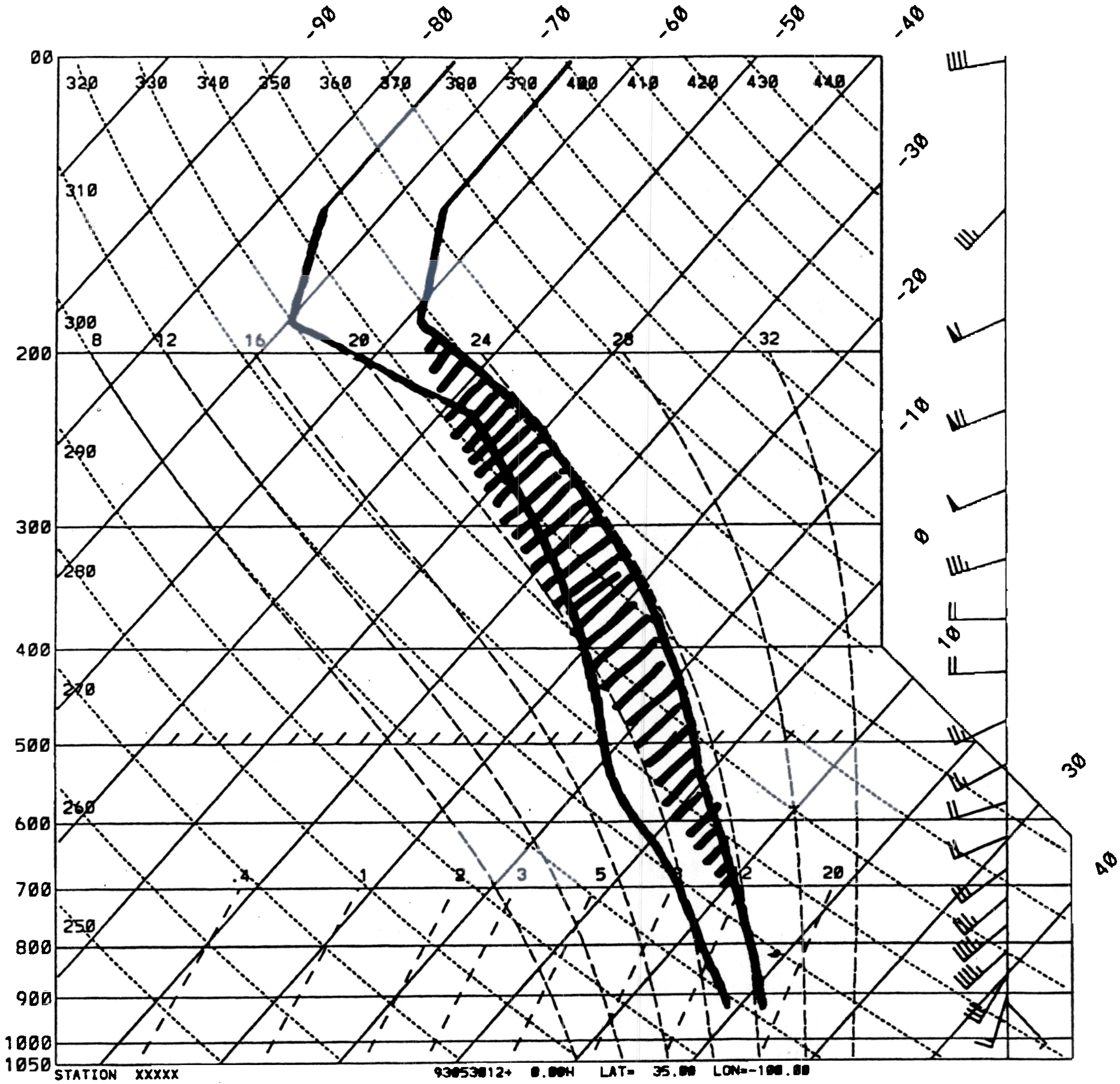
moister (smaller)
more difficult
to produce
precipitation

these are modified by "cloud-efficiency" as well



INPUT SOUNDING

BETTS



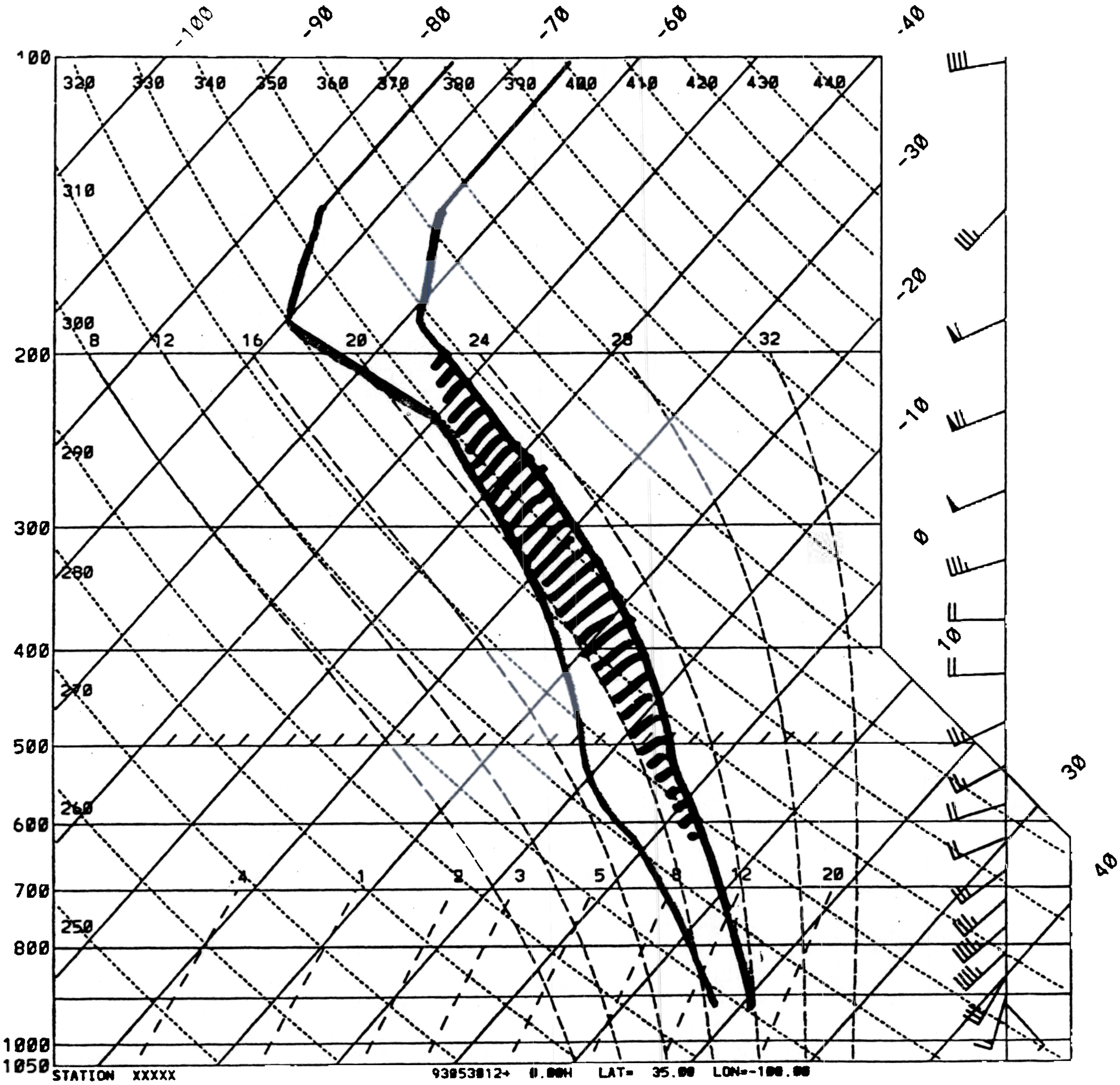
FIRST-GUESS Betts-Miller reference profiles

FIRST-GUESS ADJUSTED PROFILE

— T

— θ_v

BETTS



FINAL Betts-Miller reference profiles

FINAL ADJUSTED PROFILE

— T

— θv

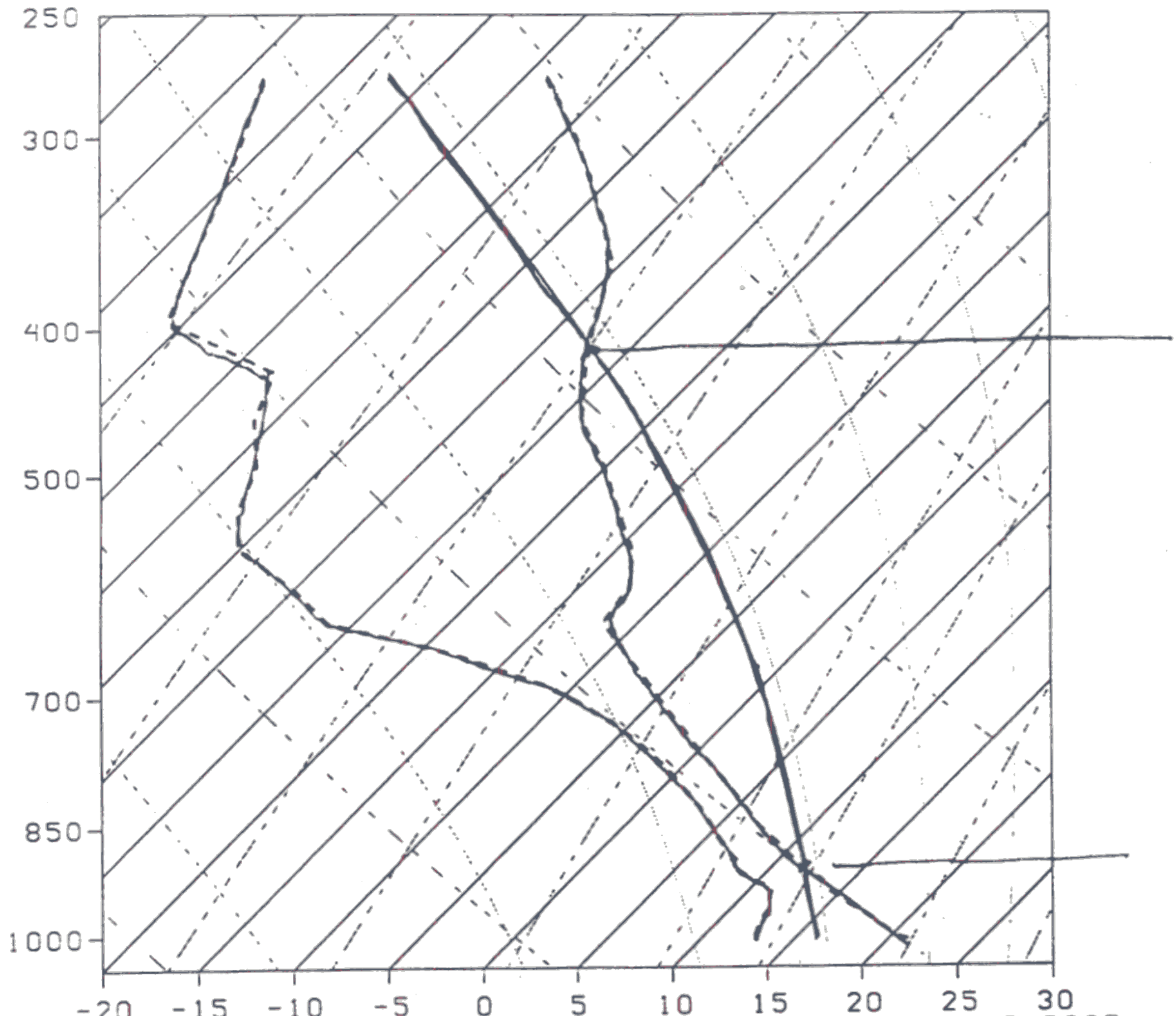
STEP #1

Determine Cloud Depth

If > 290 mb → DEEP CONVECTION

IF < 290 mb → SHALLOW ∴ NO PRECIP

980422/2200 11111 OSA chs22



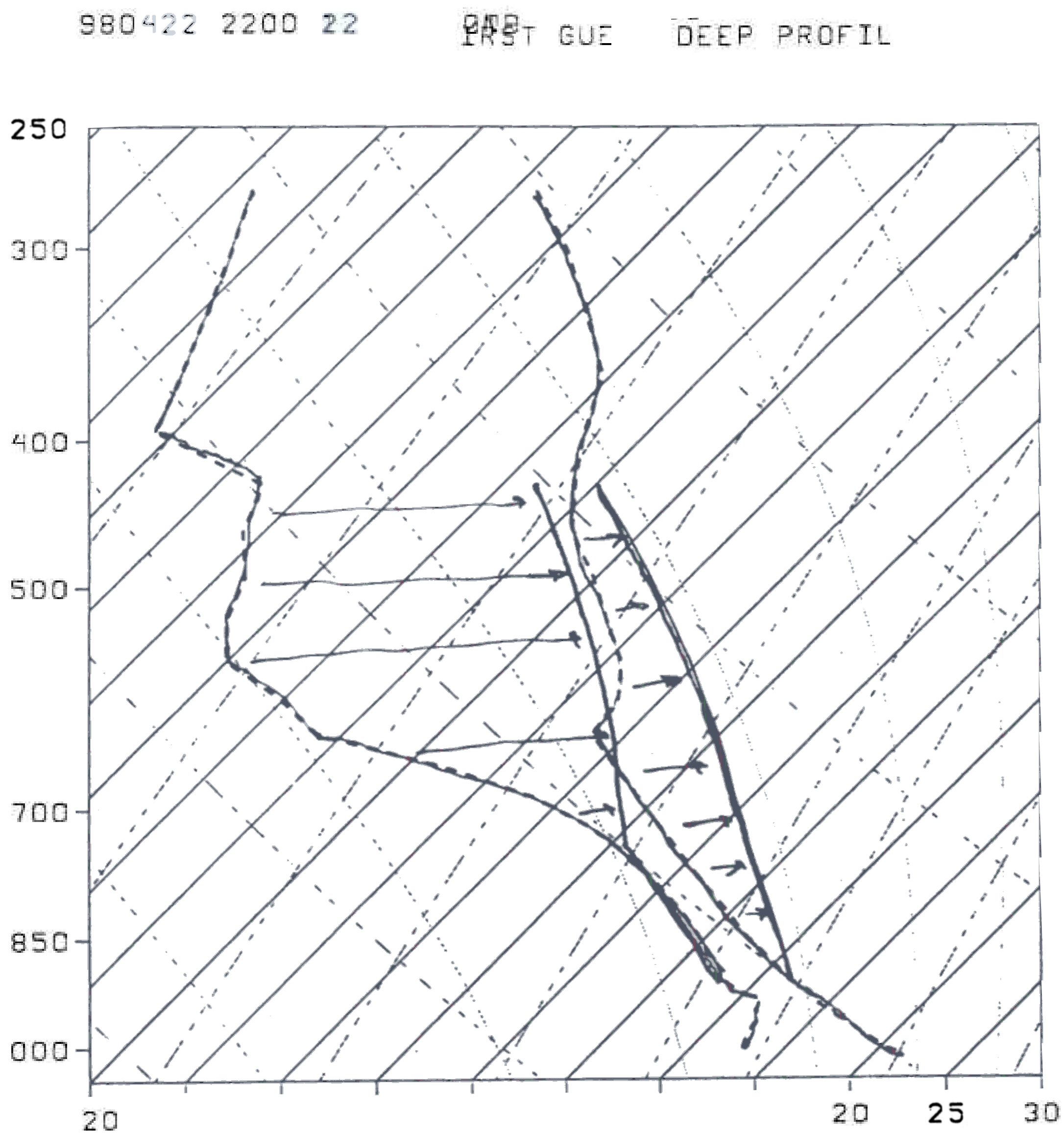
SOUNDING + MOIST ADIABAT THROUGH CLOUD BASE

1. Find most unstable parcel in lowest 130 mb above ground.

2. Find LCL of that parcel = CLOUD BASE.

STEP #2

Compute Reference Profiles



almos a ΔT, q > 0 does NOT make physical sense!

