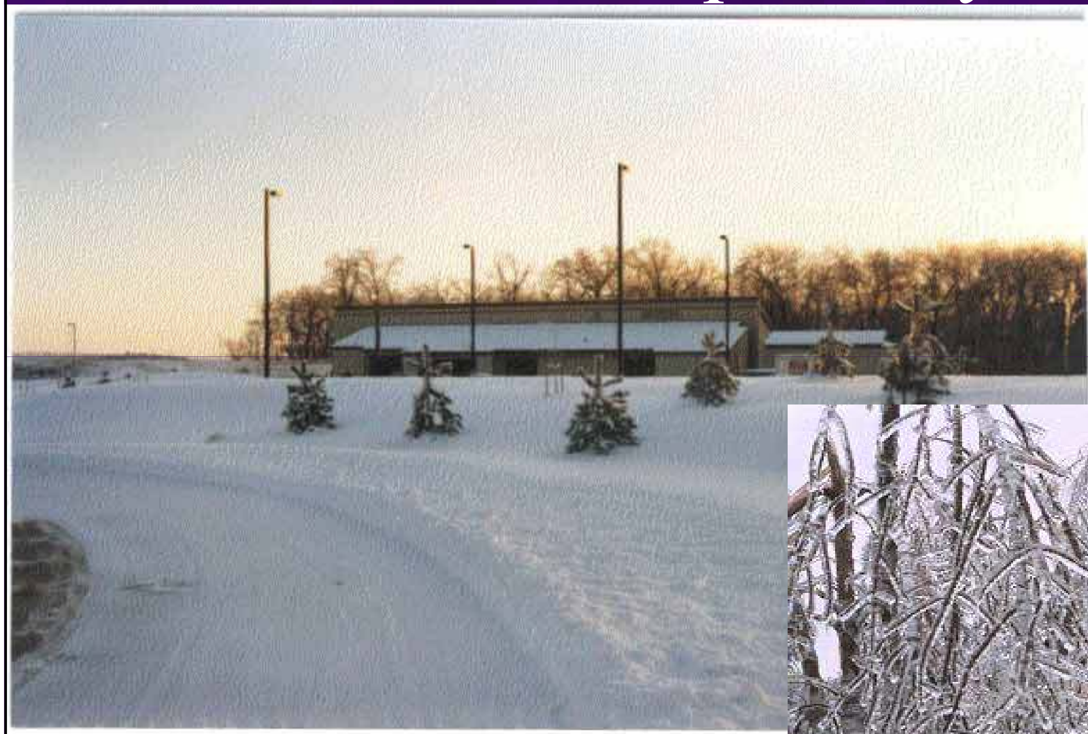
FORECASTING WINTER PRECIPITATION TYPE

A Review Prepared by Gary K. Schmocker



Winter WX Workshop
– November 2004

Partial Thickness

- Used as a first guess to estimate if a layer is below freezing
- 1000-700 mb: 2840 m (rain/snow line)
- Divide this layer to determine potential of freezing rain or sleet
-   850-700 mb: 1540 m
- 1000-850 mb: 1290-1310 m
- Look for pattern of thickness lines (overlapping)

Partial Thickness

Adapted from Cantin et al. 1990

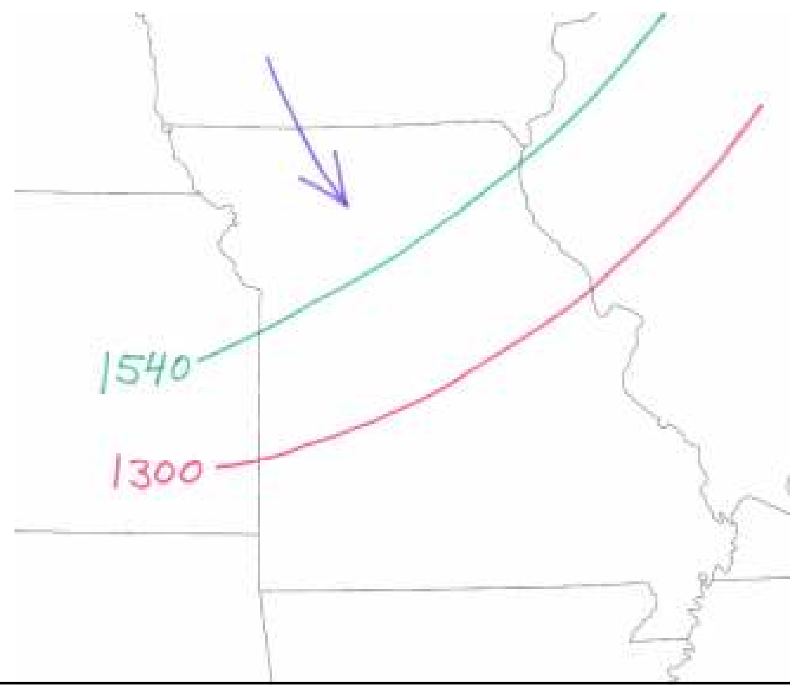
Used for southeastern Canada

Thickness (dm)		Precipitation Types	
850-700	1000-850	Significant UVV or low-level cold advection	Weak UVV and near zero low-level cold advection
<154	<129	Snow	Snow, except sleet and/or freezing rain is possible near 154
<154	129-131	Snow or sleet except may be freezing rain near 154, usually rain with south winds in warm sector	Sleet or snow except >152 usually freezing rain or drizzle, rain in warm sector with south winds
<154	>131	Rain	Rain
>154	<129	Sleet except may be snow near 154)	Freezing rain, freezing drizzle or sleet
>154	129-131	Freezing rain but may be sleet near 154	Freezing rain or freezing drizzle
>154	>131	Rain	Rain

Pcpn Change Forecast during CAA using Partial Thicknesses red line 1000-850 mb & green line 850-700 mb thickness

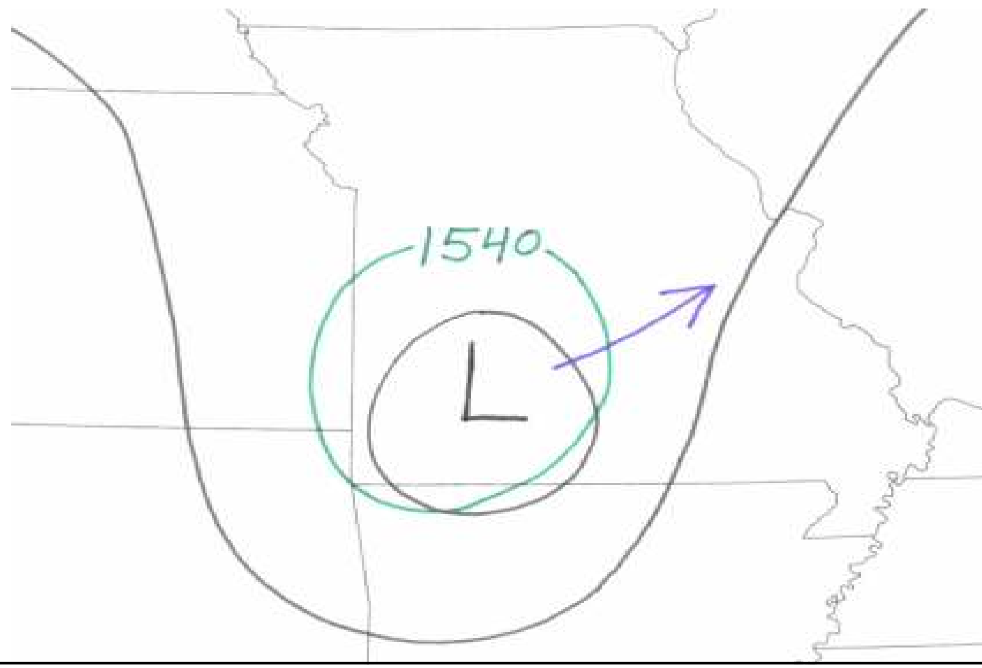
– Favors rain to snow

- Favors rain to freezing rain/sleet then snow



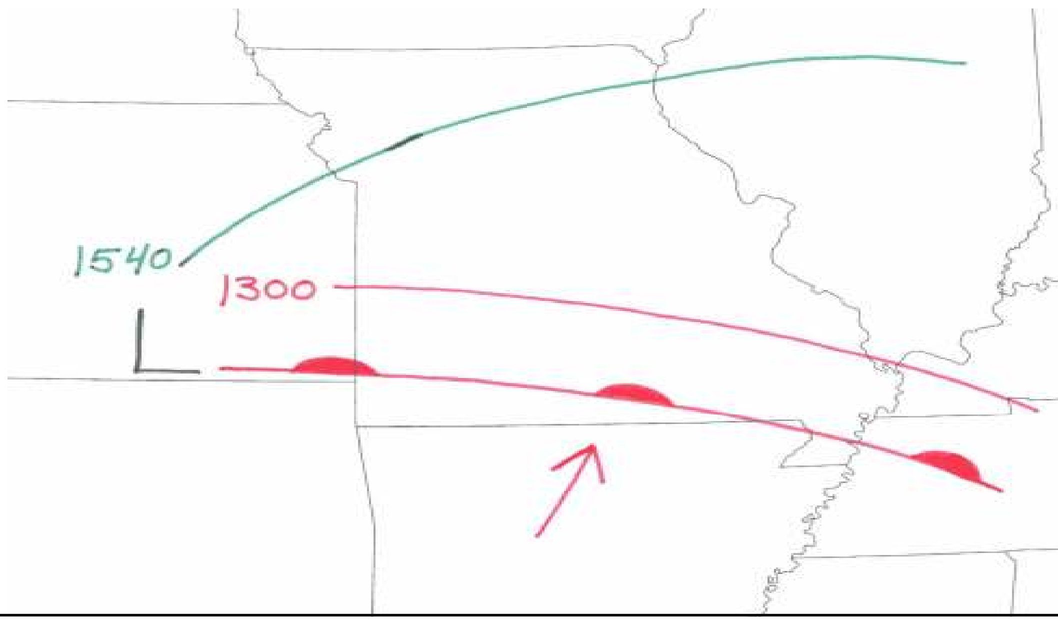
Pcpn Type with Closed (Cutoff) Mid-Upper Low

Favors rain followed by possible brief period of wet snow underneath or just north or west of low–sfc based warm layer may partially or completely melt snowflakes



Pcpn Type with Isentropic Upglide of Warm, Moist Air "Overrunning" Arctic Air Mass

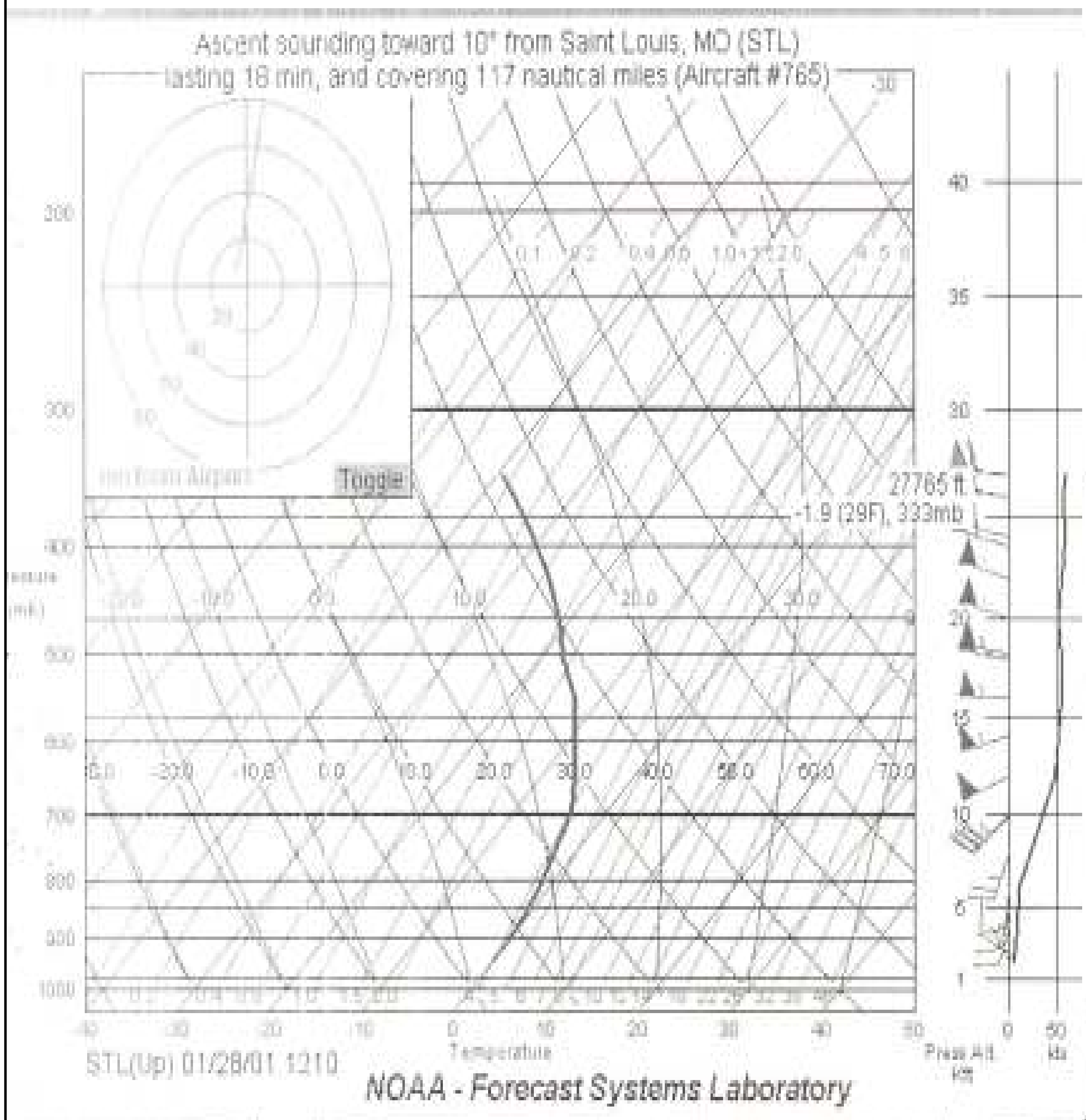
Favors freezing rain/sleet with shallow cold air over STL-elevated warm layer will partially or completely melt snowflakes with refreezing in the cold sfc layer