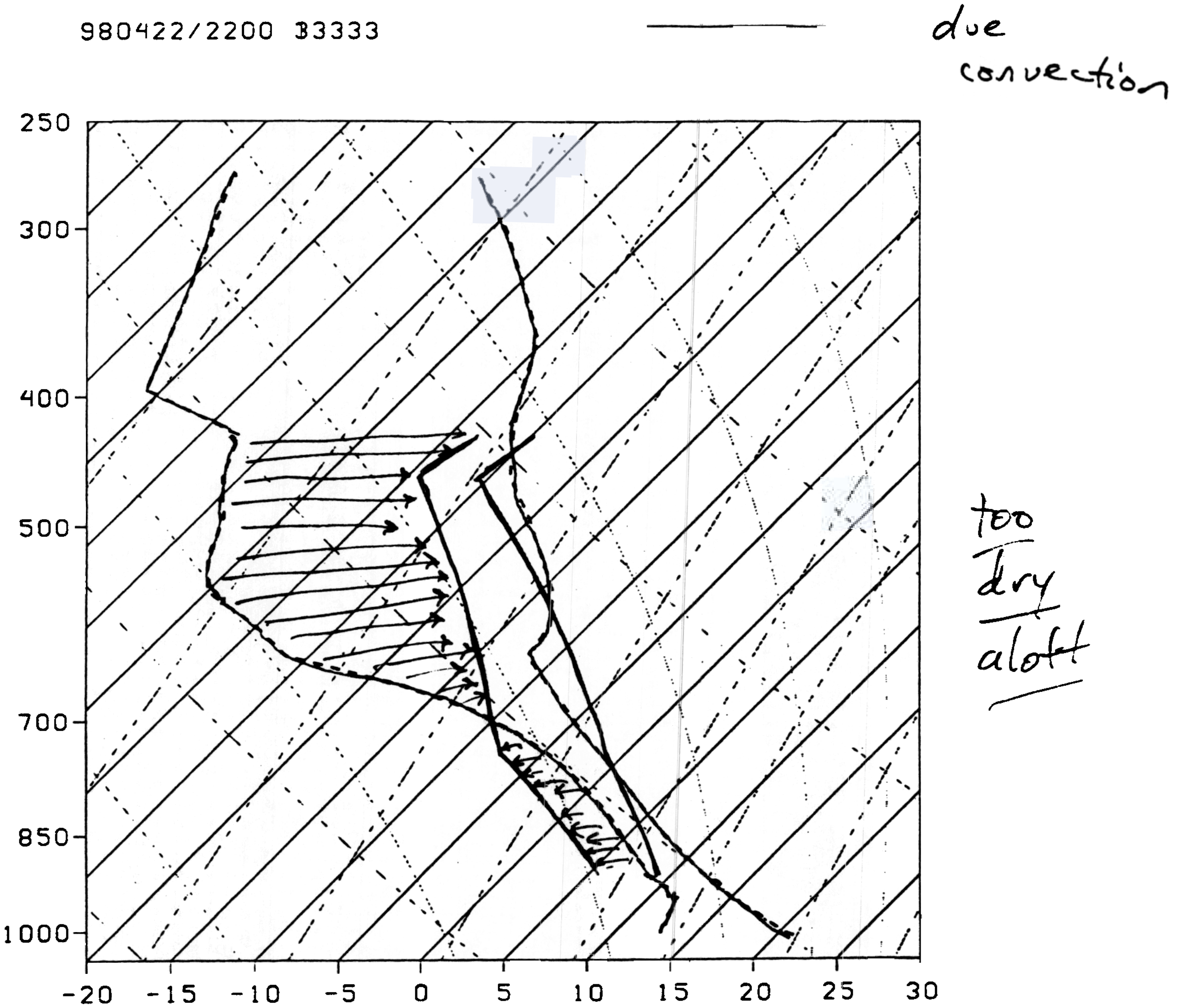
Temp profile - starts at T(mode) at cloud base goes p slightly more unstable than moist diaba up to 0 C level, then connects to origina moist adiaba at cloud top

2 q profile prescribed DSP profile

STEP #3

Adjust Reference Profiles to total enthalpy

$$\sum \left[c_p \Delta T + L \Delta q \right] \Delta p = 0$$



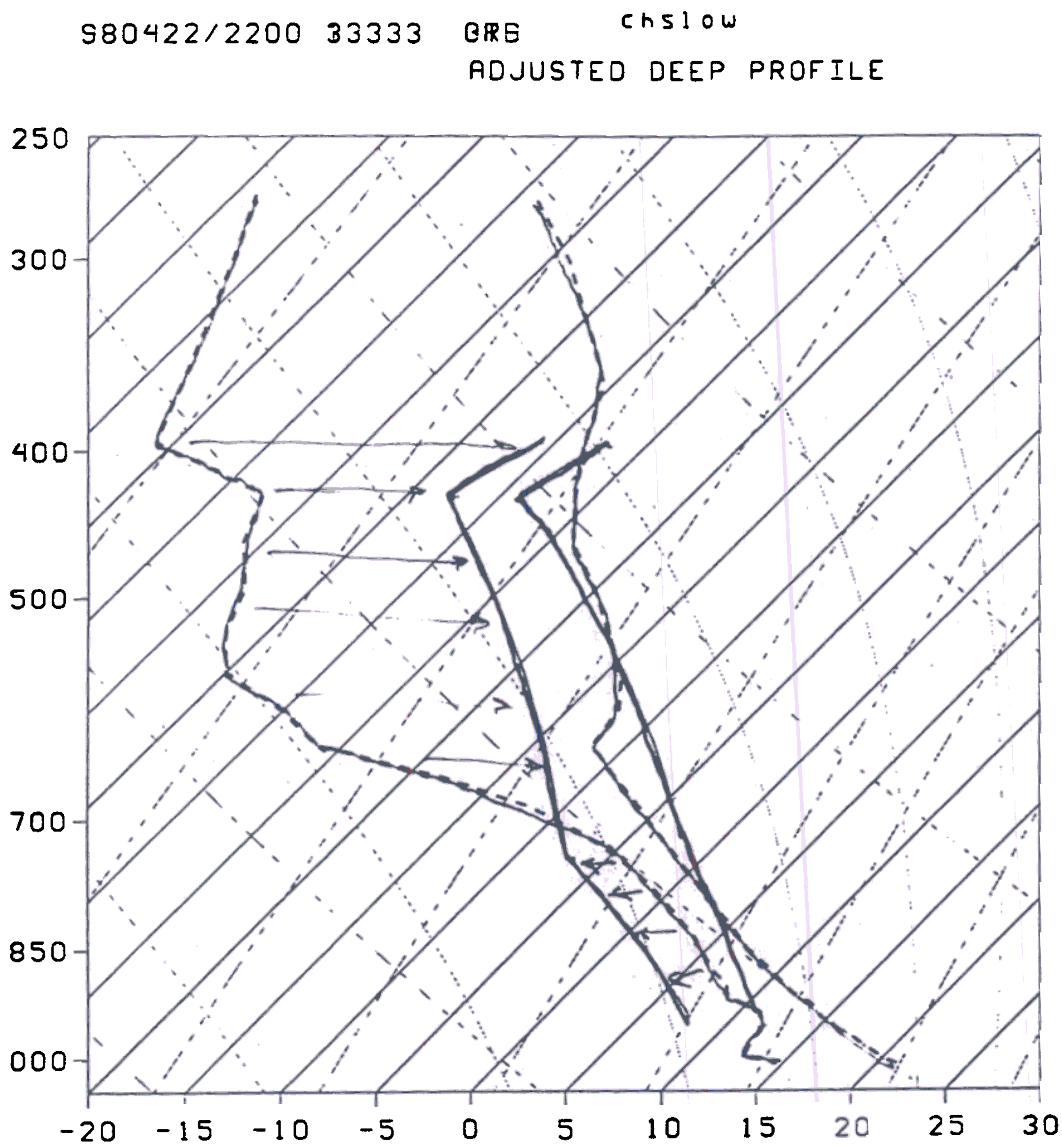
STEP #4

Compute precip $= [\Delta q] \frac{\Delta p}{g}$

if > 0 SUCCESS!

if ≤ 0 goto SHALLOW ∴ no precip

... After enthalpy adjustment
ended up right back
as we started



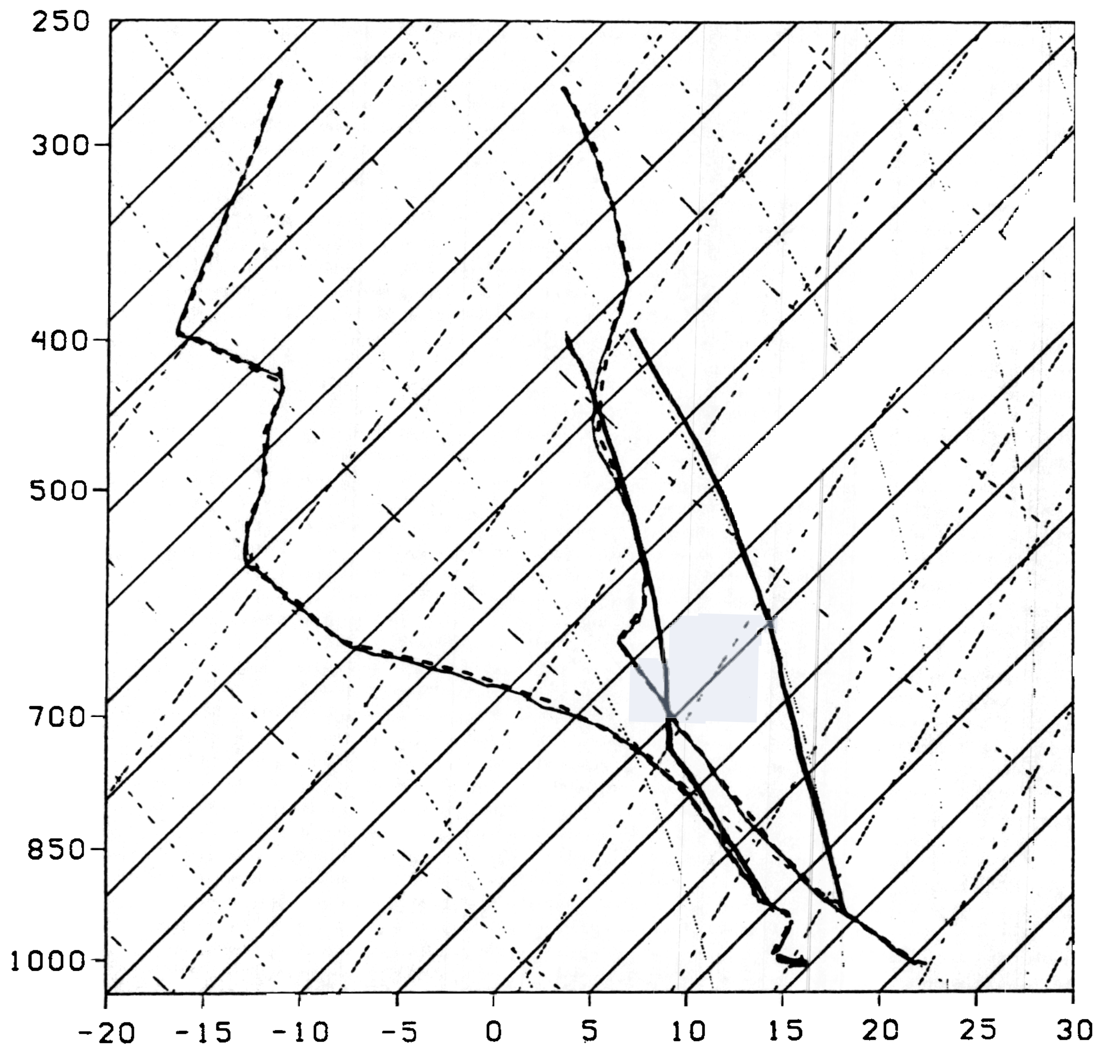
TOO DRY

NO PRECIP

Modified sounding

Add 2° to low level Td

980422/2200 22222 chslow FIRST GUESS DEEP PROFILE

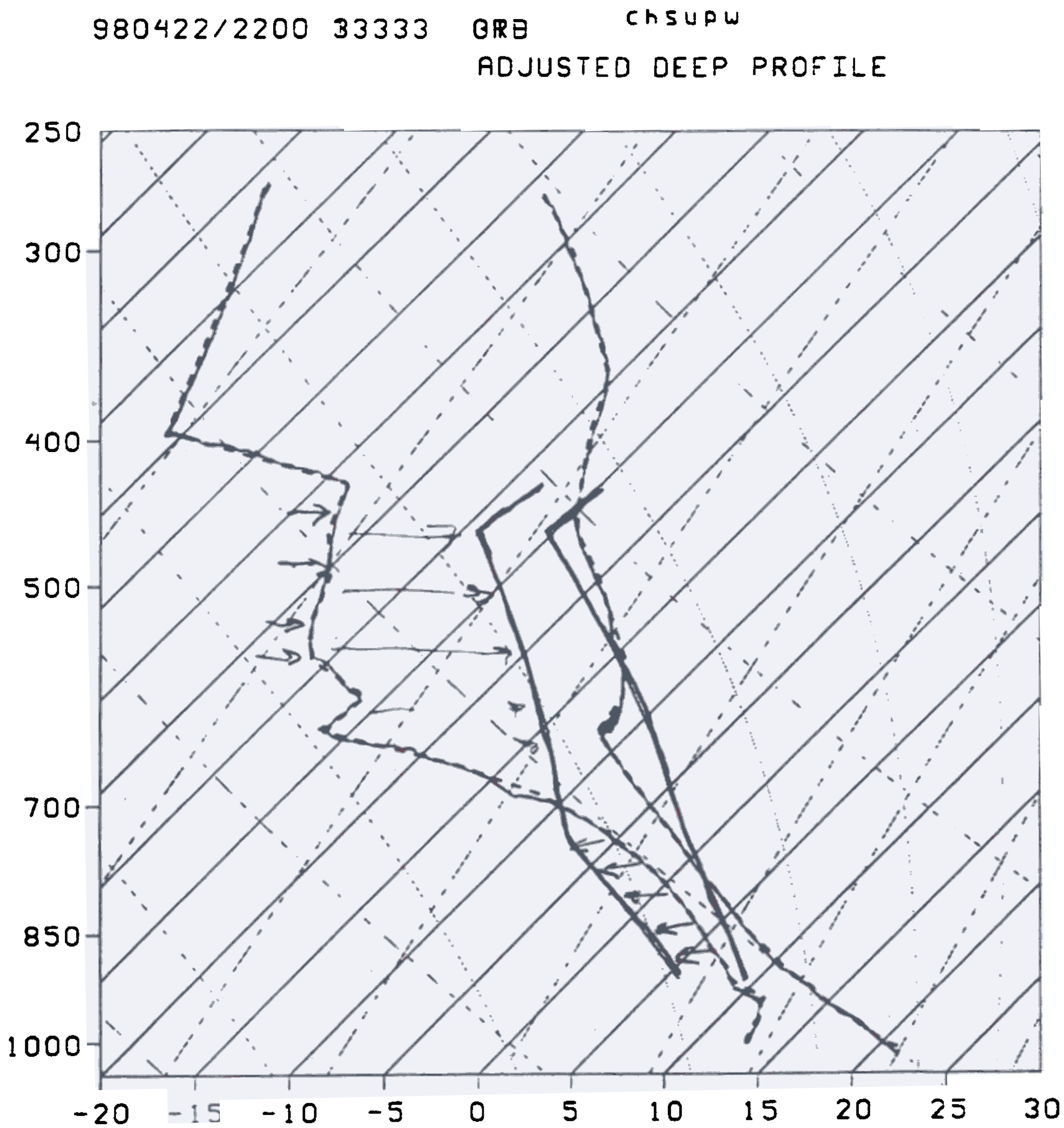


More CAPE

still too dry

will require larger enthalpy adjustment

Modified sounding
increase moisture
between 400 - 600 mb
(by about 3° Td)



NOW THERE IS ENOUGH MOISTURE TO PRODUCE PRECIP

CHS 2 hours later

convection has broken out in the model

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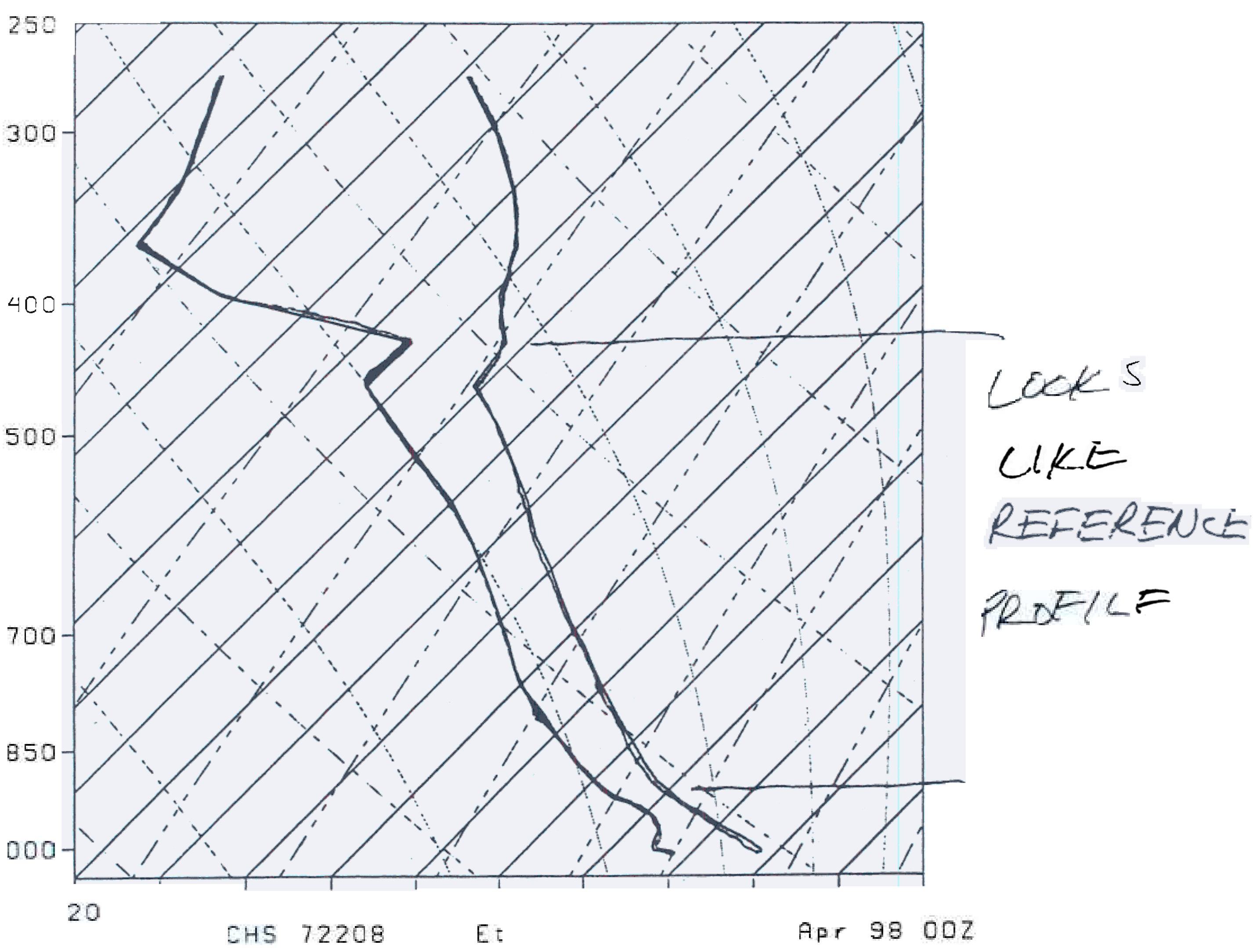

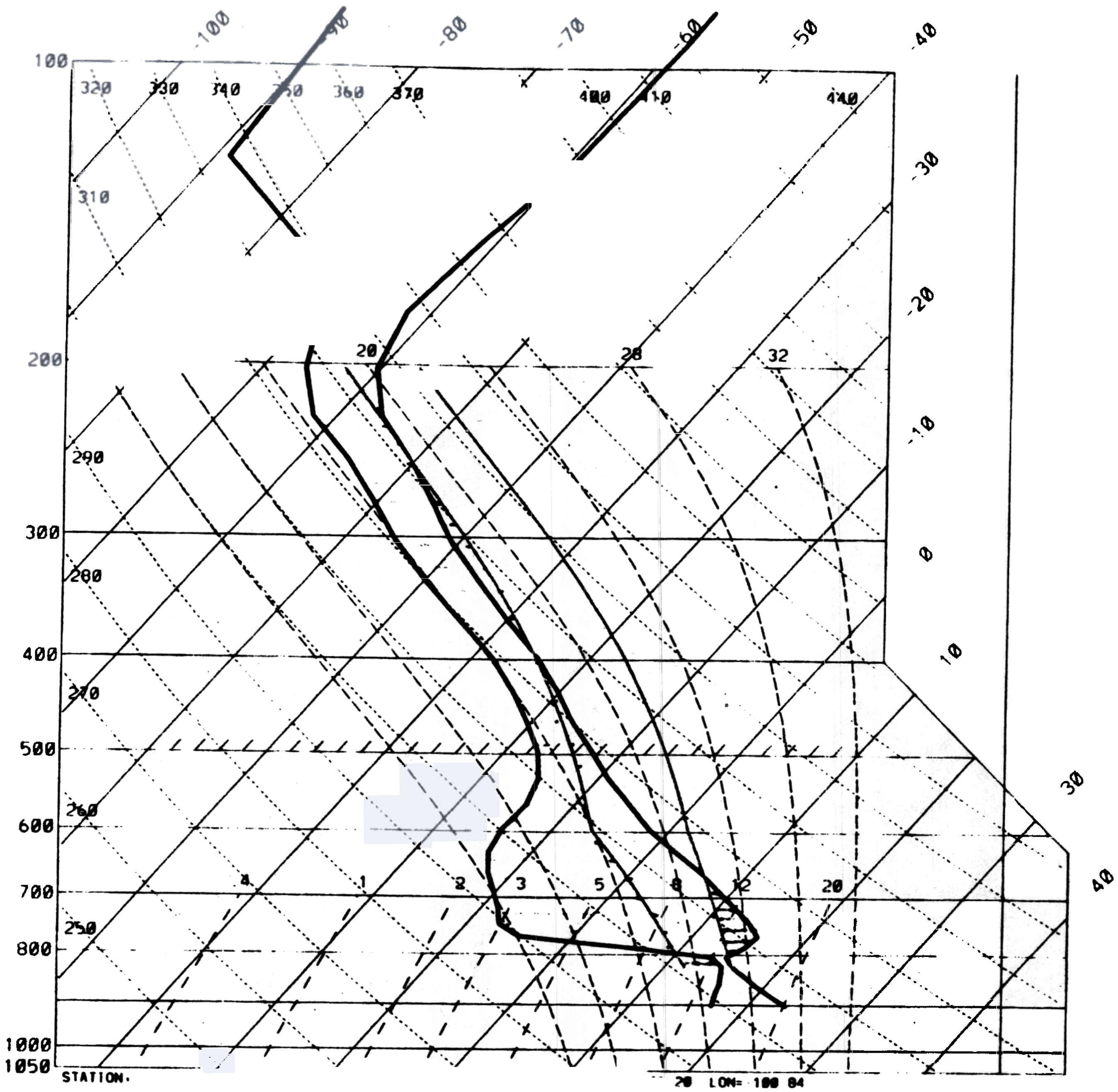

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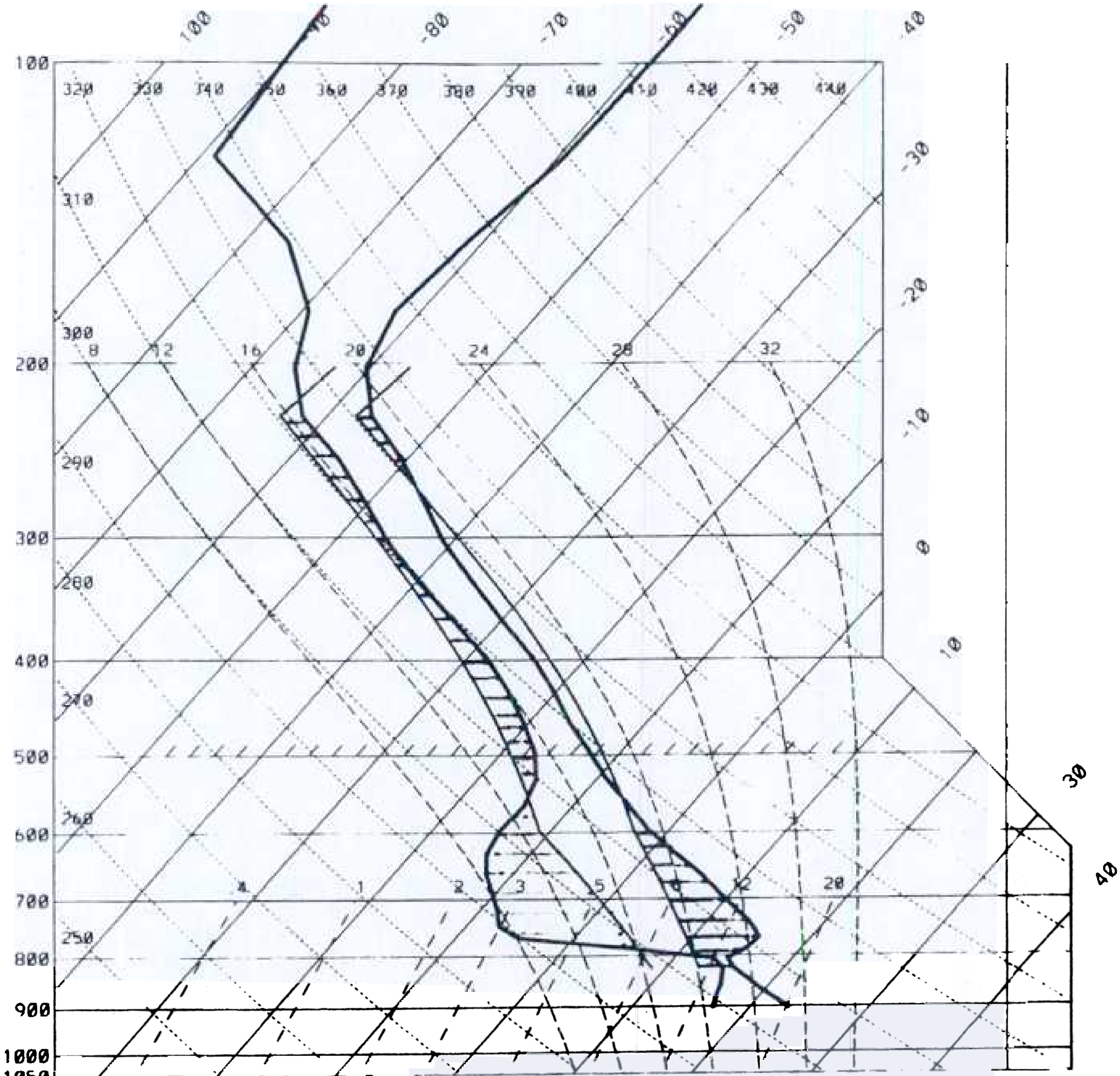
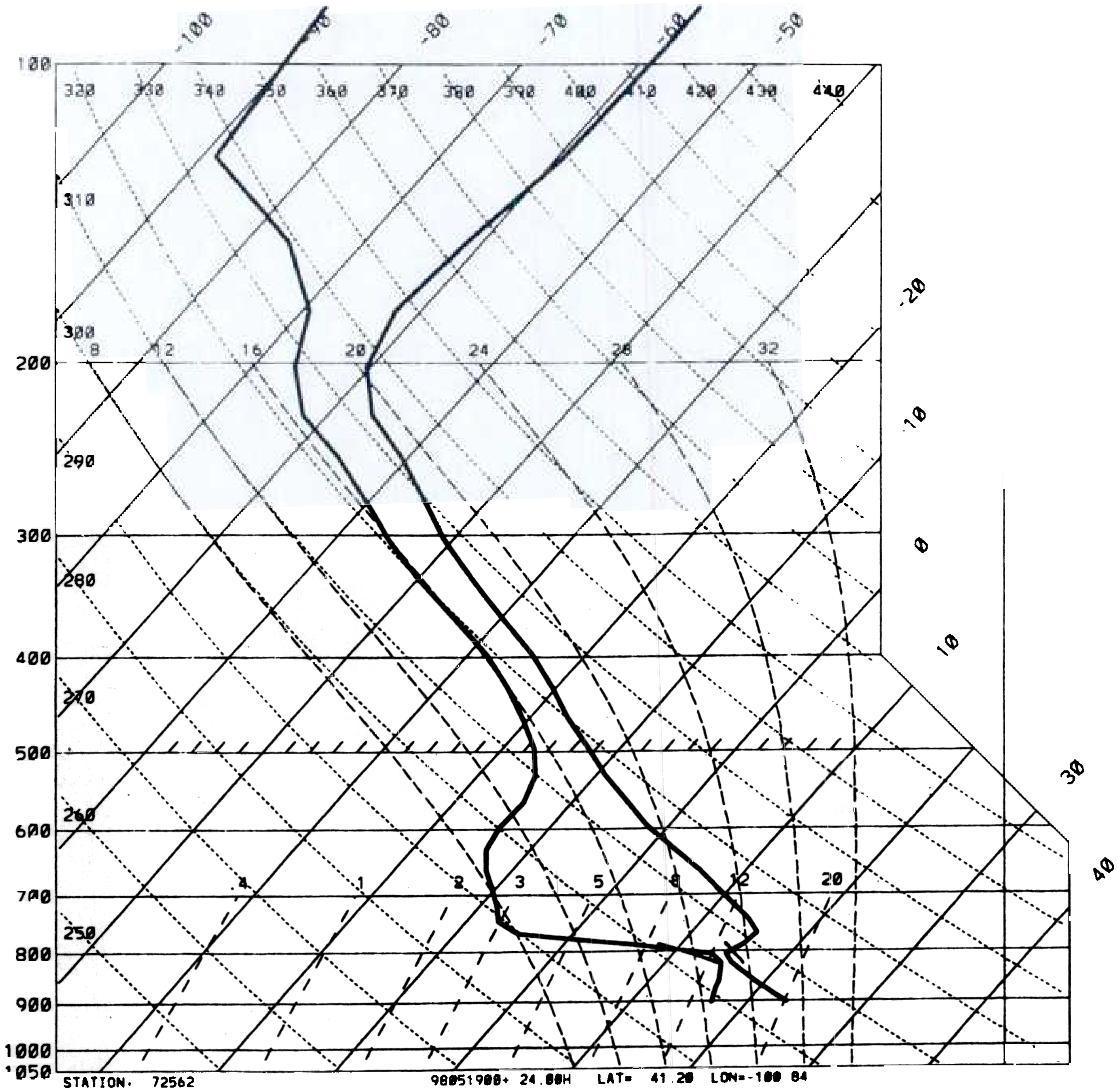


AFTER ENTHALPY CORRECTION

NEGATIVE PRECIP!!

NEGATIVE PRECIP: $\sum_{\text{BOTTOM}}^{\text{TOP}} \delta q_v > 0$

$\sum_{\text{BOTTOM}}^{\text{TOP}} \delta T < 0$

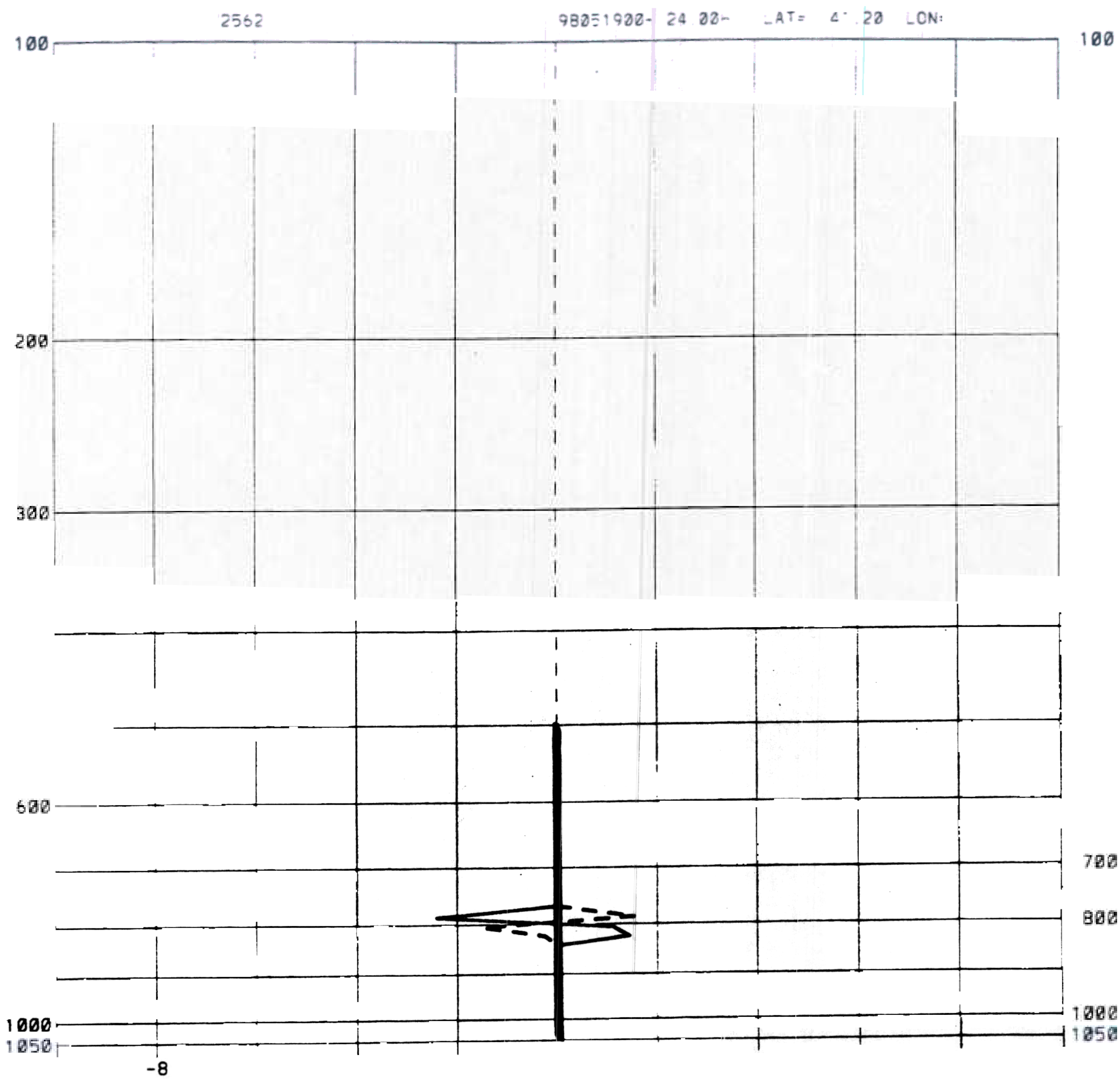


BMJ SHALLOW CONVECTION NO RAINFALL!!!!