Soundings

- Superior to using partial thickness
  - can resolve thin warm layers (>0°C)
- For STL use ACARS soundings or model soundings (initial or forecast from RUC, ETA, LAPS, or GFS)
  - use BUFKIT Program or display Bufr files on AWIPS
- ACARS Website: http://acweb.fsl.noaa.gov/
  - displays weather data from automated sensors on commercial aircraft
- Interactive Soundings Website: http://www-frd.fsl.noaa.gov/mab/soundings/java/
  - interactively displays soundings from RUC2, MAPS, RAOBs, Profilers, & ACARS

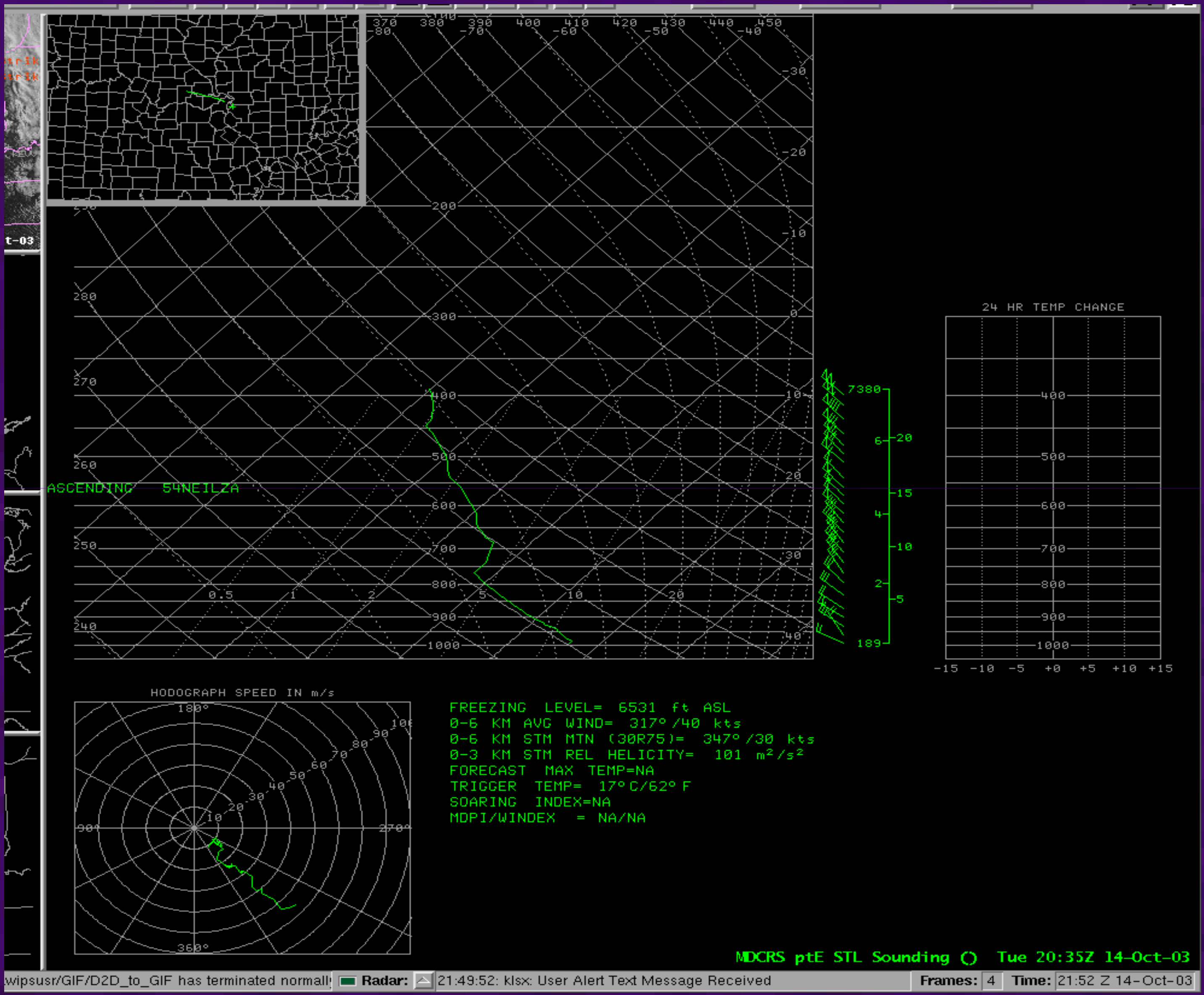
An Example of ACARS Data at STL



STL(Up) 01/28/01 1210
ascent sounding toward 10° from Saint Louis, MO (STL)
lasting 18 min, and covering 117 nautical miles (Aircraft #765)

P_alt (ft)	mb	t/td (°C)	w_dir/w_spd (kts)	Bng/Rng from gnd pt (nm)	
2000	942	0.0/-----	127°/007	319°/009	1211 UTC
2490	925	-0.1/-----	295°/008		
4030	874	-0.3/-----	198°/010	336°/009	1211 UTC
4779	850	-0.6/-----	194°/011		
6030	811	-1.0/-----	188°/012	345°/011	1212 UTC
8040	752	-2.5/-----	202°/024	352°/015	1213 UTC
9886	700	-3.7/-----	229°/035		
10030	696	-3.8/-----	231°/036	355°/018	1213 UTC
12050	641	-6.5/-----	245°/049	359°/023	1214 UTC
14060	594	-9.8/-----	253°/053	1°/027	1215 UTC
16010	549	-13.0/-----	269°/056	2°/030	1216 UTC
18040	505	-17.5/-----	276°/057	3°/034	1216 UTC
18303	500	-18.0/-----	277°/056		
20020	466	-21.3/-----	283°/053	4°/038	1217 UTC
22020	428	-25.8/-----	283°/056	5°/045	1218 UTC
23596	400	-29.8/-----	281°/059		
24000	393	-30.8/-----	281°/060	6°/051	1219 UTC
26000	360	-36.3/-----	277°/058	6°/060	1220 UTC
26980	345	-39.5/-----	274°/060	8°/088	1224 UTC
27000	345	-39.5/-----	271°/061	10°/117	1228 UTC

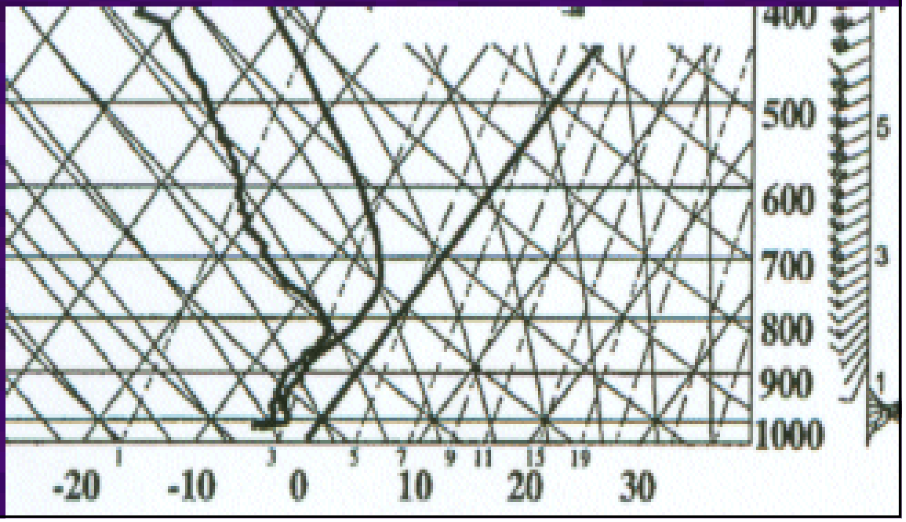
ACARS Data now on AWIPS



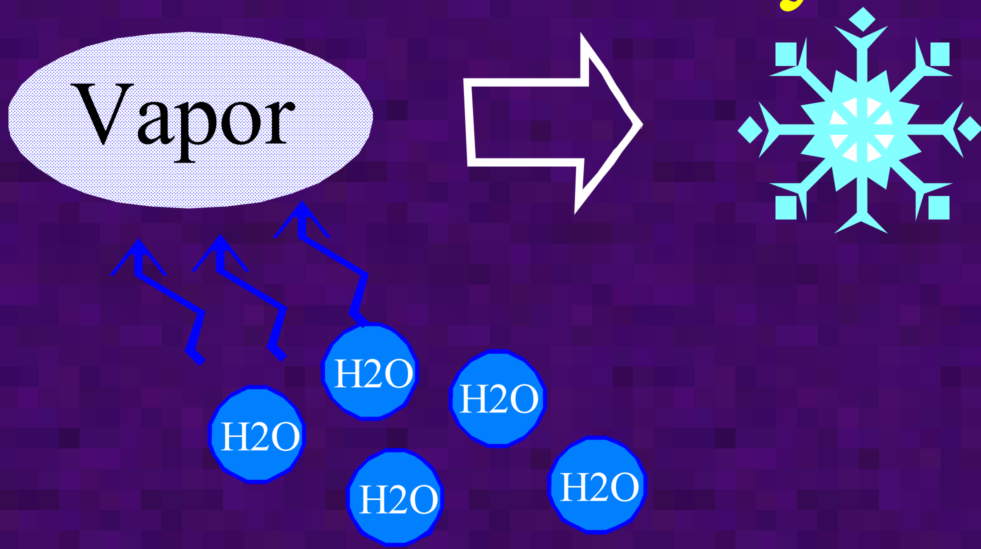
Listed as “MDCRS” in volume browser

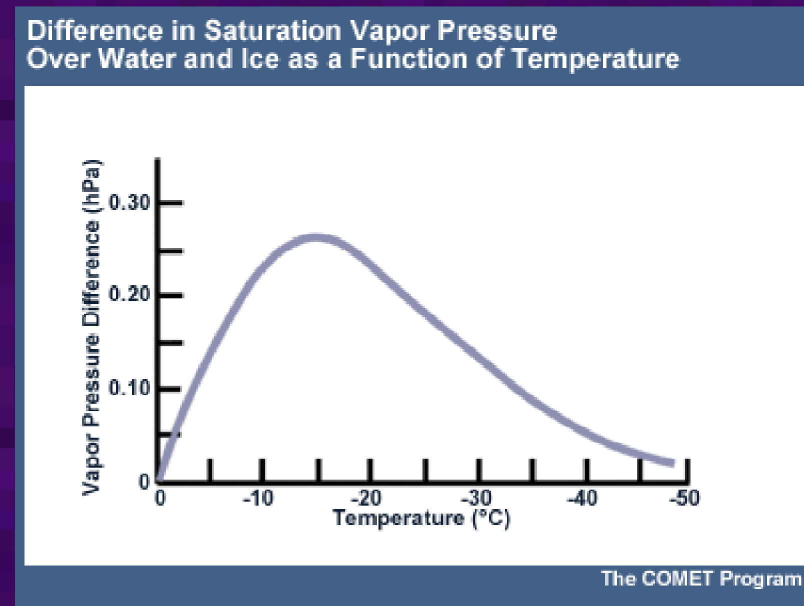
Is it Cold Enough for Ice Crystals to Form in the Clouds?

- Heterogeneous nucleation: supercooled liquid condensing onto an ice nuclei (usually clay in the midwest) to form an ice crystal
- Temperature has to be below –4° C for any ice nucleation to occur in a cloud:
  –10° to –15°C yields a high chance (60-90%) of ice being in the cloud
  - Shallow (low level) cloud decks often not cold enough for ice crystal development



Ice Crystal Growth





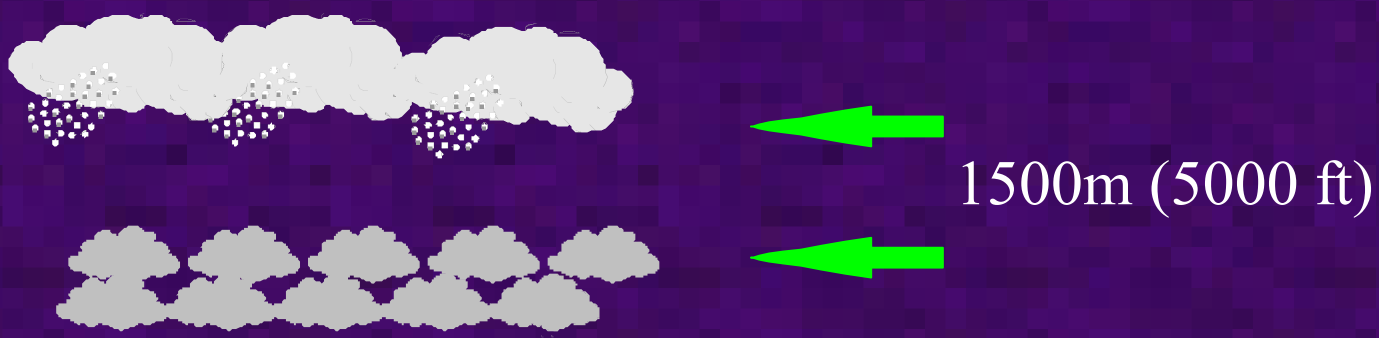
- Deposition – ice crystals growing at the expense of supercooled water droplets, maximized at -15°C (dendrites grow at -12°C to -18°C)
  - look for strong vertical motion around -15°C on time/cross sections for potential heavy snowfall/high snowfall rates (Auer & White, 1982)

Ice Crystal Growth (Continued)

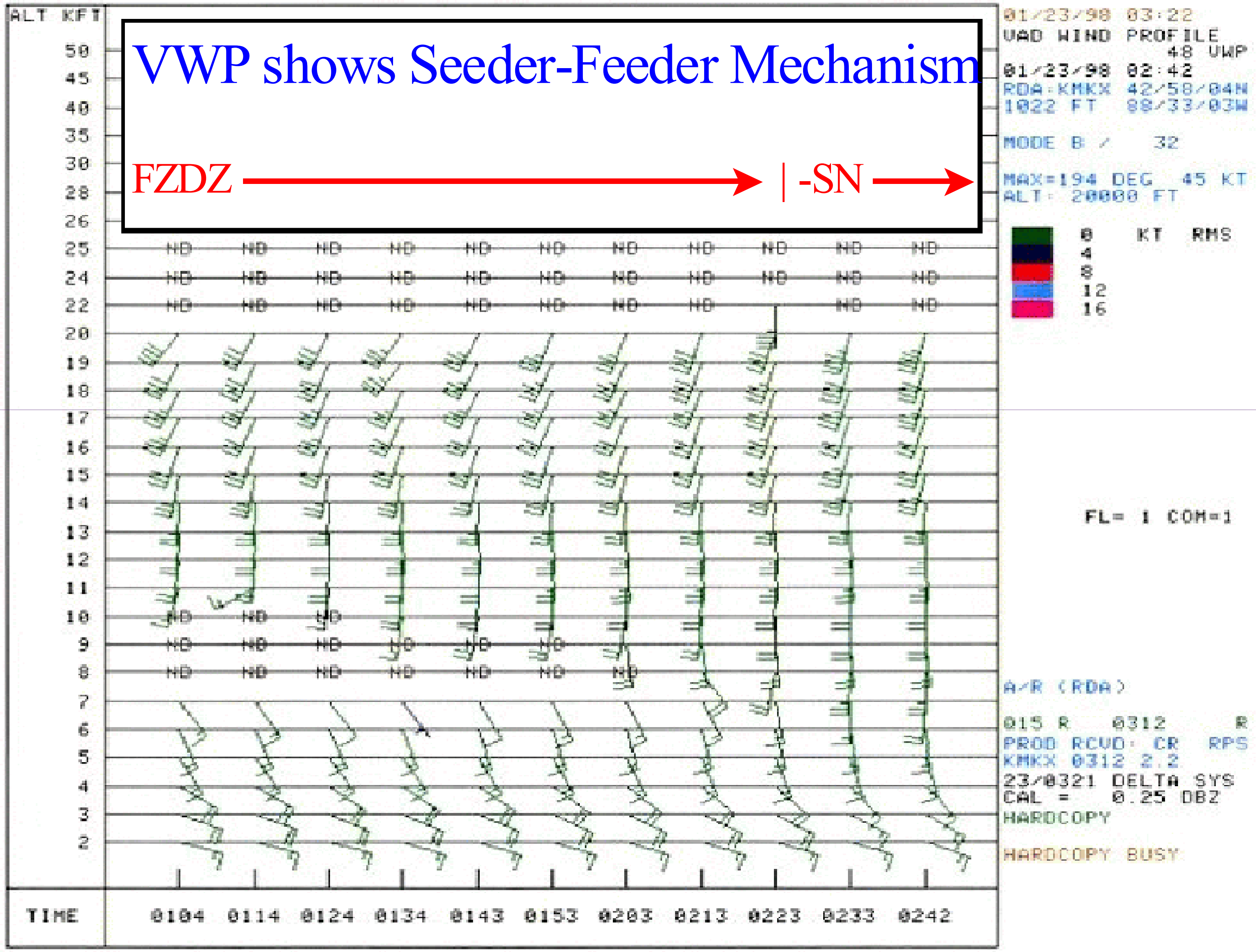
- Accretion or Riming – ice particles overtaking or capturing supercooled liquid water droplets (lower portion of cloud, maximized in saturated layer with temperatures between 0°C and -10°C)
  - excessive riming produces graupel or snow pellets
- Rime splintering – Ice particle splintering during the freezing process produces more ice nuclei (maximized at -5°C)
- Aggregation – ice particles colliding and coalescing to form snowflakes. Largest snowflakes occur with a deep moist isothermal layer near 0°C (below 700 mb).

Seeder-Feeder Mechanism

- A cloud with ice crystals can "seed" a lower warmer cloud (feeder)
- About 5000 ft or > between cloud layers - ice will evaporate/sublimate before reaching the feeder cloud - seeder-feeder most effective with a separation of 3500 ft or less
- Use IR Satellite for higher cloud temperatures
- WSR-88D VWP to assess distance between clouds



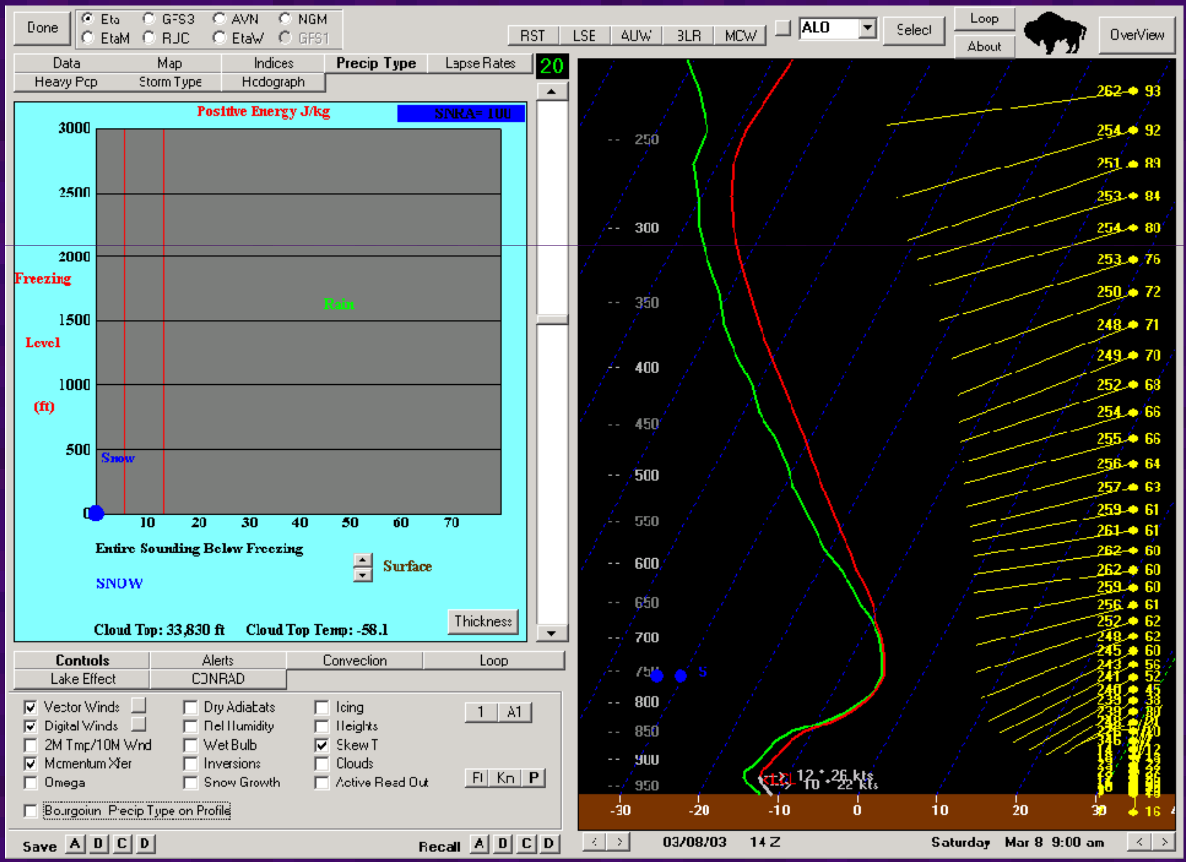
VWP shows Seeder-Feeder Mechanism



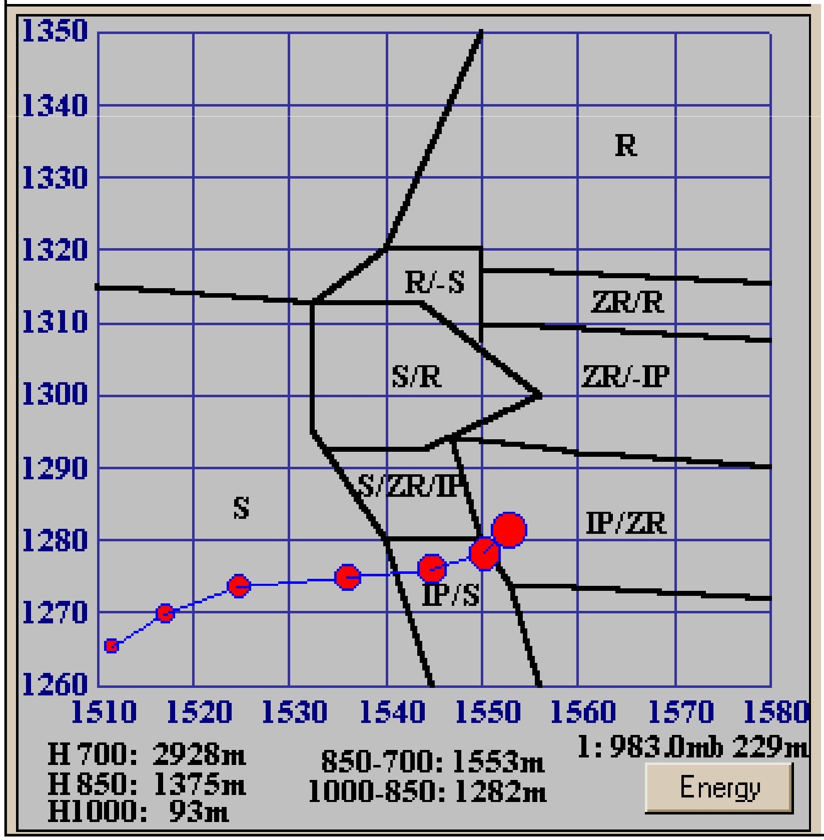
BUFKIT Sounding Program

- Uses the BUFR grid files which contain the full resolution of the model soundings (ETA, RUC, and GFS)
- Three different & independent p-type BUFKIT displays:
  - model output of p-type displayed on the profile itself (lower left side of sounding profile)
  - partial thickness nomogram
  - Bourgouin energy area technique
- Display tine-height sections to look for the "Cross Hair" signature