...LLOW ONLY SHALLOW CONVECTION:

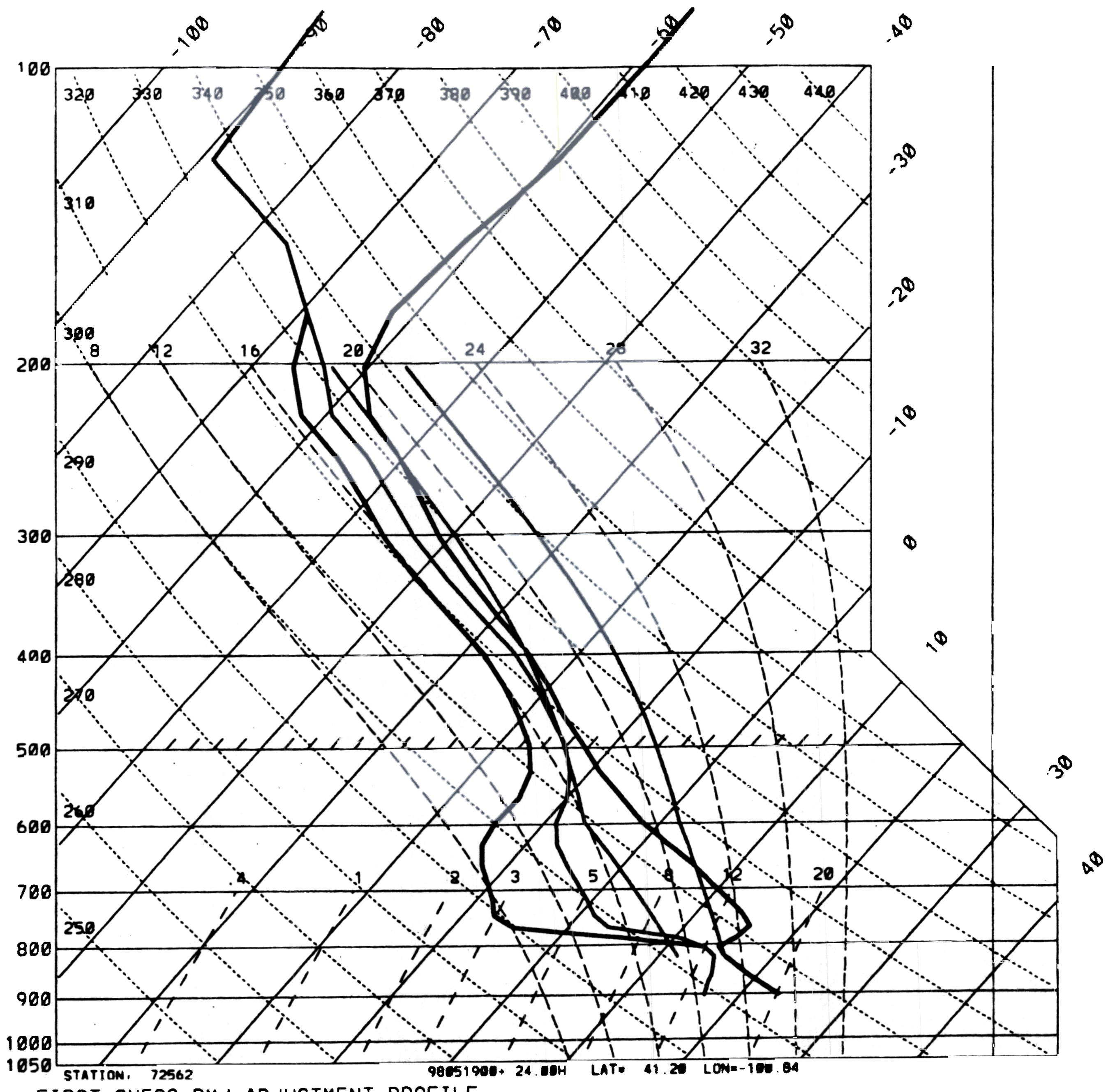
$$\sum_{\text{BOTTOM}}^{\text{TOP}} \delta q_v = 0$$

$$\sum_{\text{BOTTOM}}^{\text{TOP}} \delta T = 0$$

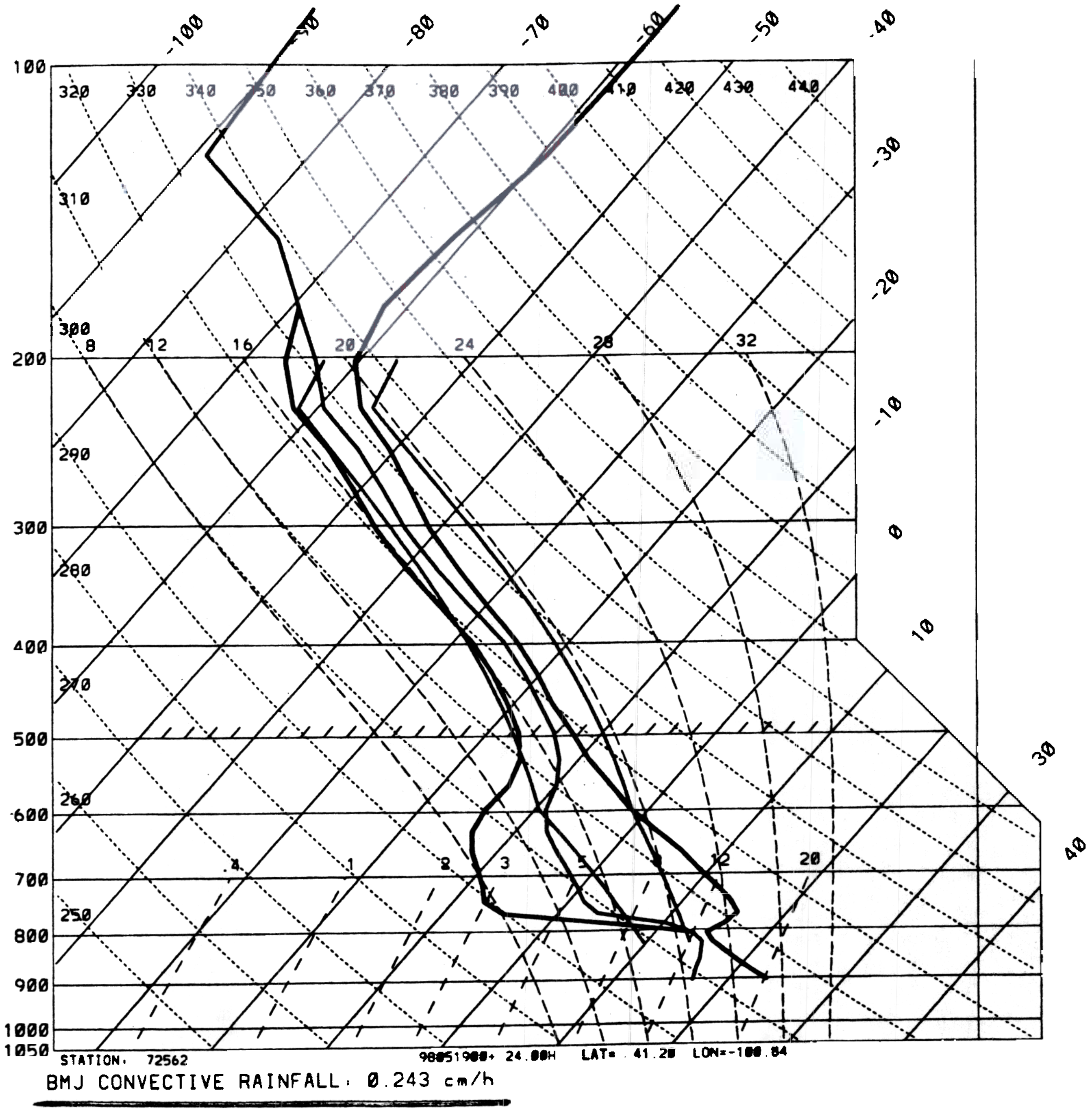


BMJ HEATING (K/h)

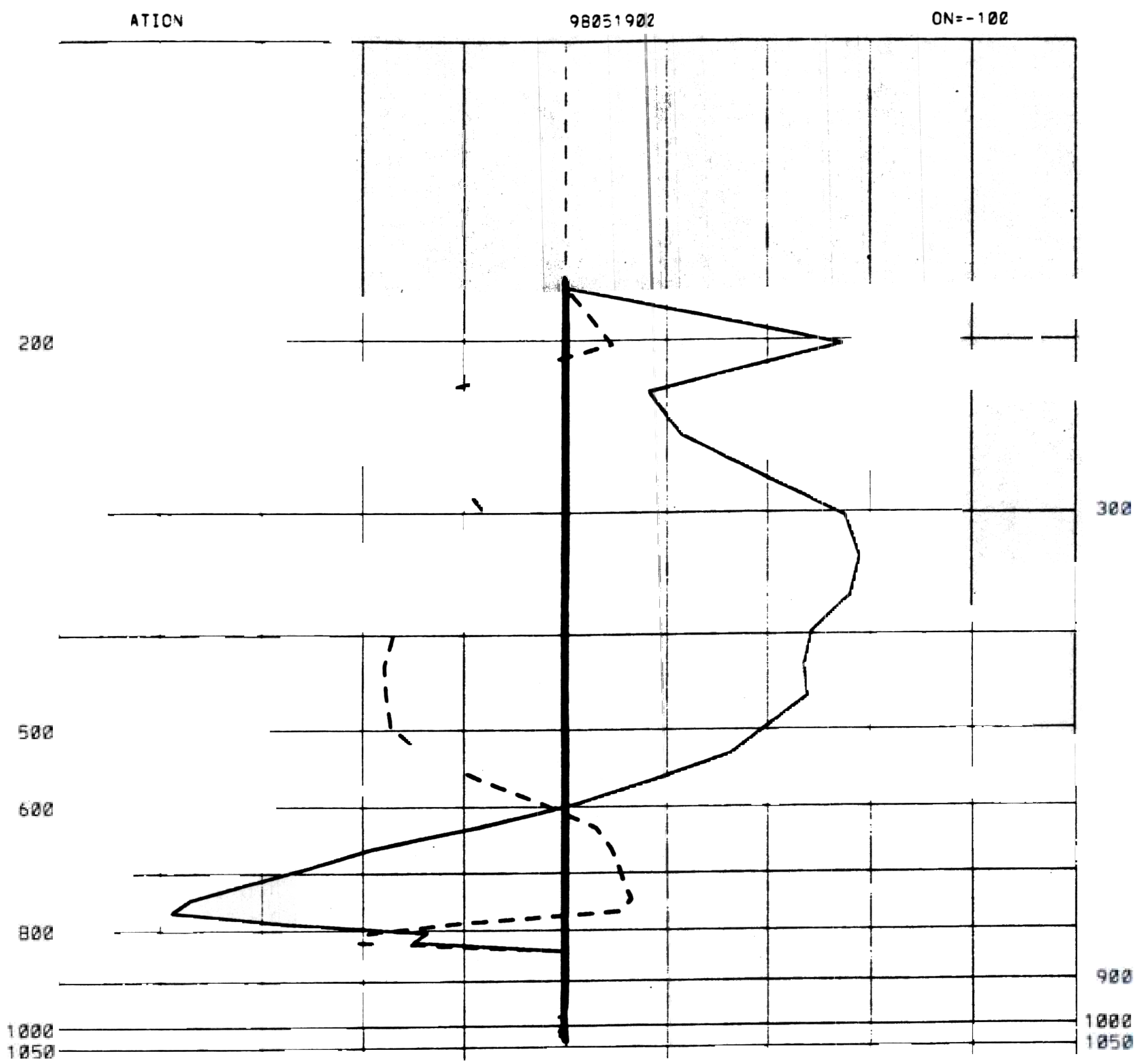
INCREASE CLOUD-LAYER R.H. BY 20%



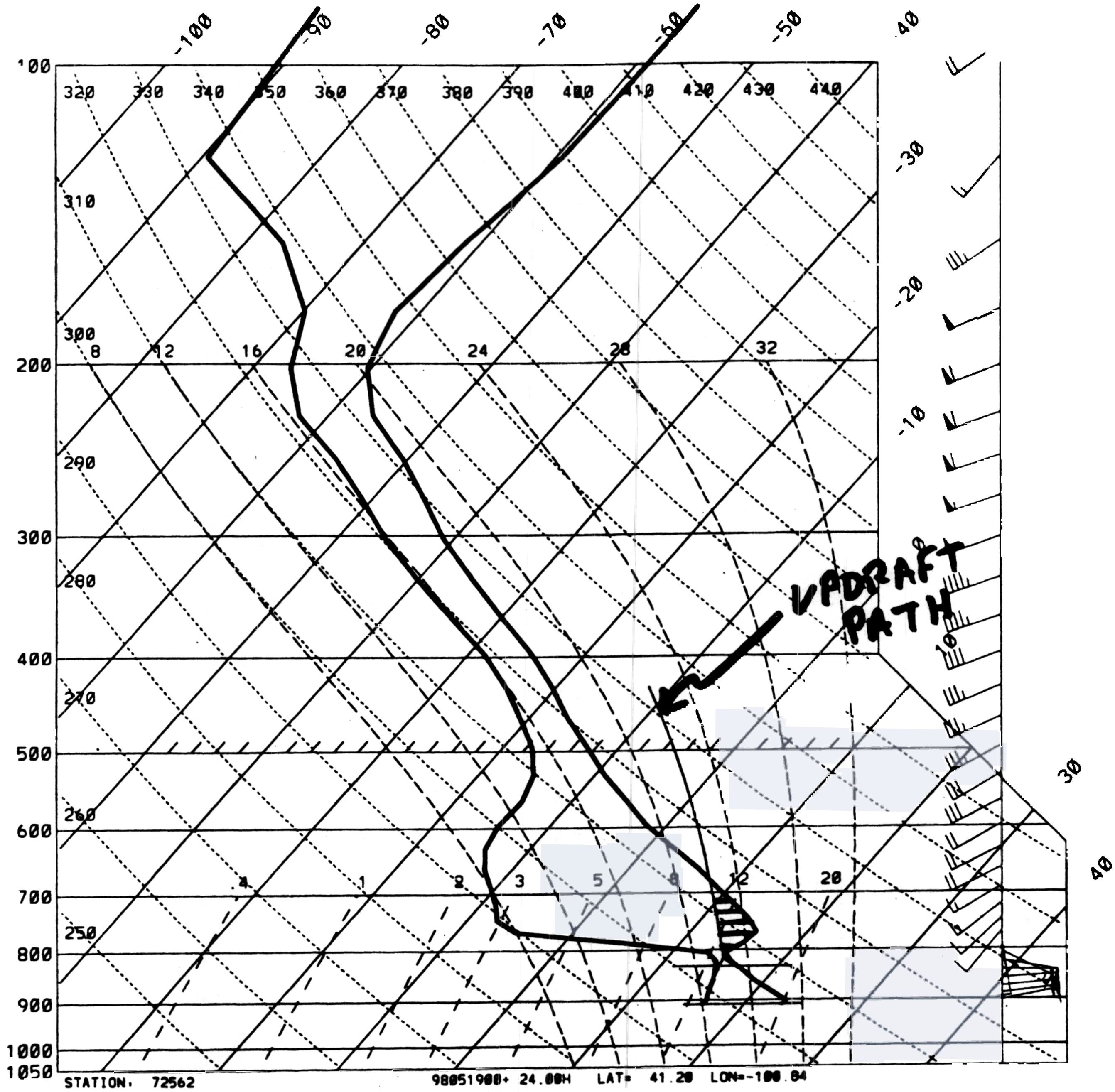
FIRST GUESS BMJ ADJUSTMENT PROFILE.