Example of BUFKIT Display with P-Type Forecast

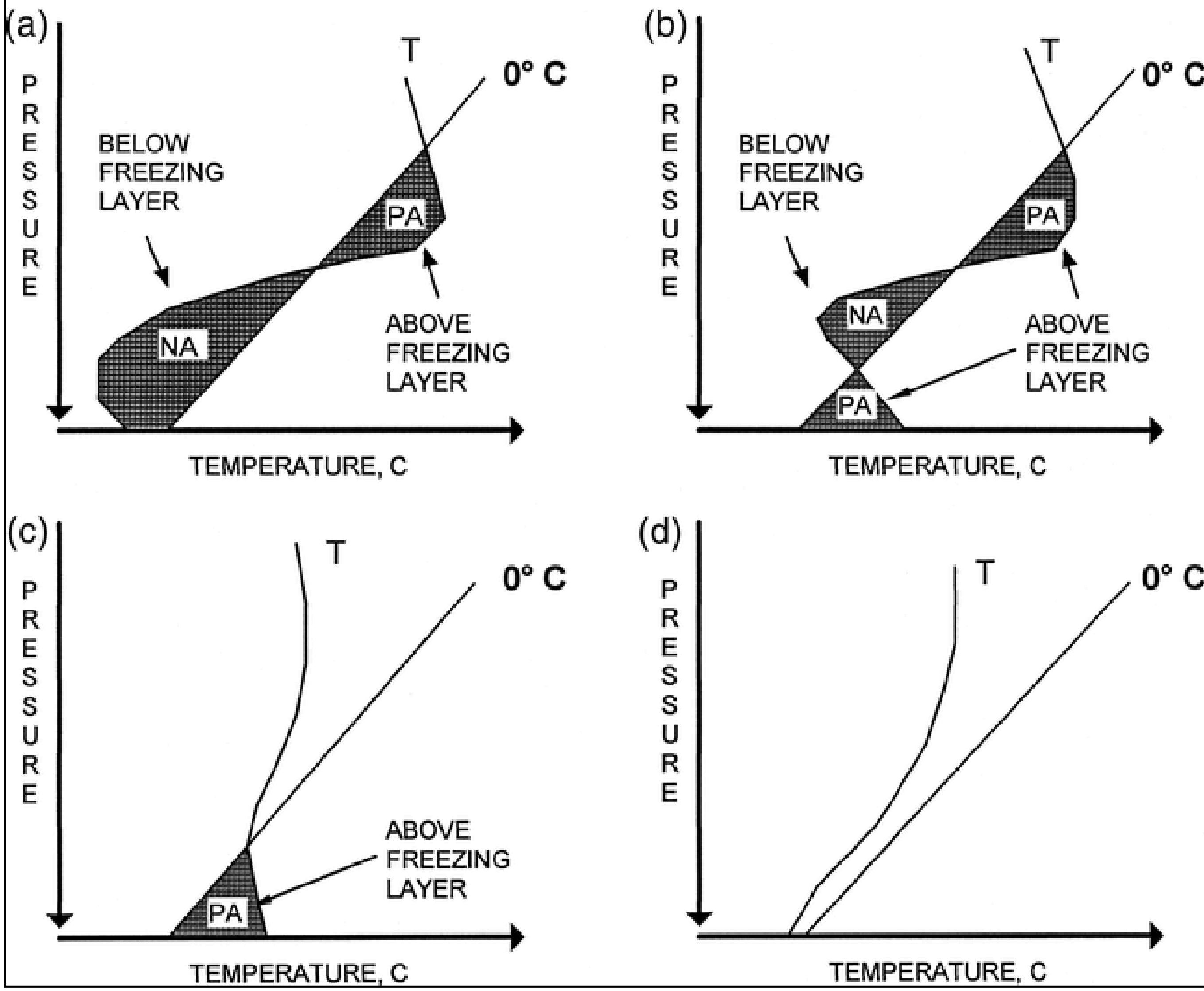


Using the Partial Thickness Nomogram in BUFKIT



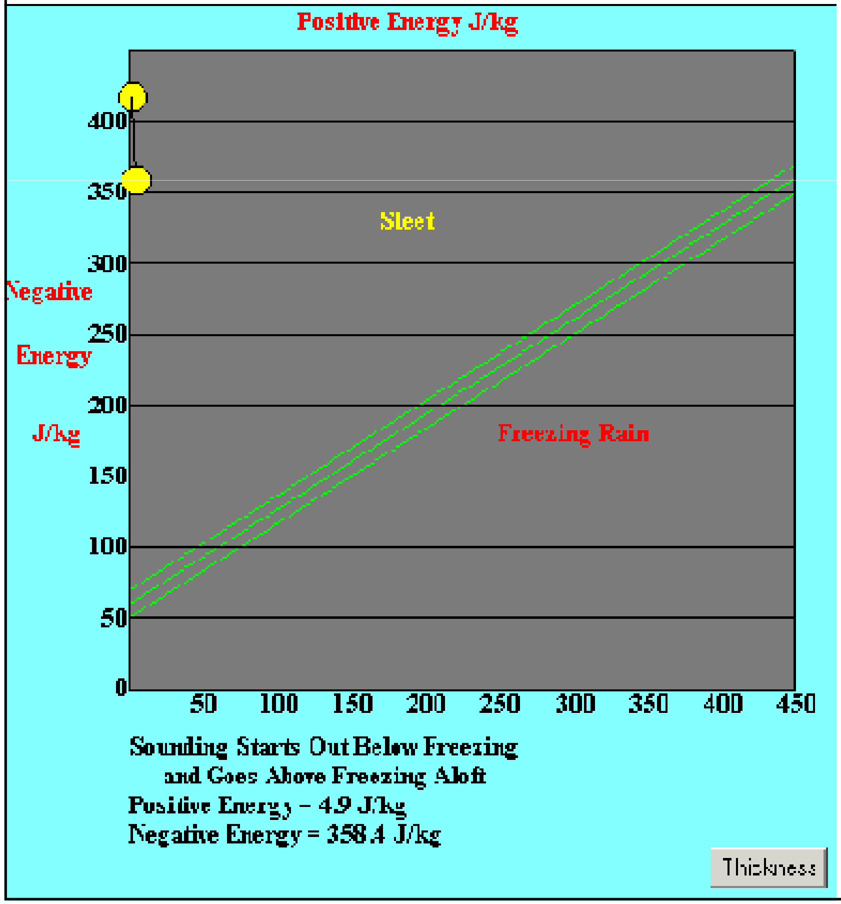
- Nomogram developed from a database of cases over the SE U.S. (Keeter et al.)
- X axis: 850 –700 mb thickness
  Y axis: 1000-850 mb thickness
- The largest circle represents the last p-type fcst
- "Looping" function allows forecaster to see model p-type fcst trends
  - low to mid level thermal advections and changes in stability

Bourgouin Energy Area Technique in BUFKIT



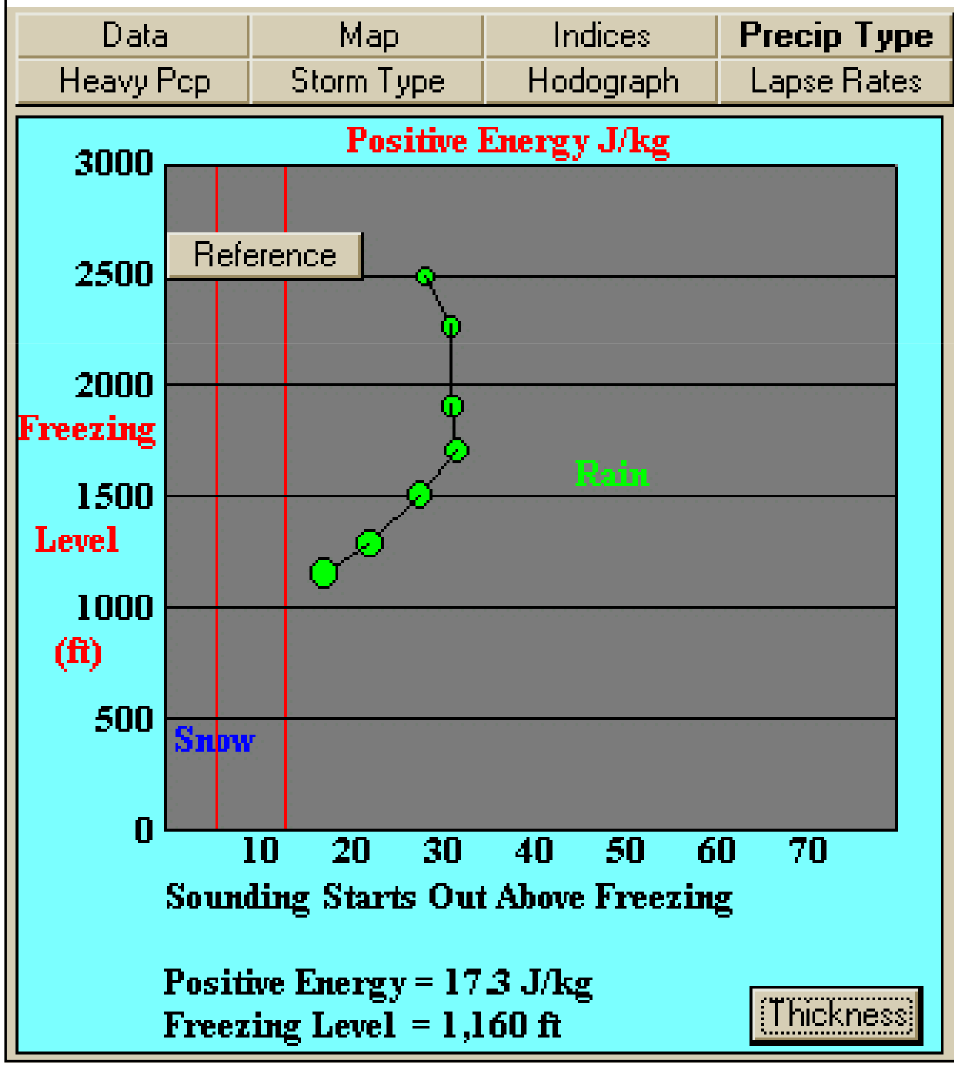
- Consider 4 possible temperature profiles:
  a) FZRA, PL, SN
  b) RA, PL
  c) RA, SN
  d) SN, FZDZ, FZRA
- Compute the positive (PA) and negative (NA) energy areas in each layer

1. Warm Layer Aloft



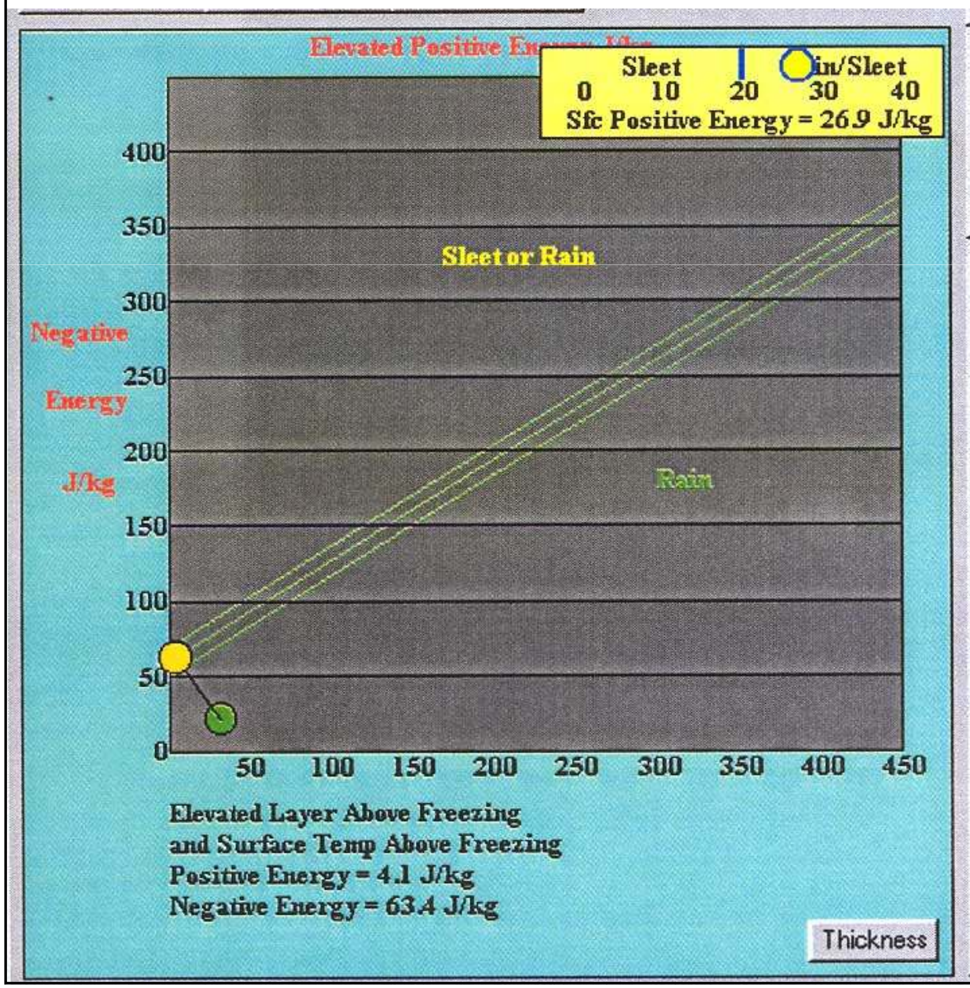
- P-Type (usually sleet or freezing rain) based on amount of (+) energy (energy or size of an area is proportional to the mean temperature and depth of layer) in elevated warm layer (>0°C) versus (–) energy in cold surface based layer (<0°C)

2. SFC Based Warm Layer



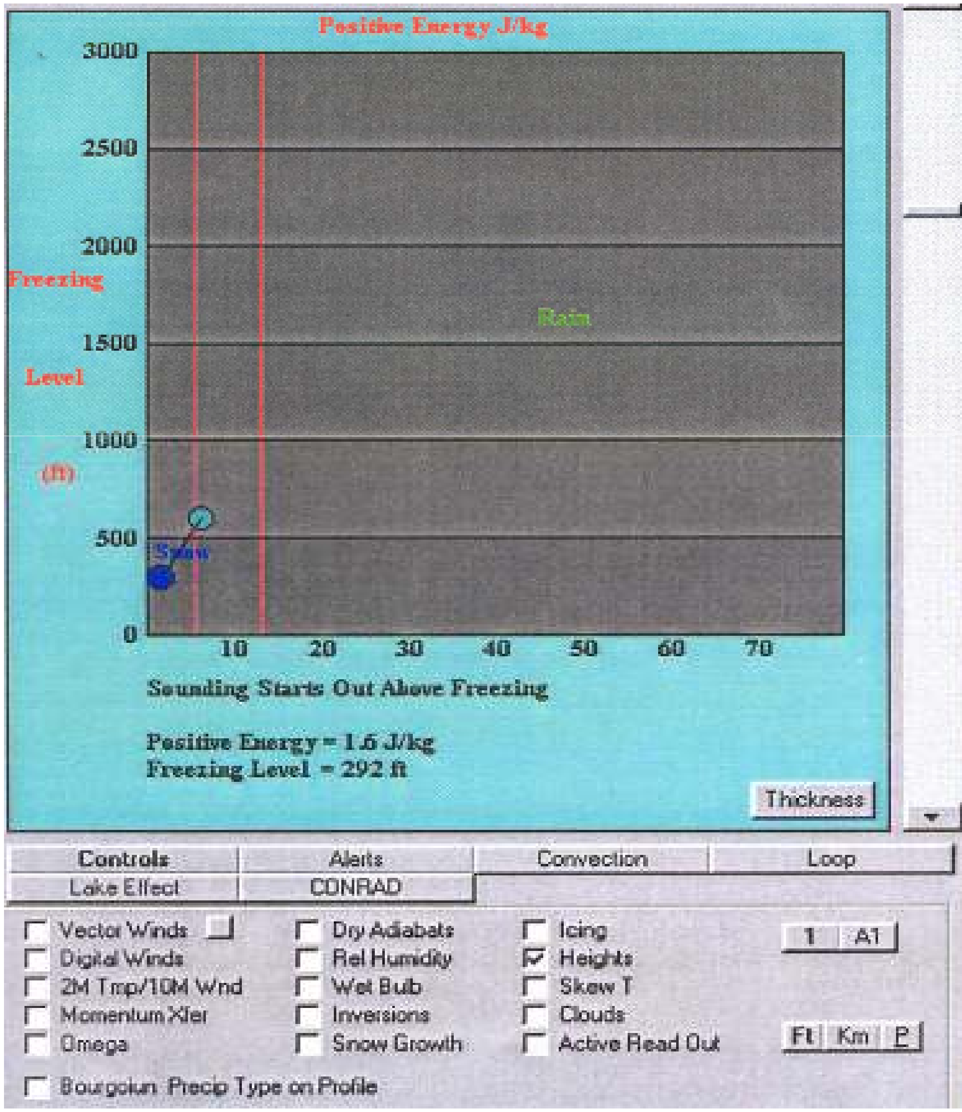
- Uses both the height of the freezing level and the amount of (+) energy in the sfc based warm layer to determine p-type (either rain or snow)

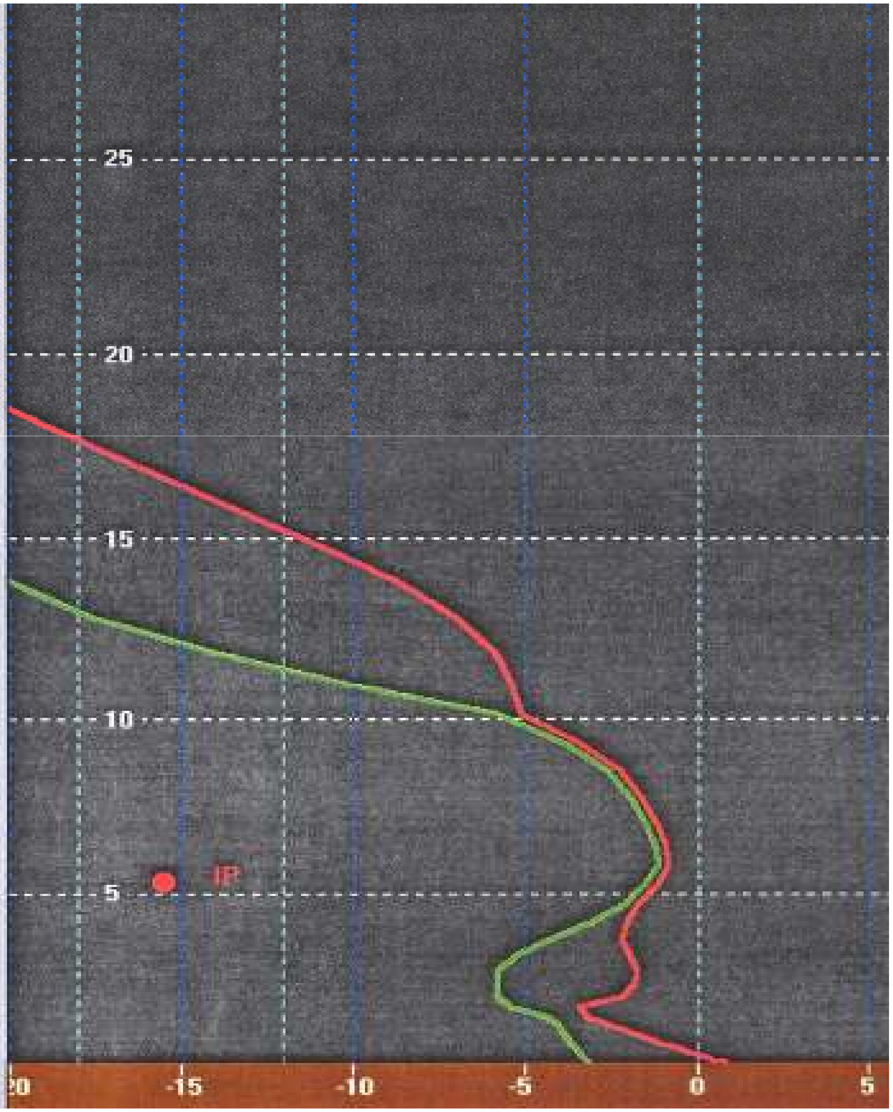
3. Both an Elevated Warm Layer & a SFC Warm Layer



- P-type either sleet, a mix of rain & sleet, or rain. It first determines if sleet is possible (rather than freezing rain which will become rain in sfc warm layer) based on amount of (+) energy in elevated warm layer versus (–) energy in cold layer below. Then if sleet is expected, it determines if it will melt or not by the amount of (+) energy in sfc warm layer (upper right box).

Model fcsts sleet, but Bourgouin says snow?