DEEP CONVECTION ALLOWED

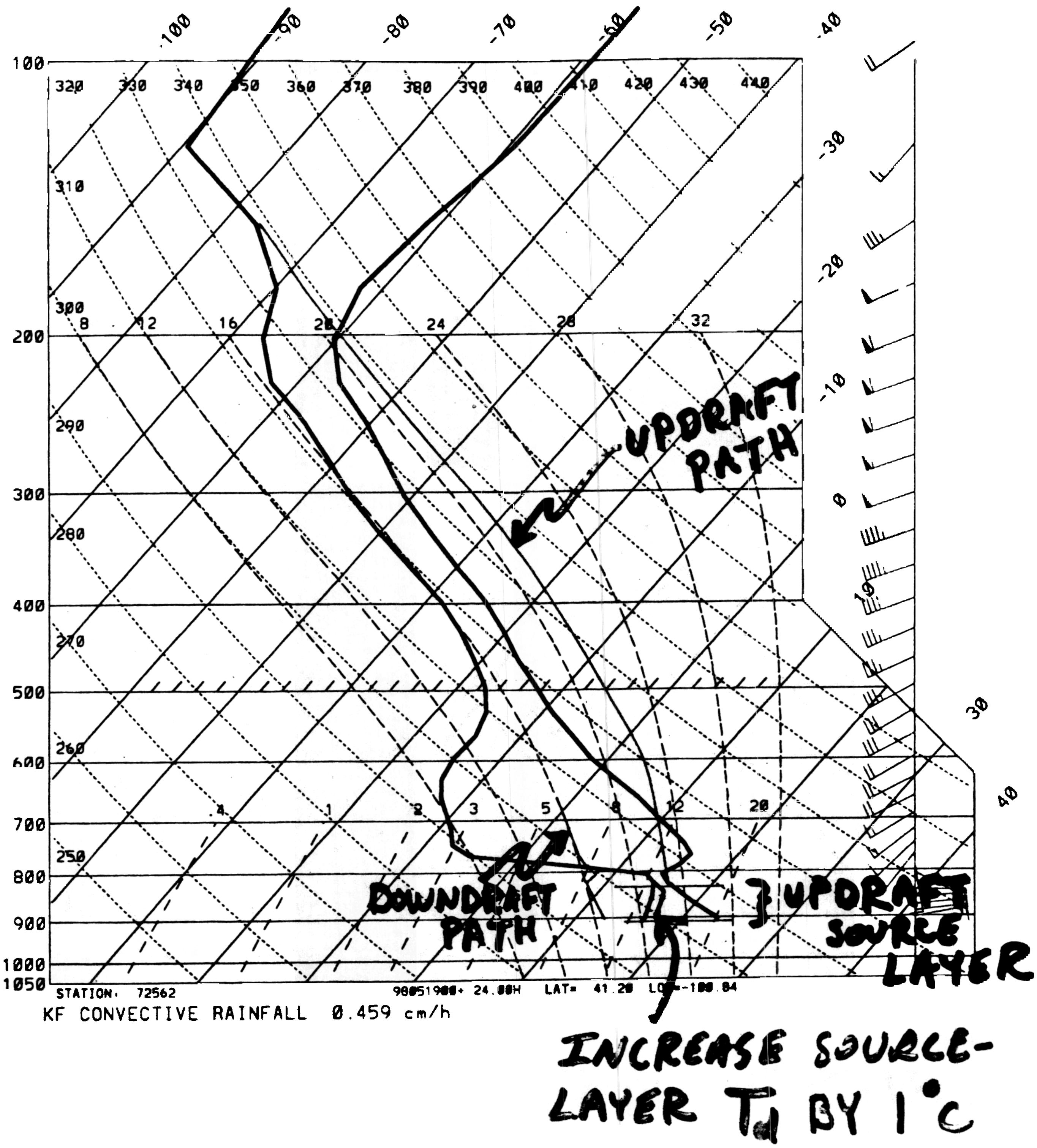


BMJ HEATING (K/h)

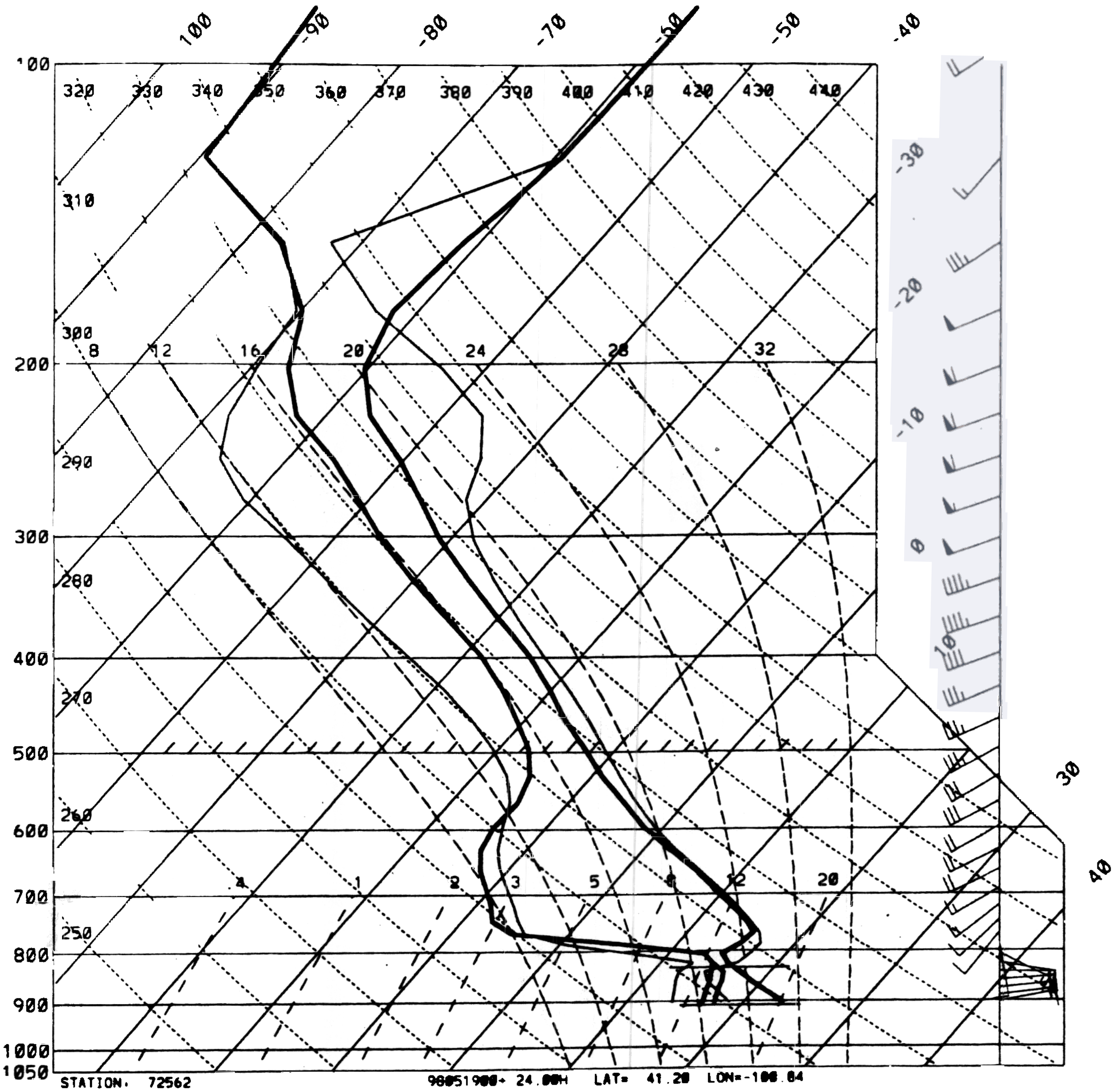


NO KF FROM THIS LAYER - CAP TOO STRONG !!!

KF TRIGGER: NO CONVECTION,
CAP TOO STRONG!