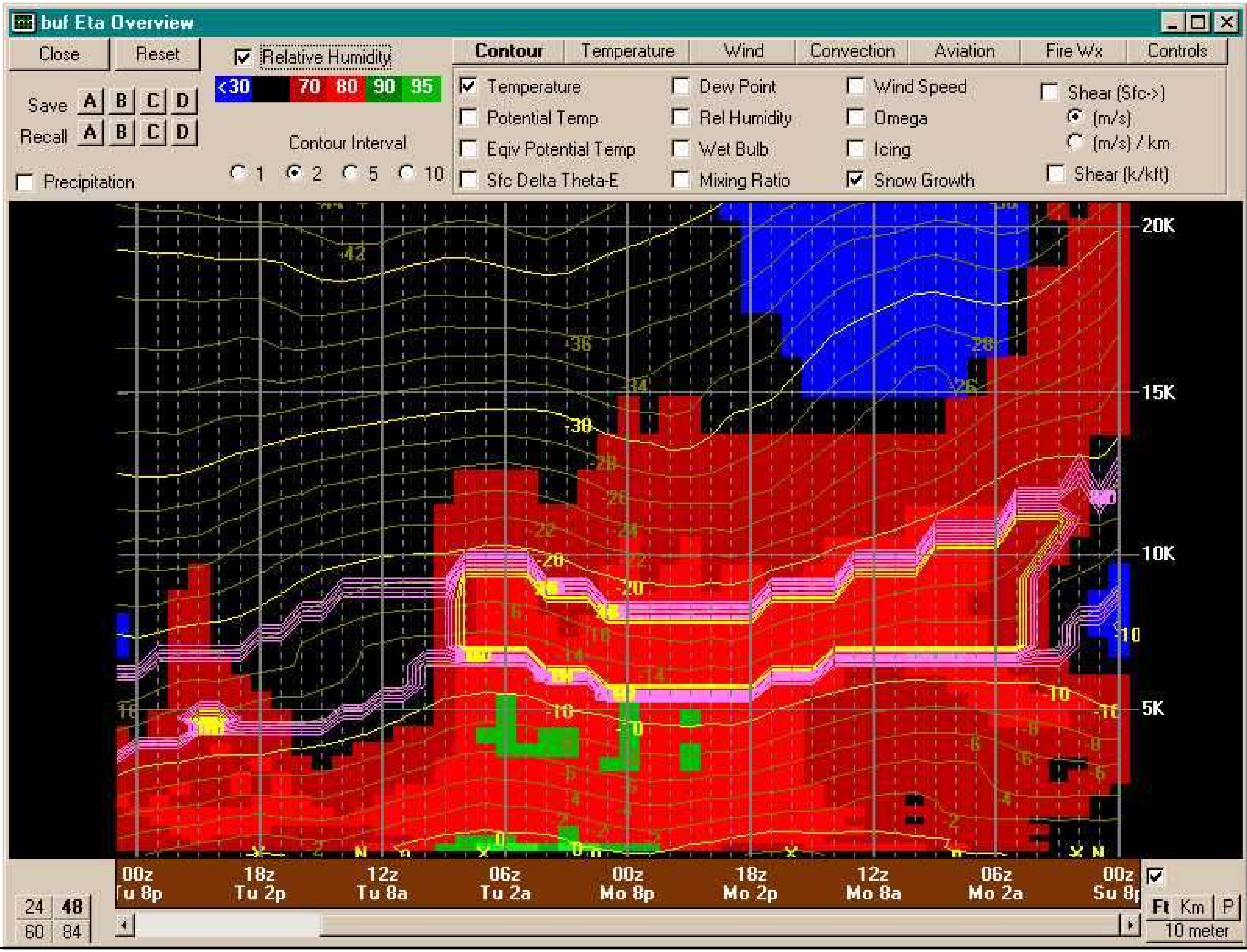




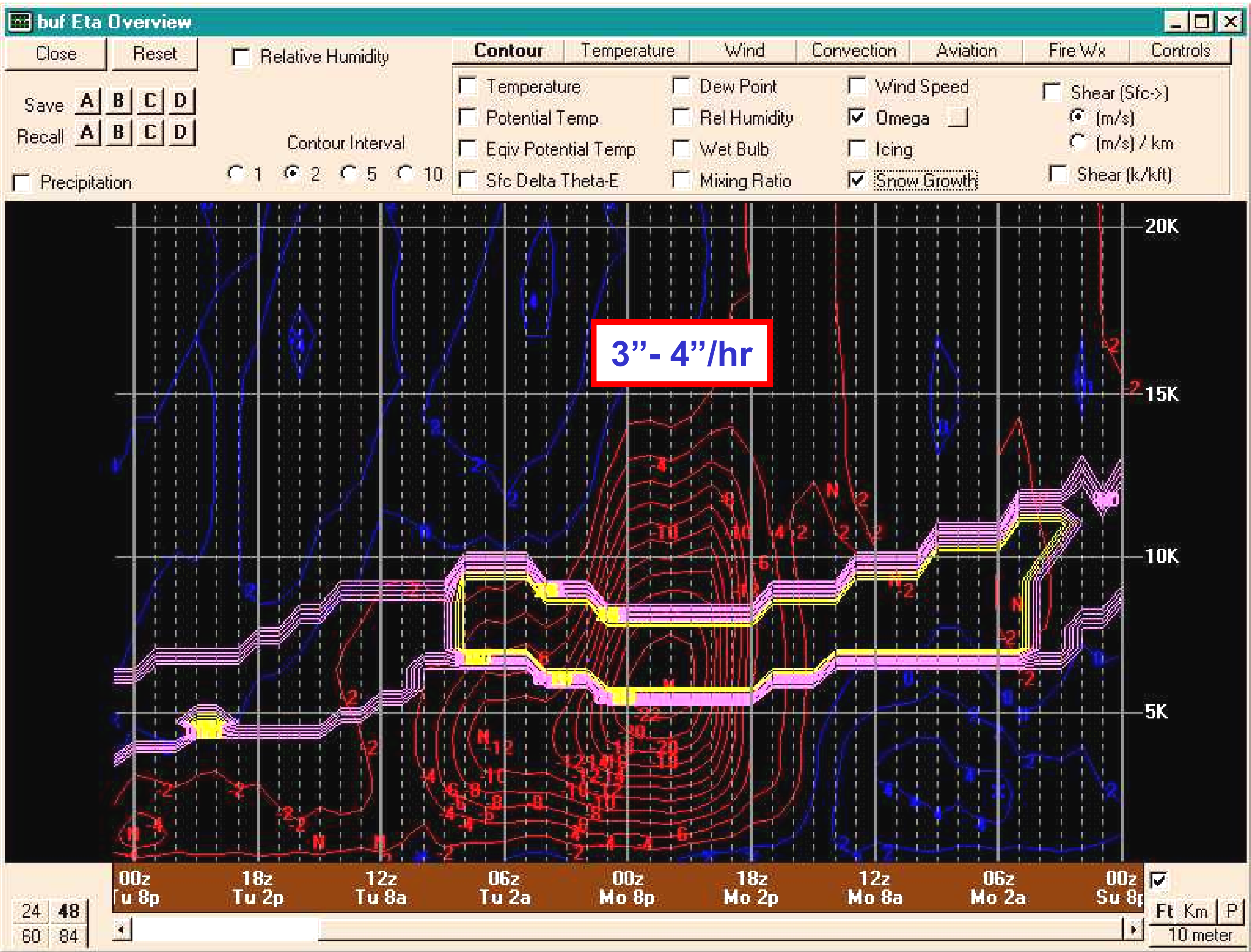
Using BUFKIT to Identify the "Cross Hair" Signature

- The intersection of:
  - moderate lift: omega max at least 10 ub/s (20 km eta) or 15 ub/s (12 km eta); omega values a function of model resolution
  - temperatures favorable for dendrite formation: (-12 to -18°C)
  - RH>75%
- Signature should be present in 2 of 3 successive model runs (run to run consistency)

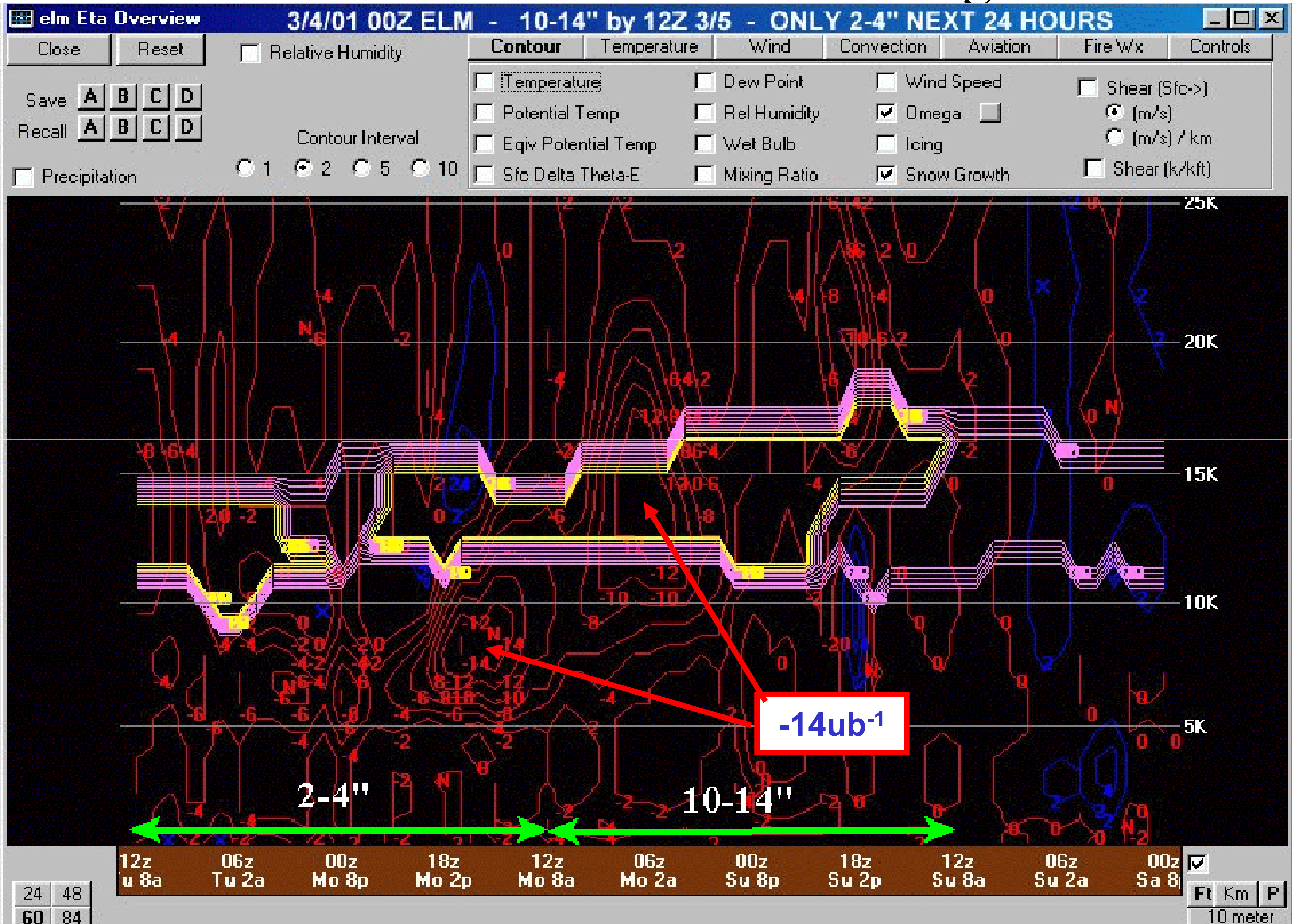
Combination of RH & Dendritic Growth Zone



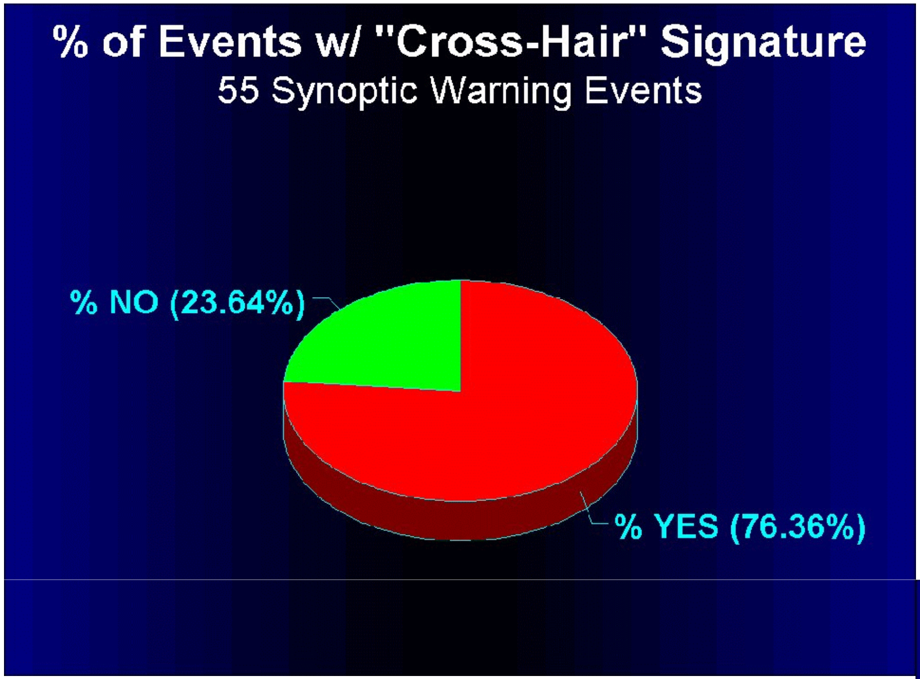
Combination of omega & dendritic growth zone



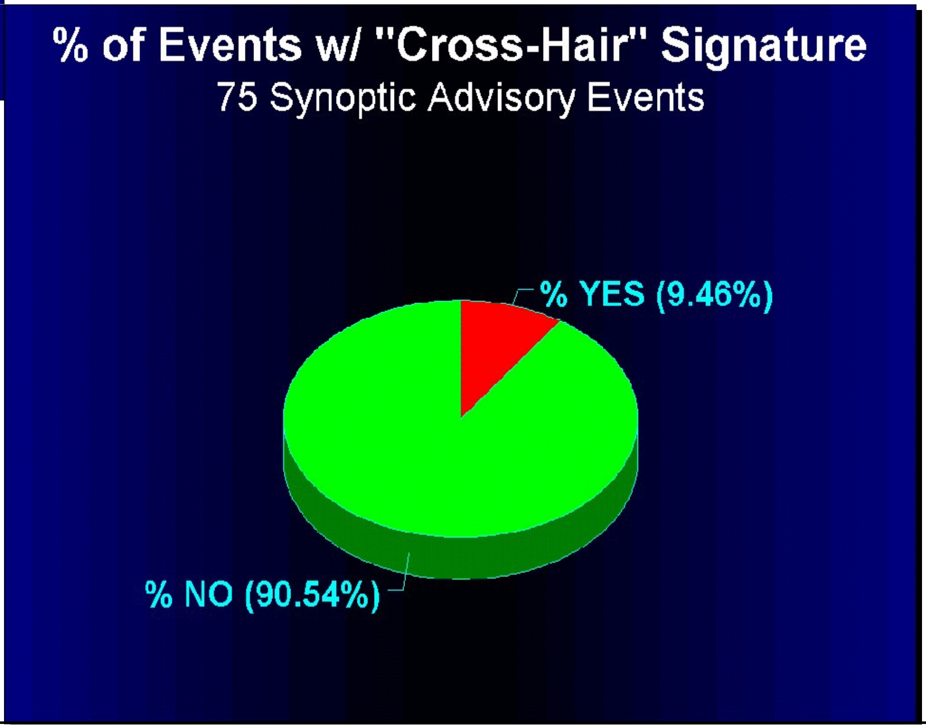
-14 ub/s within & later below dendritic growth zone



Waldstreicher Snow Study

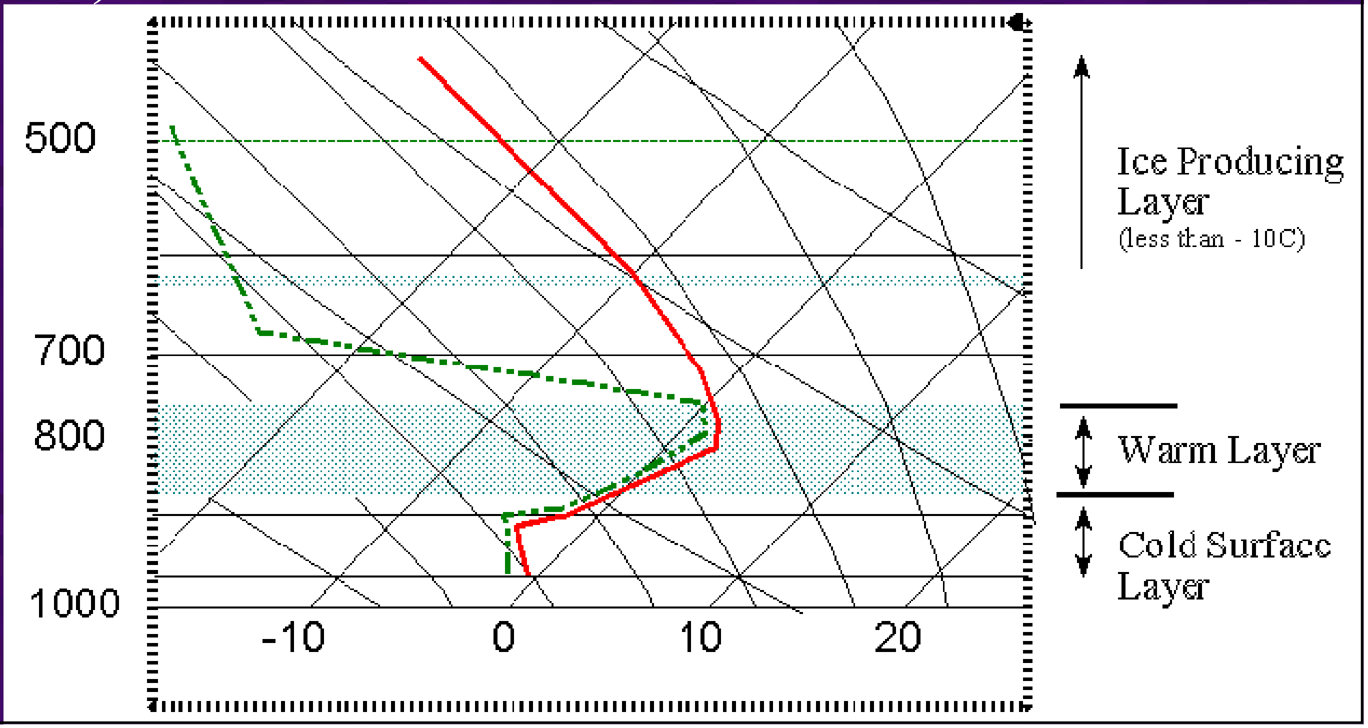


- Snow Cases in Northeast U.S. in 1998-2001
- "Cross-Hair" Signature may have utility in distinguishing warning vs. advisory events