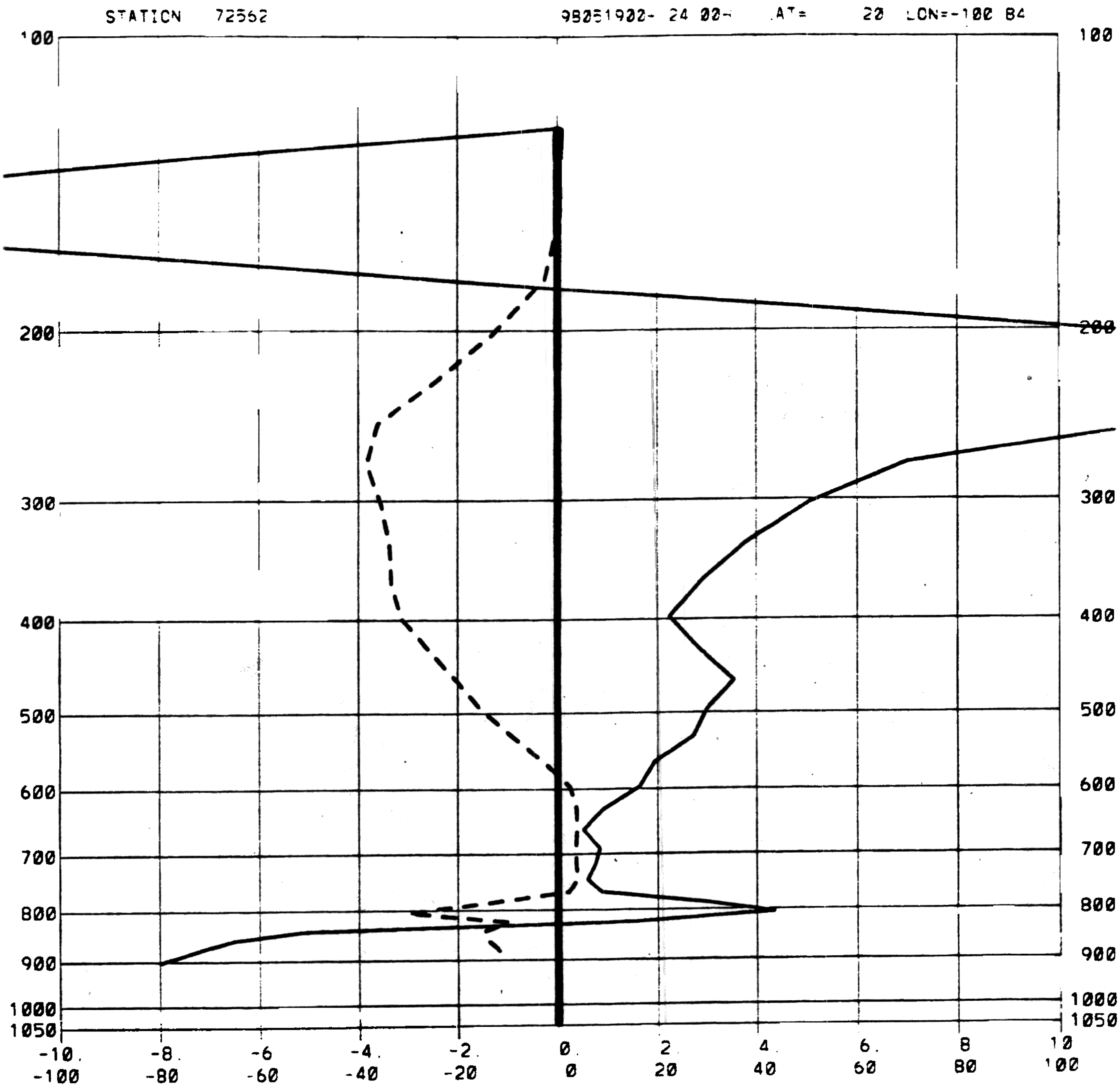


KF TRIGGER: SOME PARCELS BREAK CAP, INITIATE DEEP CONVECTION

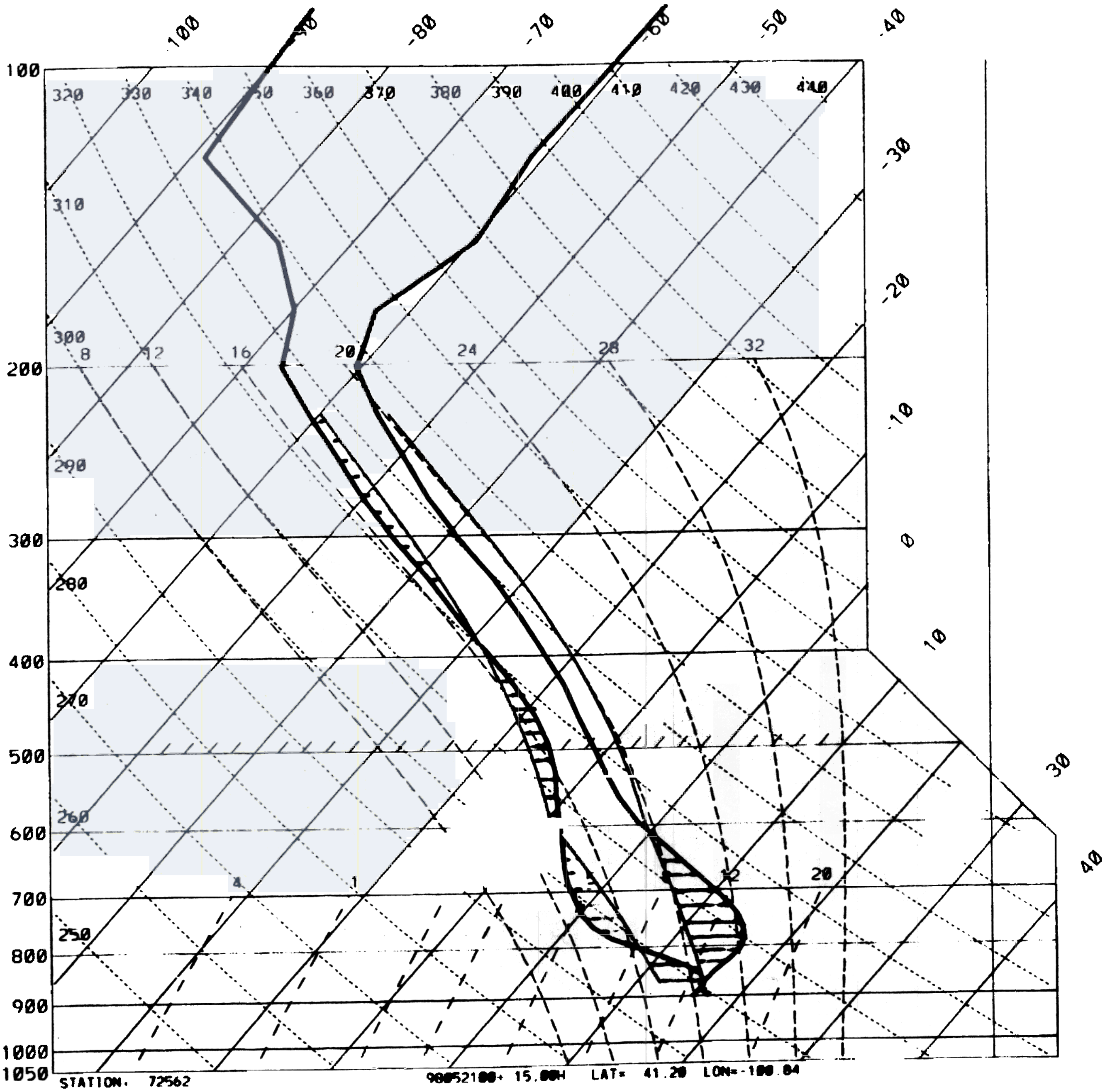


KF CONVECTIVE RAINFALL: 0.459 cm/h

KF CONVECTIVELY-ADJUSTED PROFILE

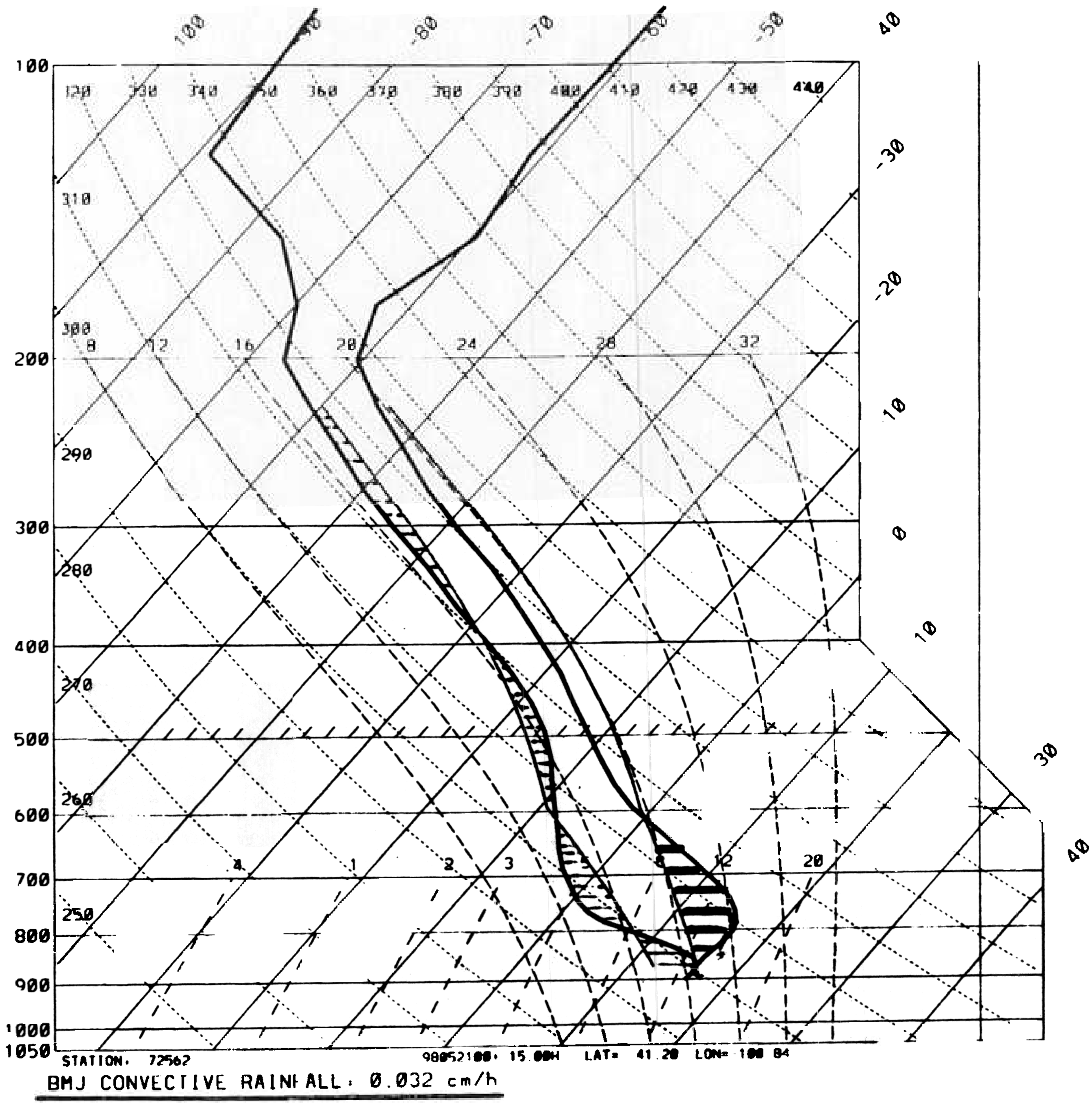


KF HEATING (K/h)

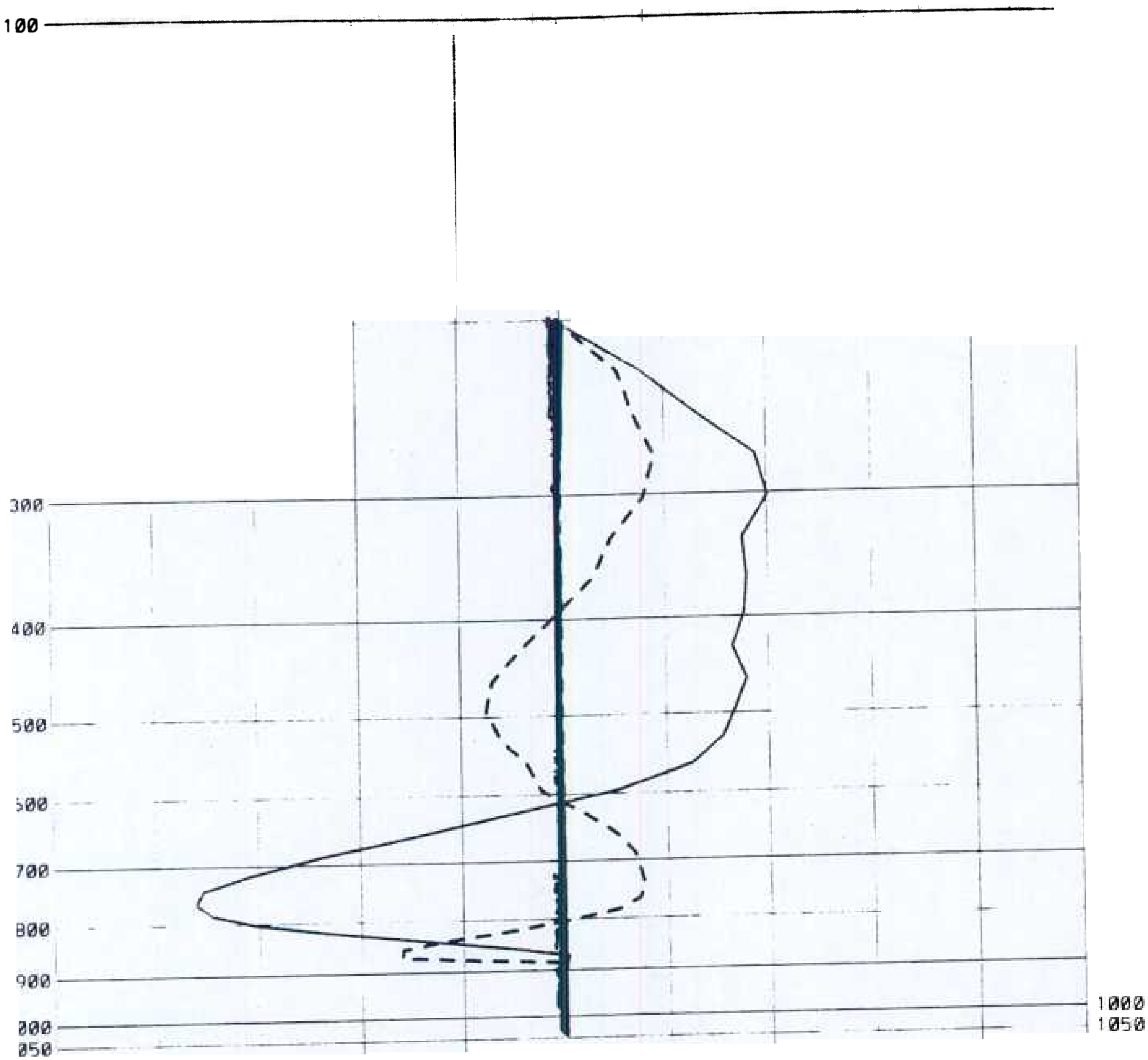


FIRST GUESS BMJ ADJUSTMENT PROFILE

AFTER ENTHALPY ADJUSTMENT:
DEEP CONVECTION ALLOWED

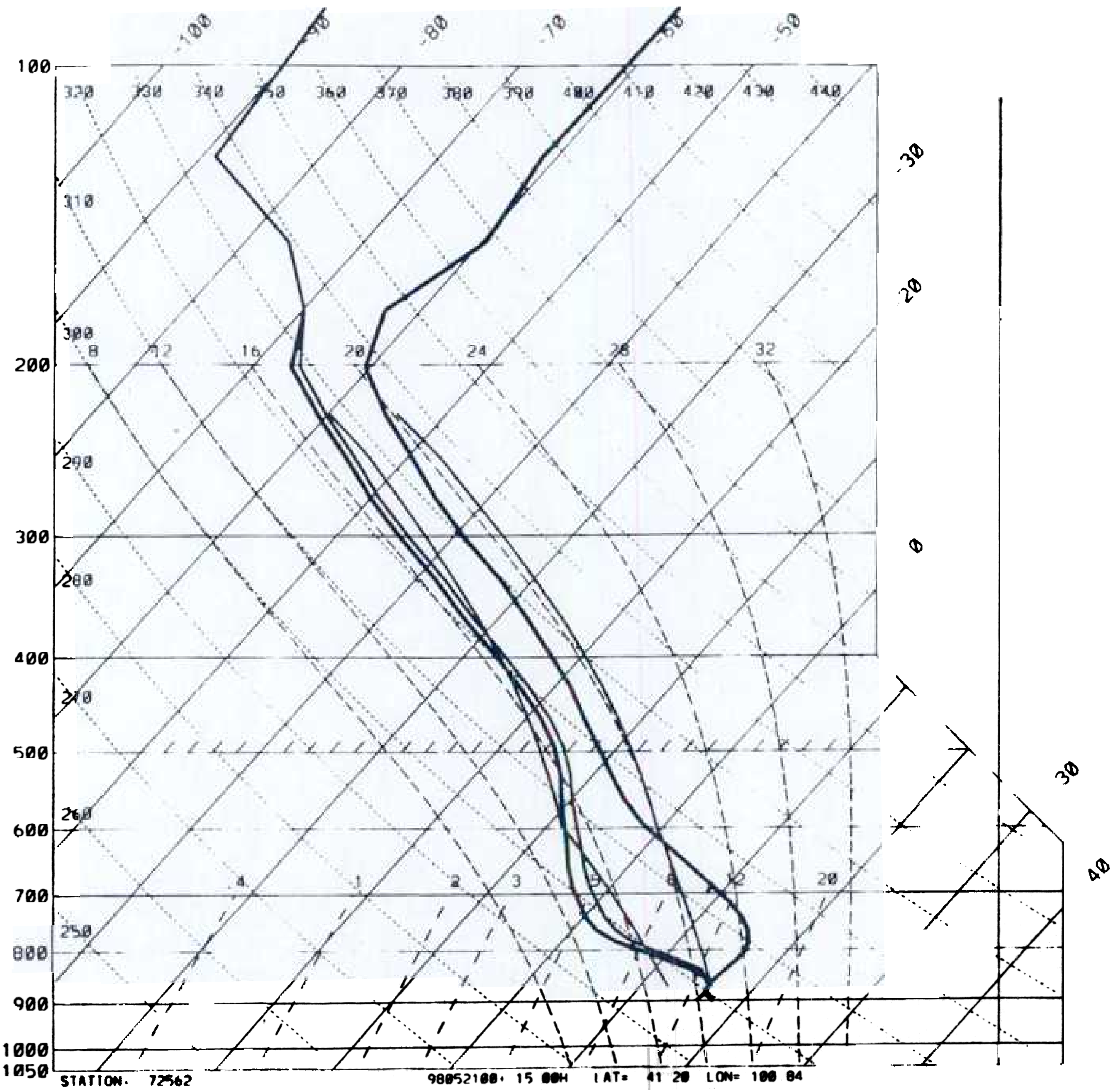


RAINFALL: 0.032 cm/h



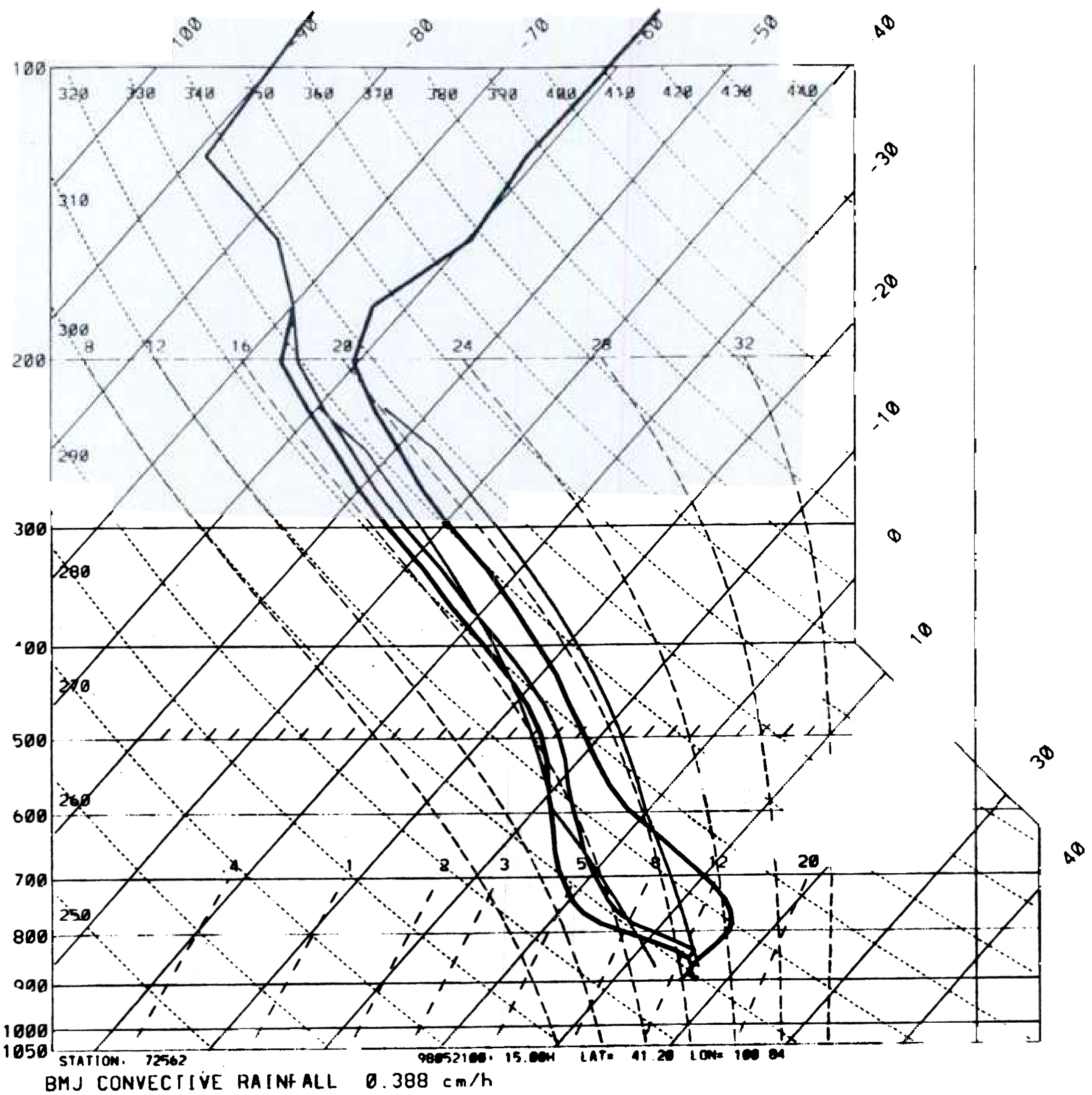
BMJ HEATING (K/h)

INCREASE CLOUD-LAYER R.H. BY 5%:



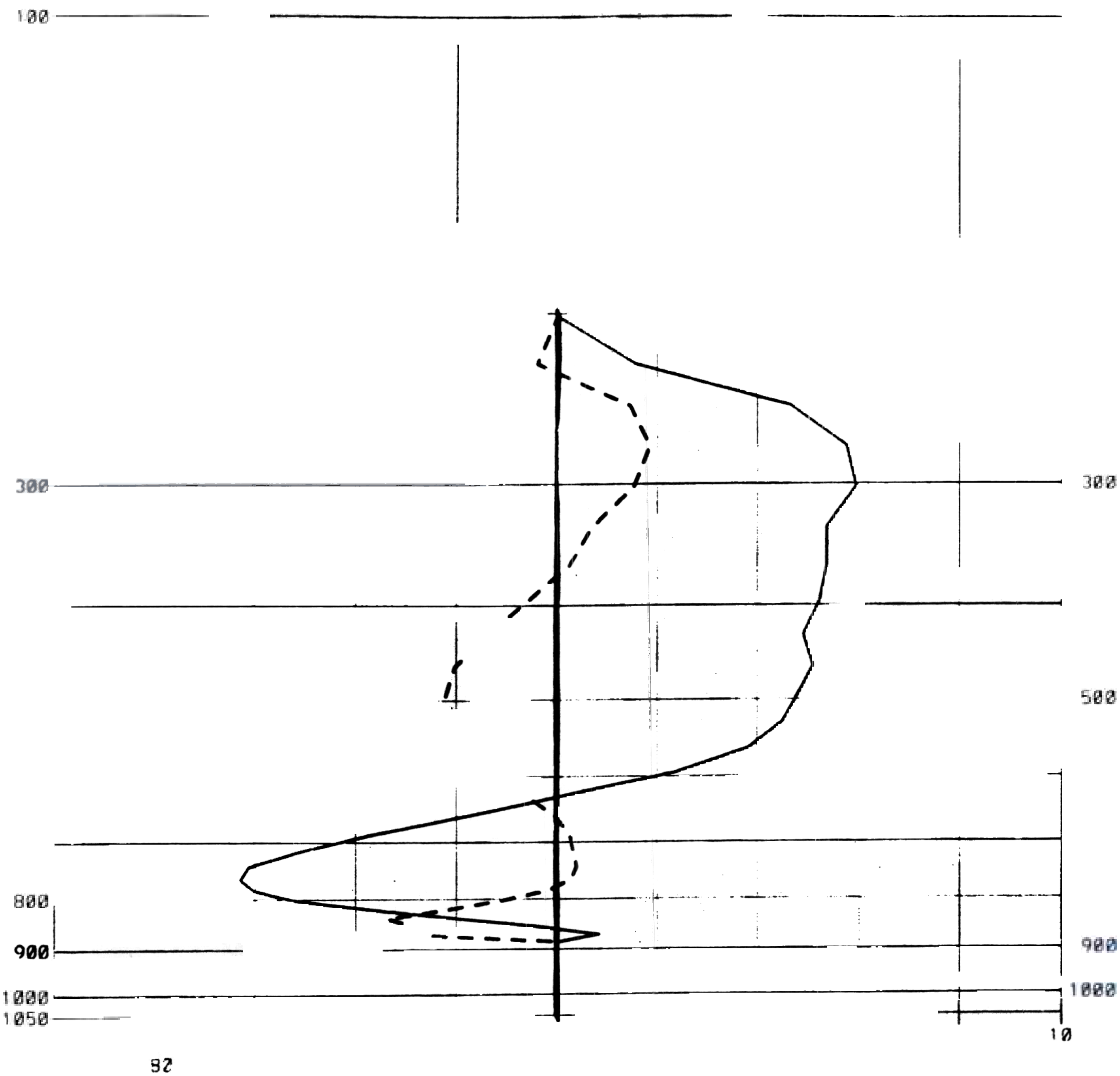
RAINFALL: 0.211 cm/h

INCREASE CLOUD-LAYER R.H. BY 10%

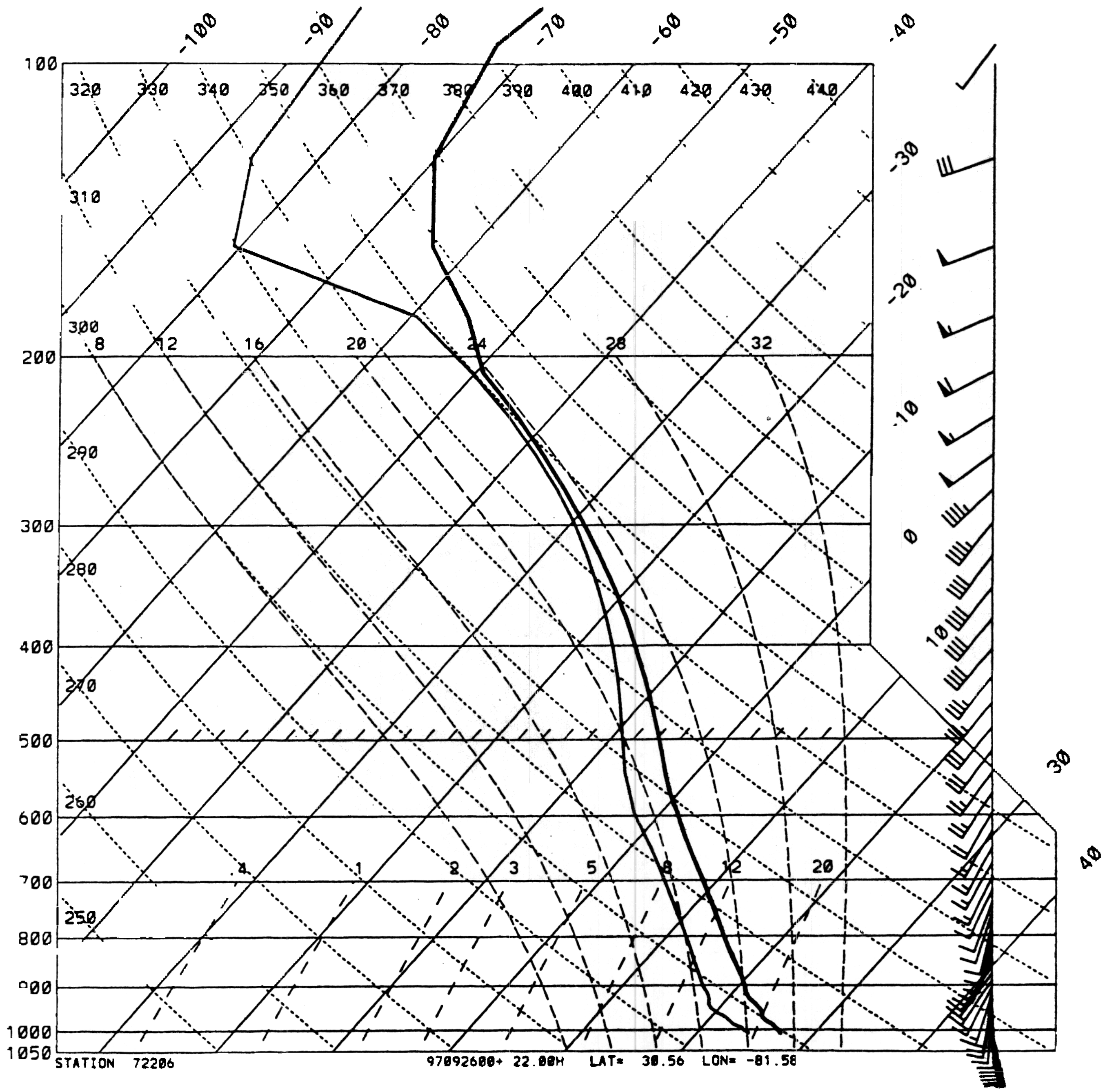


RAINFALL: 0.388 cm/h

d(RH)=10%

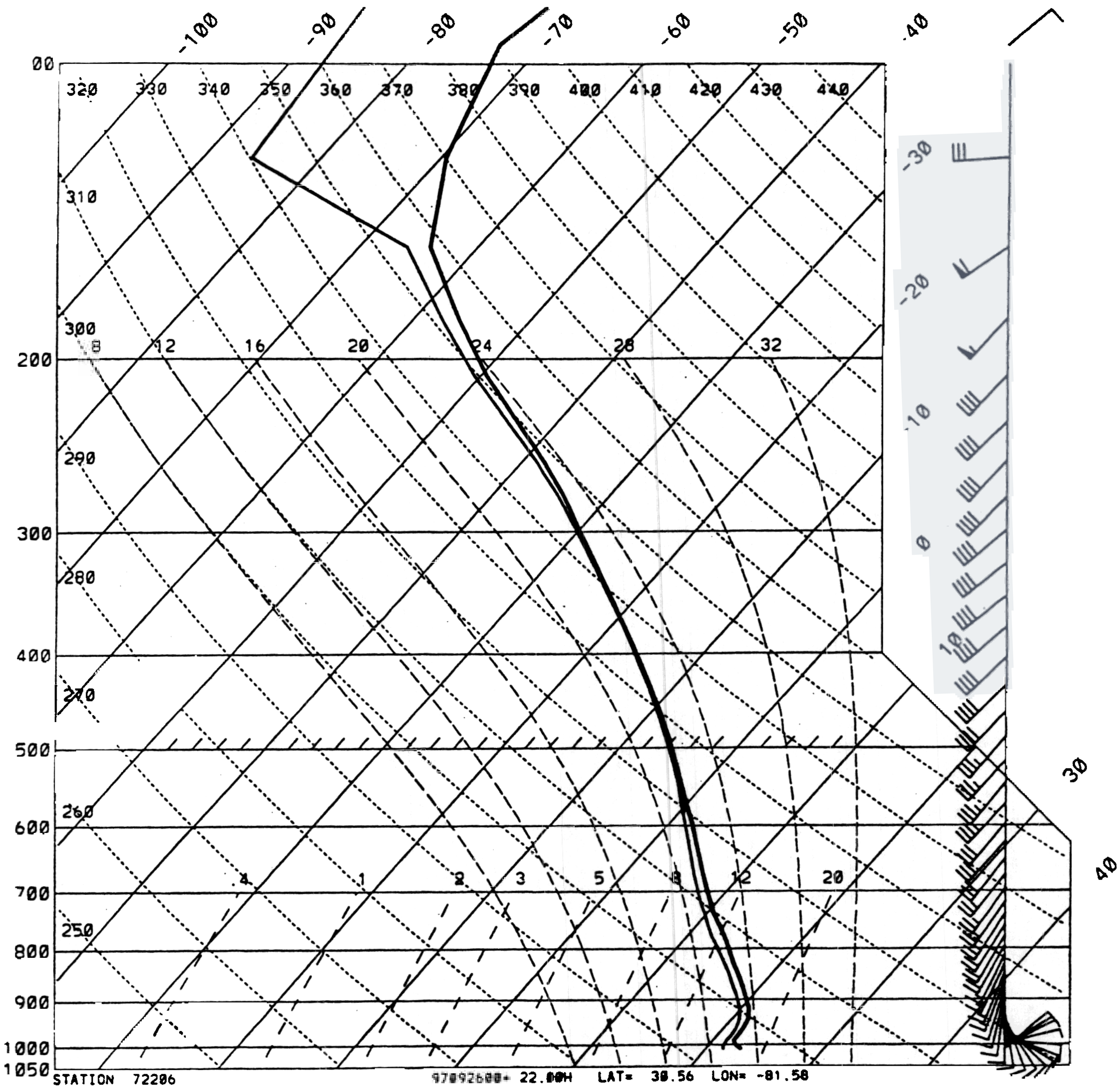


BMJ HEATING (K/h)



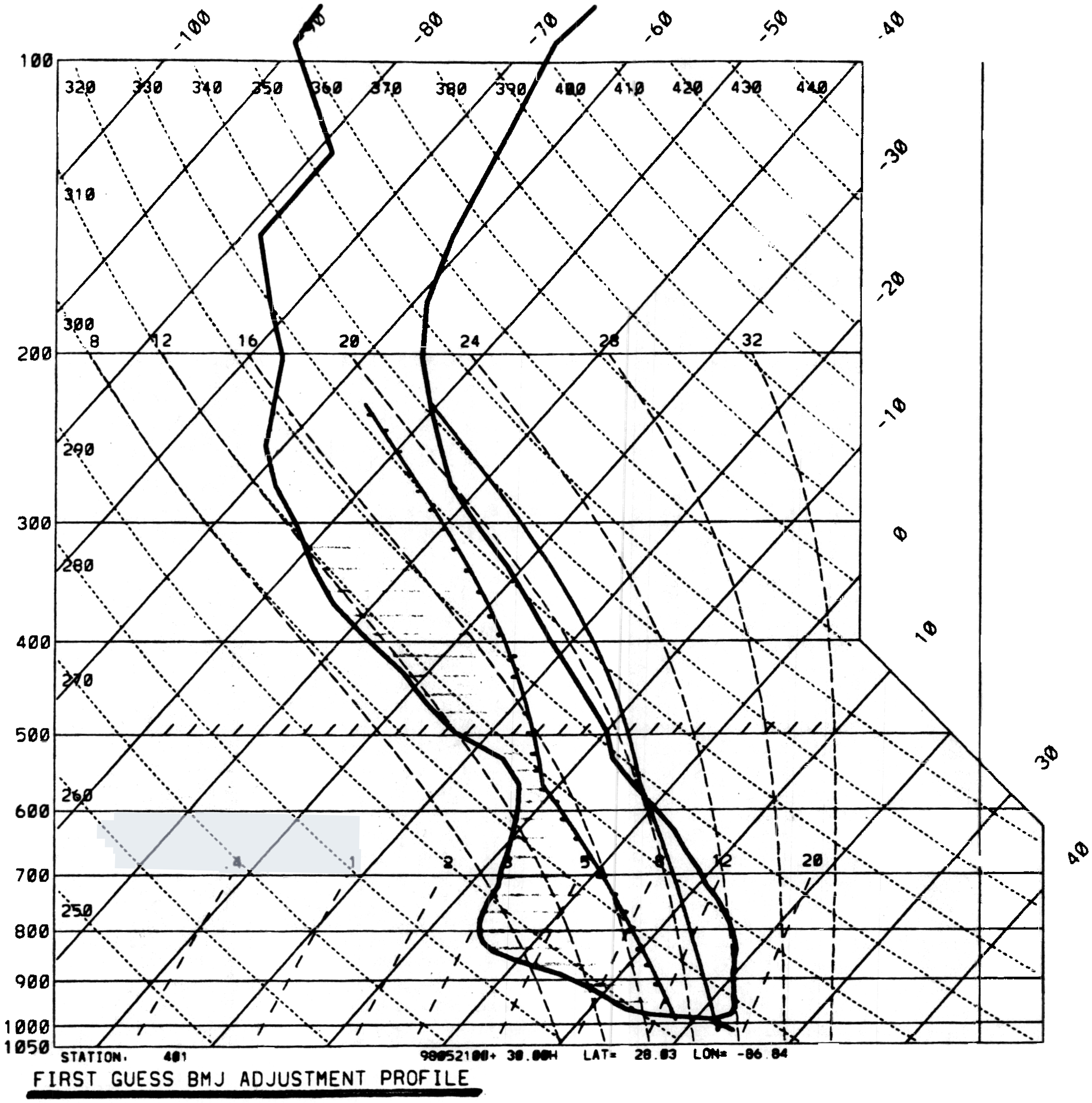
Betts-Miller-Janjic Run
Predicted JAX Sounding
03Z 9/26/97 + 22 h