P-Type with an Elevated Warm Layer

- Cooler mid-level air mass – cloud top (Is it cold enough for the formation of ice crystals?)
- Elevated warm air mass (warm layer-possible melting depending on the temperature and depth of this layer)
- Surface-based cold (arctic) air mass (freezing of supercooled water on contact, or refreezing of partially melted snowflakes)



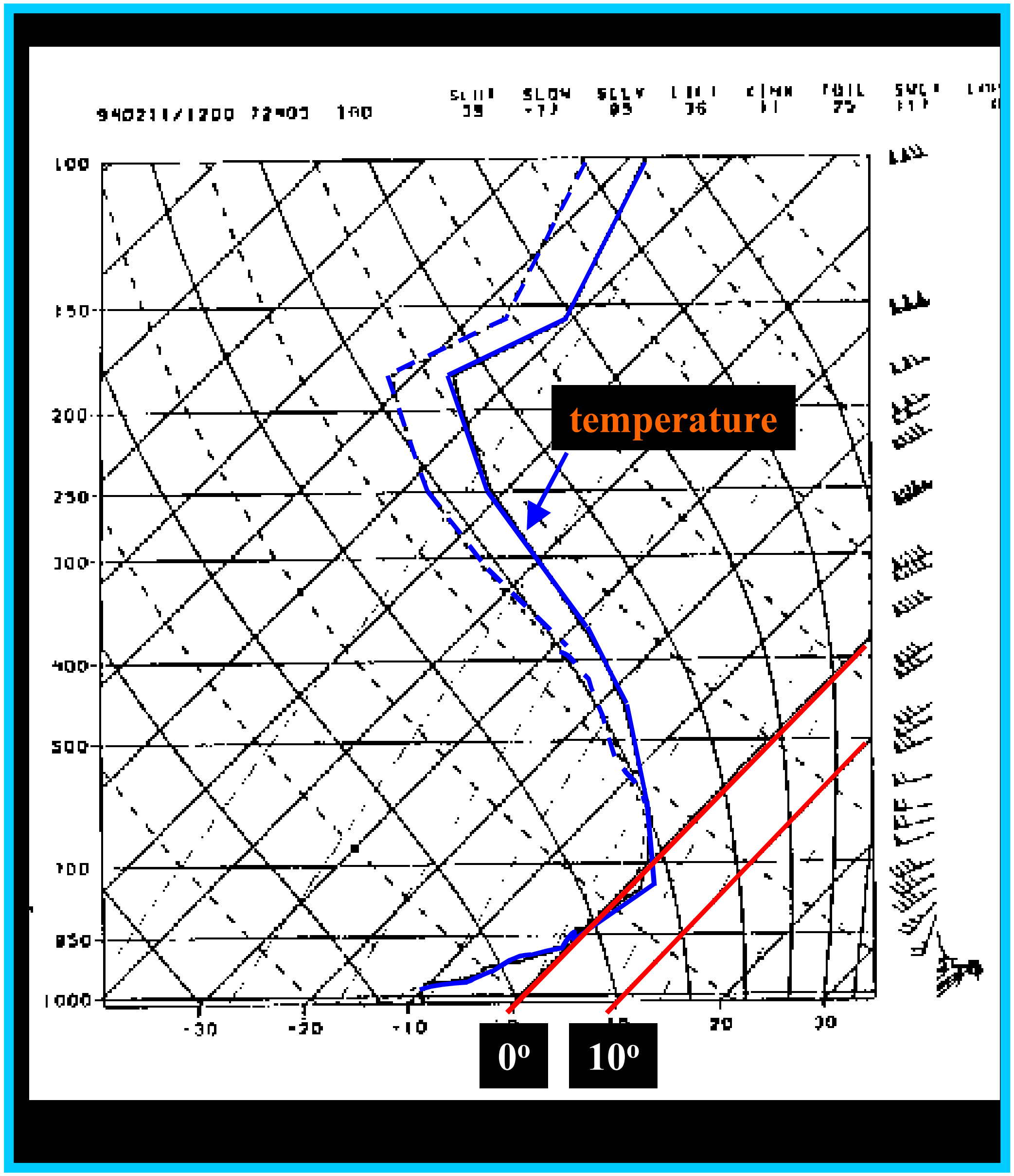
Elevated Warm Layer

- Precipitation type based on warm layer max temperature (Stewart 1985 & Stewart and King 1987)
- Depth of the warm layer is proportional to the max warm layer temperature (Zerr 1997)
- If ice is introduced into the warm layer, and the surface temperature is below 0°C:
  <1°C warm layer max temp.– very little melting with refreezing to snow
  1 to 3°C – partial melting favors sleet, but snow (near 1°) or freezing rain (near 3°) may be mixed in
  >3-4°C – complete melting of snowflake resulting in freezing rain

* Vertical Motion dependent

Warm Layer Maximum Temperature	Precipitation Type *with* ice introduced	Precipitation Type *without* ice introduced
< 0.5C	Snow	Freezing Drizzle/Rain**
0.5C to 3C	SN/PL Mix (0.5C) to All Sleet (3C)	Freezing Drizzle/Rain**
> 3C	Freezing Rain/Drizzle*	Freezing Drizzle/Rain**

PRECIPITATION TYPE

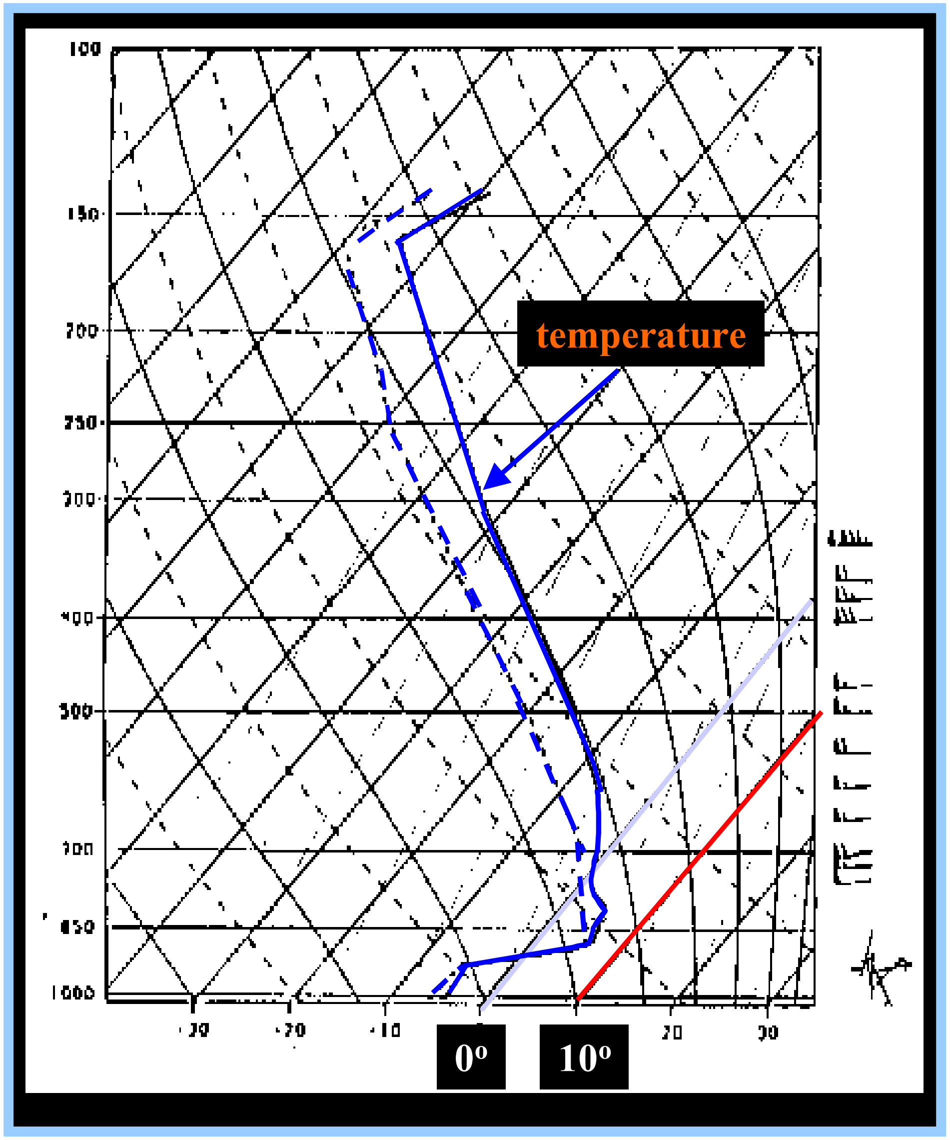


An ice pellet sounding

Note: temperature of warm layer is 1°-3° C

From Wes Junker (HPC)

PRECIPITATION TYPE



A freezing rain sounding

Note: temperature of the warm layer is above 4° C.

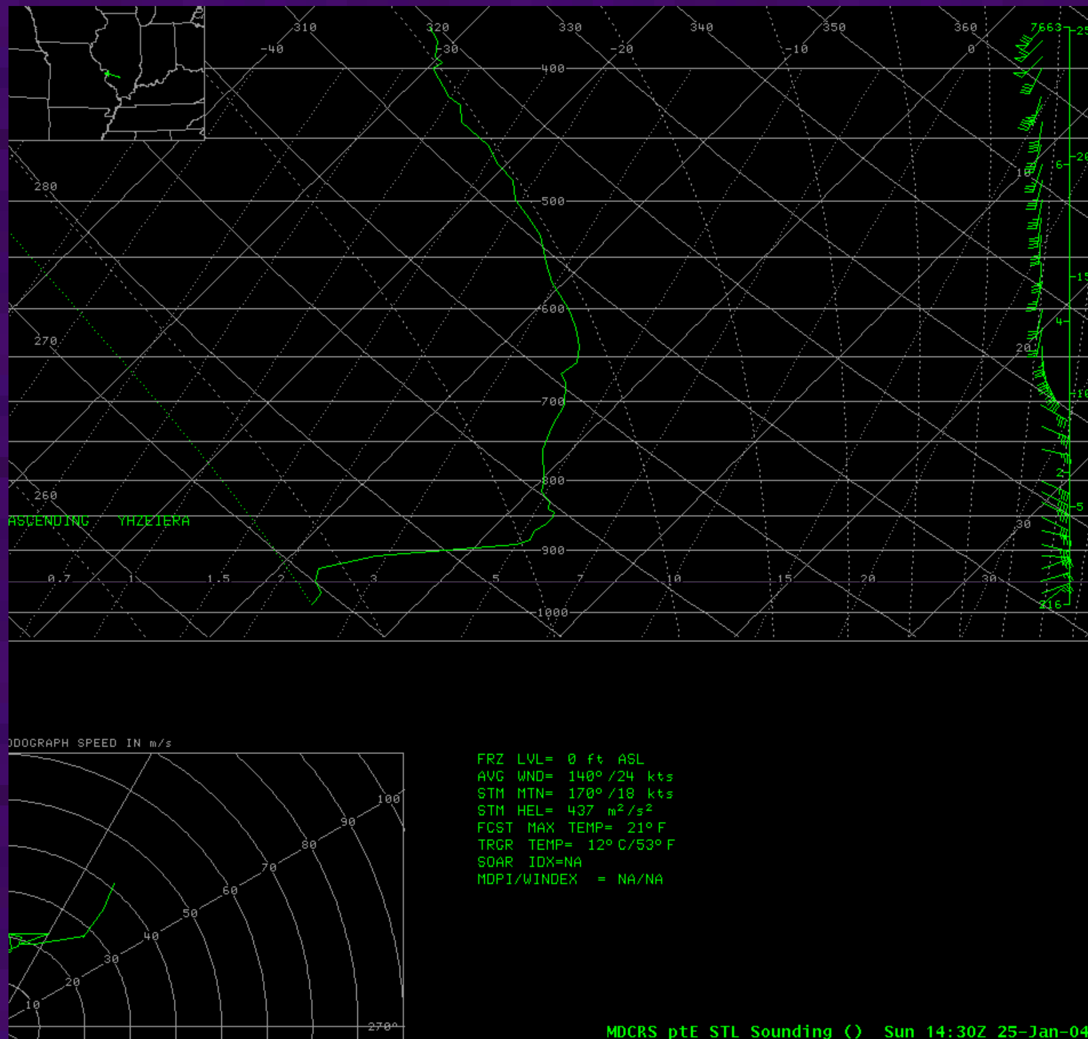
Unfortunately, a shallow warm layer may not show up on a forecast sounding. Use a combination of forecast soundings and MOS guidance to help predict the most likely precipitation type.