HEAVY CONVECTIVE + NONCONVECTIVE RAIN

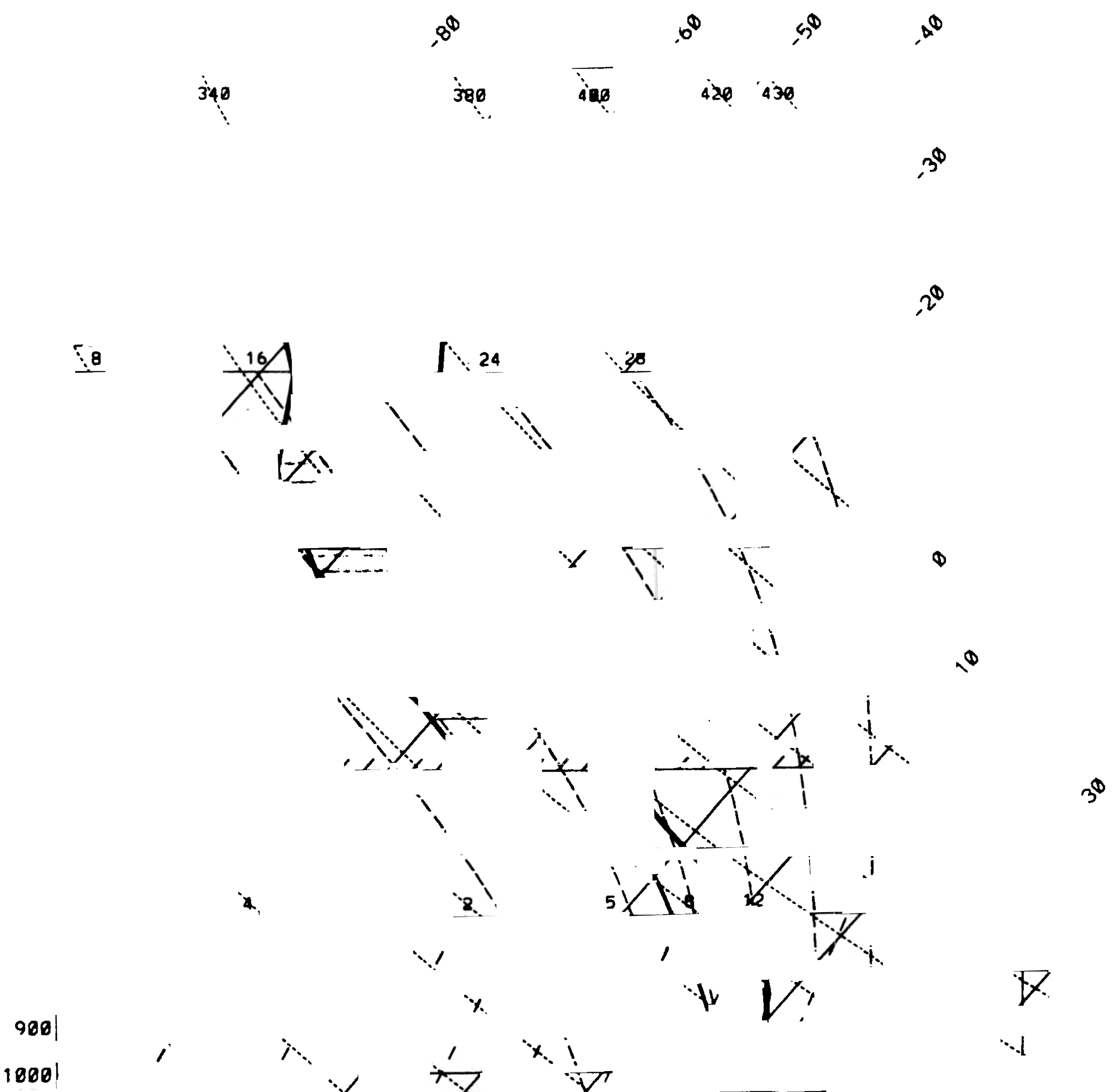


Kain-Fritsch Run
Predicted JAX Sounding
03Z 9/26/97 + 22 h

HEAVY CONVECTIVE + NONCONVECTIVE RAIN

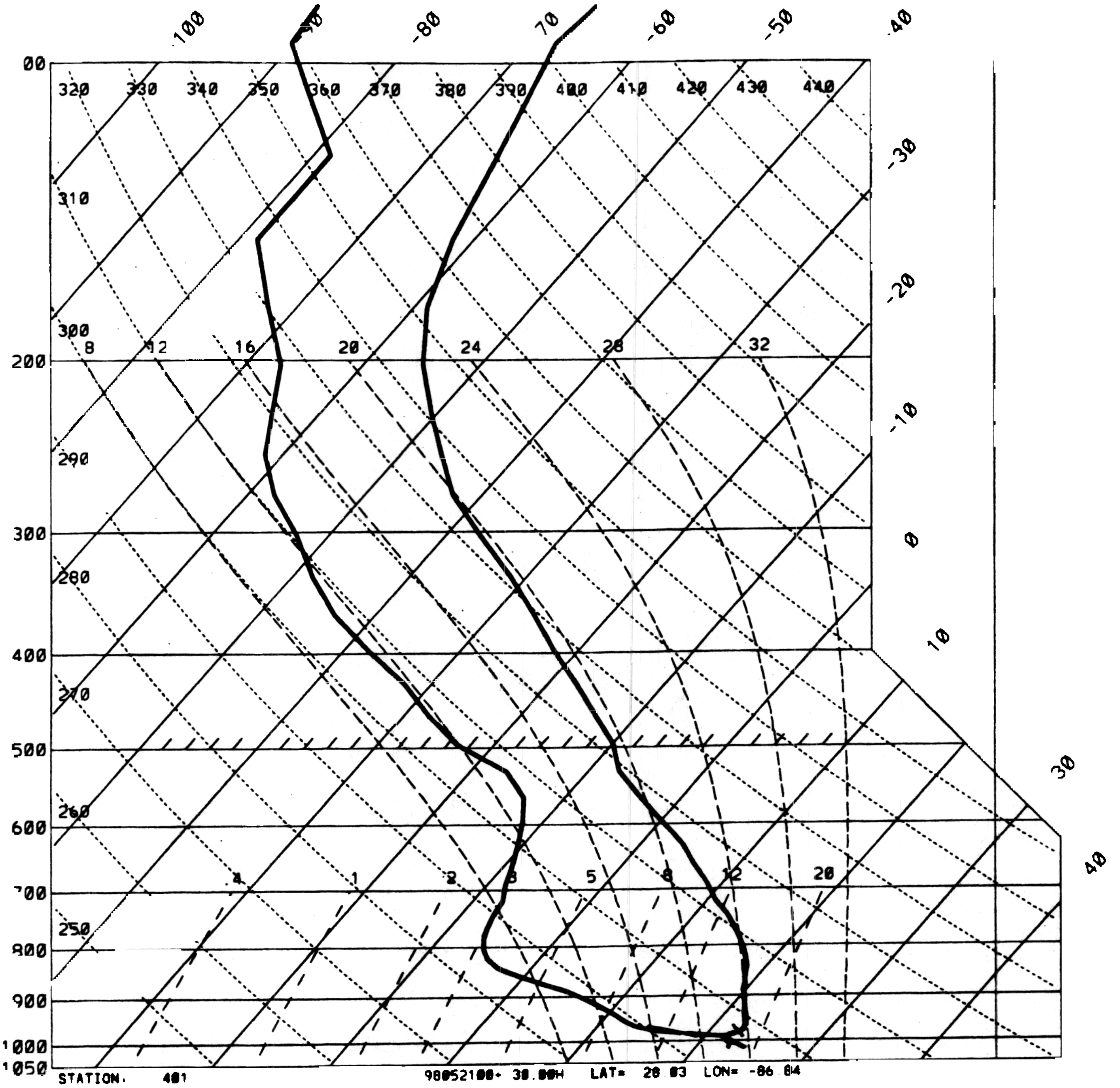


OVER GULF OF MEXICO

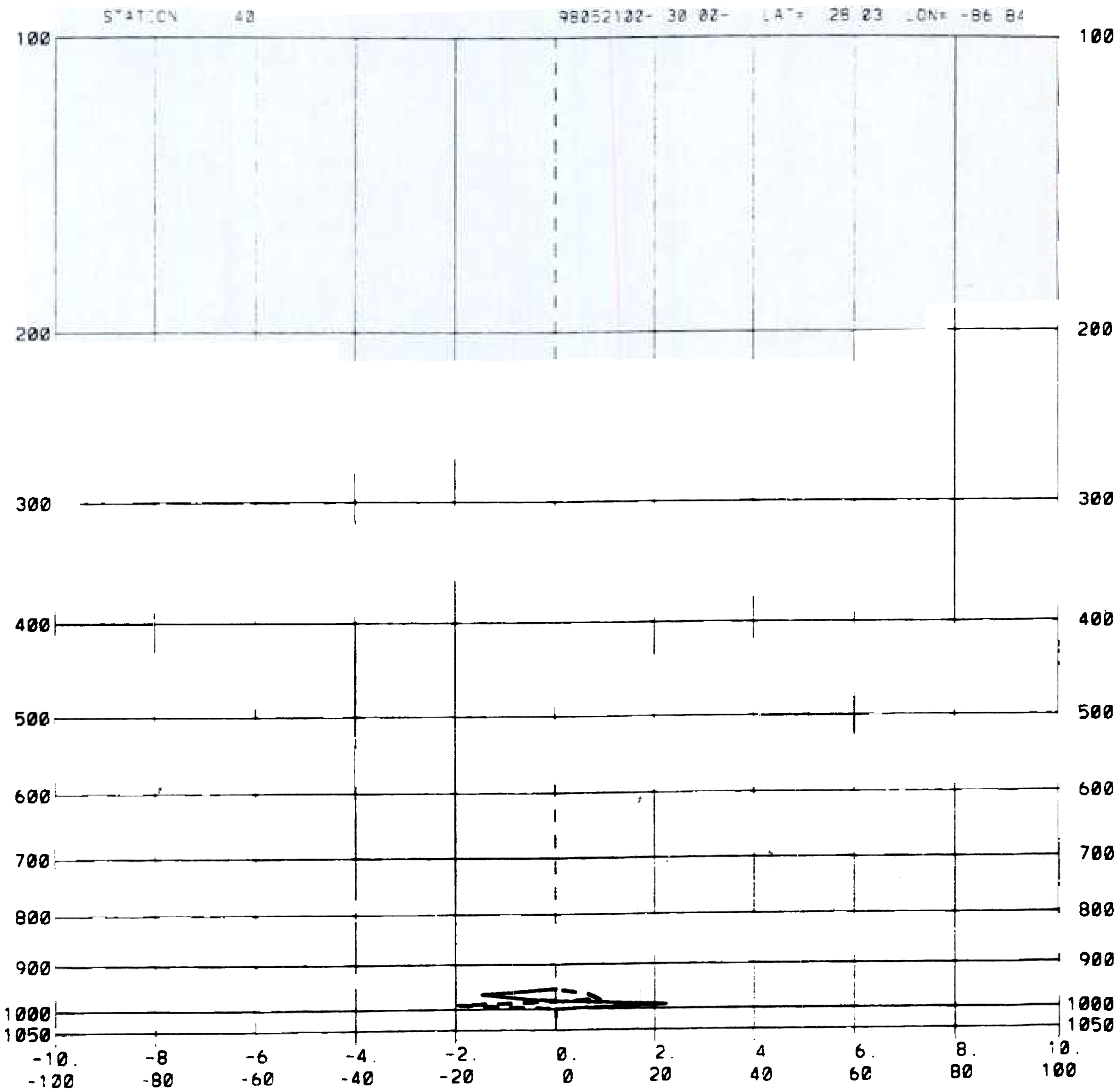


STATION 401 98052100+ 30.00H LAT= 28.03 LON= -86.84

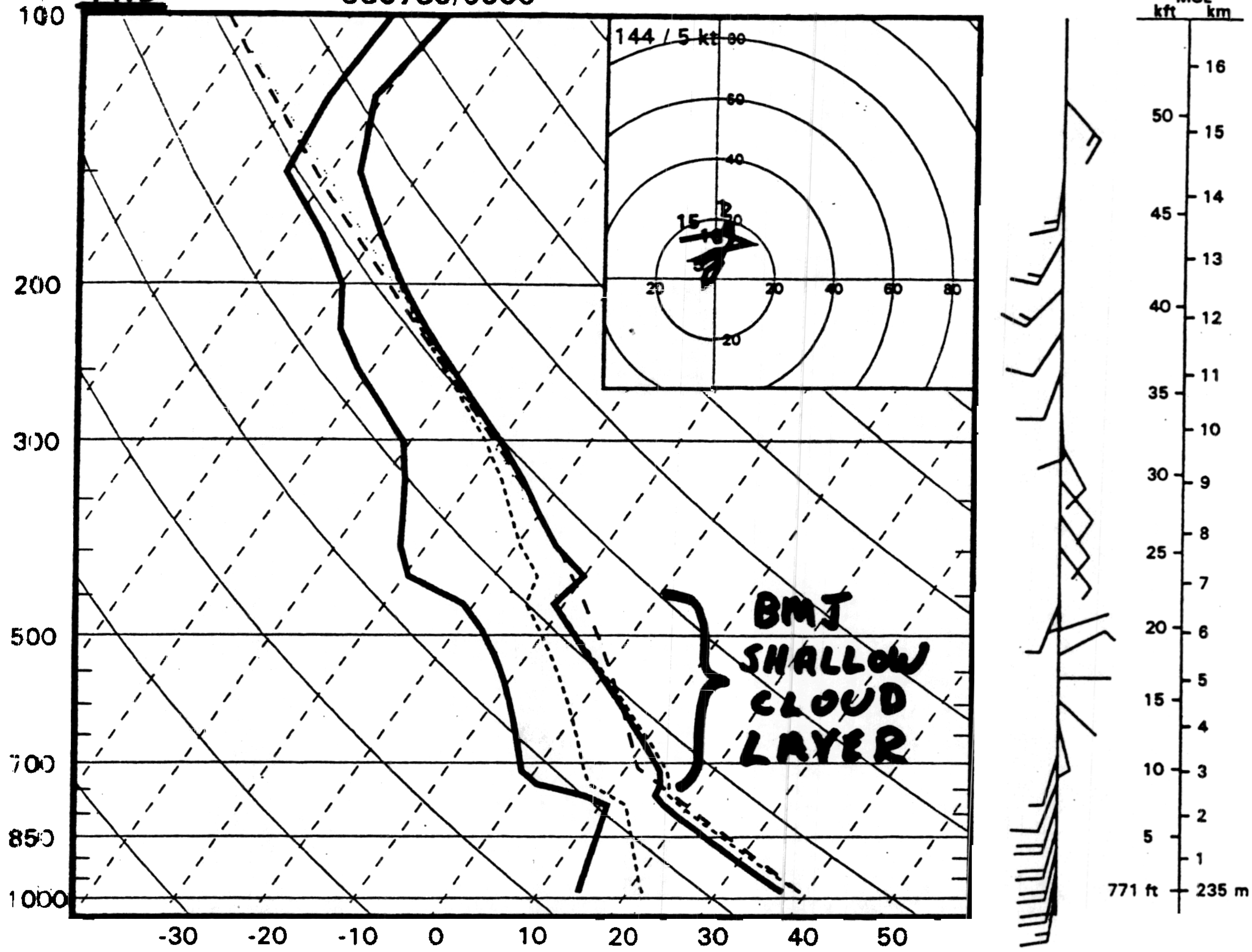
AFTER ENTHALPY CORRECTION - NEGATIVE PRECIP!!



BMJ SHALLOW CONVECTION; NO RAINFALL!!!!


STATION 40
98052102- 30 02- LAT= 28 23 LON= -86 84
100
200
300
400
500
600
700
800
900
1000
1050
-10.
-8
-6
-4.
-2.
0.
2.
4
6.
8.
10.
-100
-80
-60
-40
-20
0
20
40
60
80
100

FWD 980730/0000



THERMODYNAMIC PARAMETERS

MOST UNSTABLE PARCEL

LPL: 984mb 37C/ 14C 99F/ 58F

CAPE:	136 J/kg	LI:	M
BFZL:	3 J/kg	LImin:	0 C @ 332mb
CINH:	-87 J/kg	CAP:	3 C @ 687mb

LEVEL	PRES	HGT(AGL)	TEMP
LCL	709mb	9392ft	
LFC	396mb	24591ft	-16 C
EL	358mb	27013ft	-21 C
MPL	363mb	26680ft	

Precip Water:	1.40 in	Mean RH:	36 %
Mean Q:	10.6 g/kg	Mean LRH:	35 %
Top of Moist Layer:		762 mb / 7372 ft	
700-500mb Lapse Rate:		19 C / 7.2 C/km	
850-500mb Lapse Rate:		32 C / 7.3 C/km	
Total Totals:	49	K-Index:	28
SWEAT Index:	186	Max Temp:	102 F
ThetaE Diff:	49	Conv Temp:	102 F
FRZ Level:	15845 ft	WBZ Level:	12901 ft

Output produced by:
SHARP: SkewT-Hodograph Analysis and Research Program v3.0
J. Hart et.al., 1996, NWS/NCEP/Storm Prediction Center

KINEMATIC PARAMETERS

Sfc - 6 km Mean Wind:	118 / 3 kt	(1 m/s)
LFC - EL Mean Wind:	144 / 7 kt	(3 m/s)
850 - 300 Mean Wind:	185 / 8 kt	(4 m/s)

Sfc - 2 km Shear:	2 kt	(1 m/s)	4.37
Sfc - 6 km Shear:	17 kt	(9 m/s)	42.64
*BRN Shear:	4 m2/s2		

STORM STRUCTURE PARAMETERS

Sfc-3 km SREH:	22 m2/s2	
Effective SREH:	22 m2/s2	from 0 m.

0-2 km SRW:	15 m/s	EHI:	0
4-6 km SRW:	4 m/s	BRN:	31
6-10 km SRW:	2 m/s		