From Wes Junker (HPC)

January 25th 2004 Winter Storm

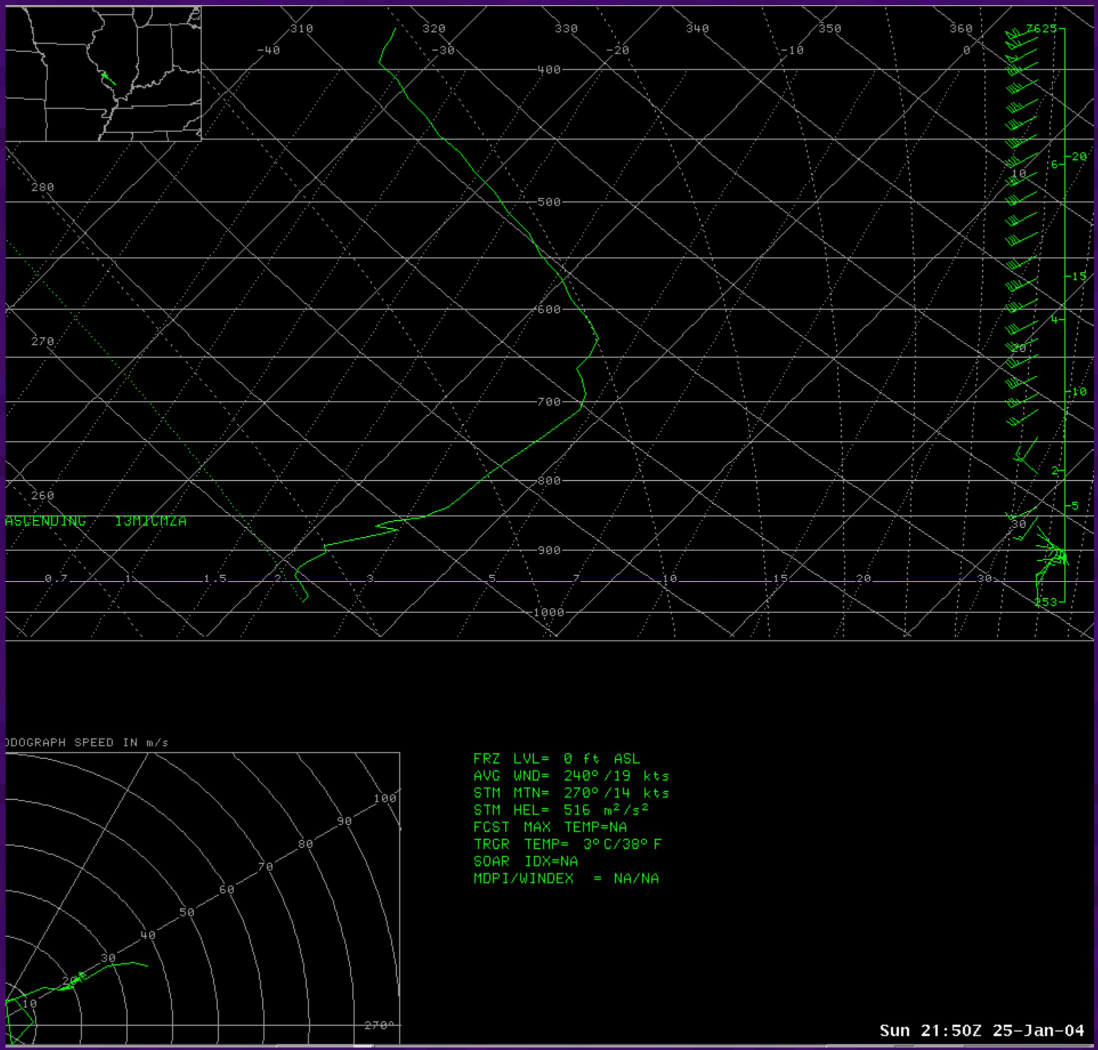
- Most significant winter weather event of 2003/2004 Fall/Winter Season for LSX CWA
- FZRA began in STL at 12Z, changed to FZRAPL at 14Z, then to all PL by 16Z, and to SN around 1830Z.
- Synoptic Setup:
  - nearly E to W quasi stationary front well south of STL
  - STL on backside (SW) of Arctic ridge
  - low level WAA ahead of approaching SW flow shortwave trough
  - upper level divergence over area in right entrance region of ULJ streak

January 25th 2004 Winter Storm (cont.)



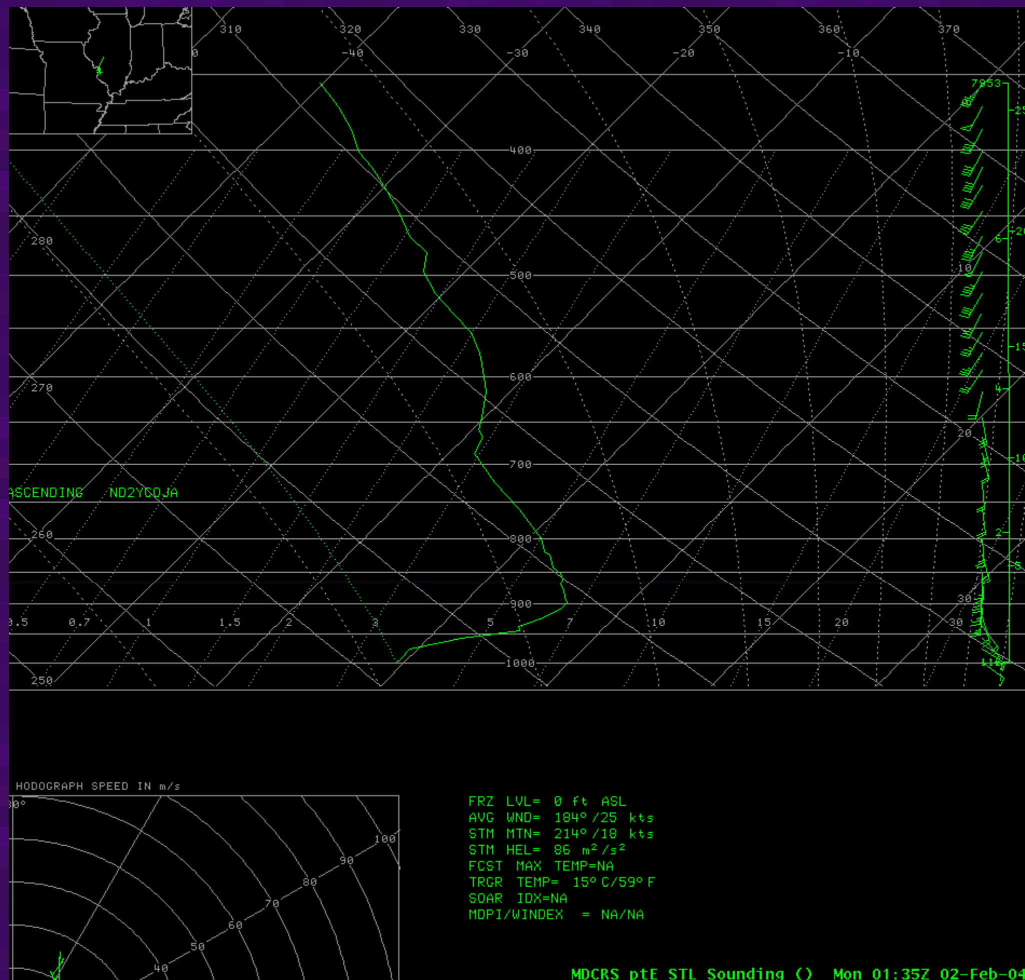
- 1430Z ACARS sounding near STL had a 3°C max temp. in an elevated warm layer
- -FZRAPL was occurring at STL at this time (sfc temp was 25°F)

January 25th 2004 Winter Storm (cont.)



- 2150Z ACARS sounding near STL has no warm layer (>0°C)
- -SN was occurring at STL at this time (sfc temp still 25°F)

February 1-2 2004 Rain/Freezing Rain Event



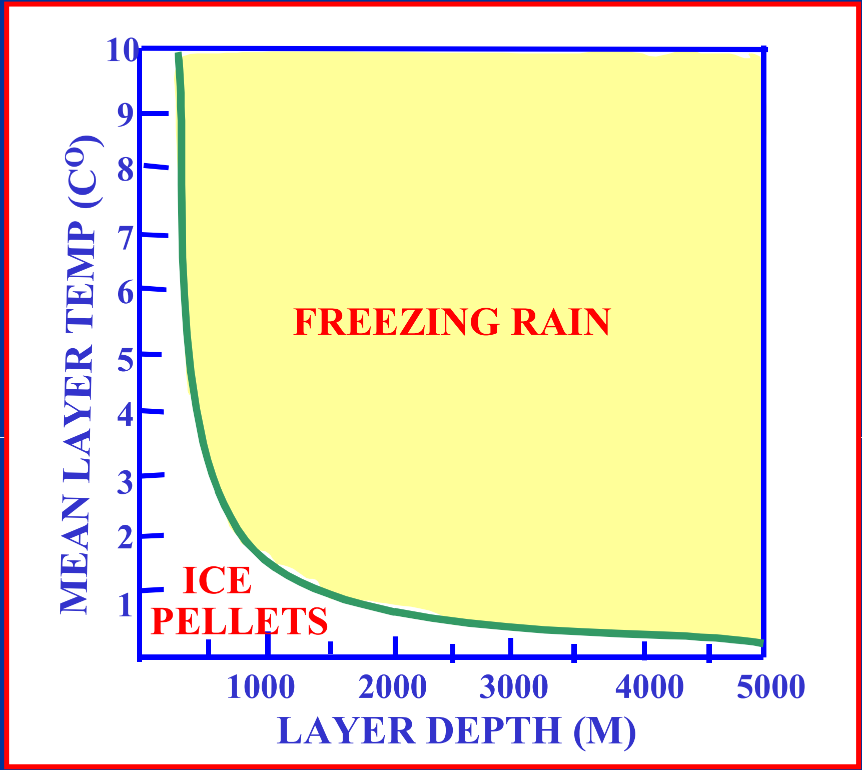
- 0135Z ACARS sounding near STL had a 6°C max temp. in an elevated warm layer
- -FZRA and -RA began at STL about 1.5 hours after this time (sfc temp. varying between 31°F and 33°F)

Elevated Warm Layer (continued)

- The Tau (nondimensional parameter – ratio of the residence time of an ice particle in the melting layer to time required for complete melting) Technique (Czys et al. 1996)
- An isonomogram was developed to try to distinguish between freezing rain and sleet
- Need to determine the depth of warm layer (>0°C), and the mean temperature of the warm layer (assuming an ice particle radius of around 400 microns)
- Sleet events favored over freezing rain with warm layer temp. <2°C and warm layer depth <1000 ft.

FREEZING RAIN OR SLEET

THE TAU TECHNIQUE - Cys et al., 1996



FROM SOUNDING

1. IDENTIFY DEPTH OF WARM LAYER (ABOVE 0^OC)

2. IDENTIFY THE MEAN TEMPERATURE OF THE WARM LAYER

3. THEN , FIND COORDINATE ON THE CHART ABOVE, THE YELLOW AREA USUALLY GIVES FREEZING RAIN WHILE THE WHITE AREA GIVES SLEET

Surface based Cold Layer

- If there is complete melting of snowflakes in elevated warm layer then freezing rain is expected with a sfc/ground temperature <=0°C with two possible exceptions:
  1.) if cold sfc layer is >= 2500 ft (750 m) deep & minimum temp. is <= - 6°C supercooled raindrops could refreeze to form ice pellets
  2.) if minimum temperature in cold sfc layer < = -10°C then snow is possible as new ice crystals can form & grow

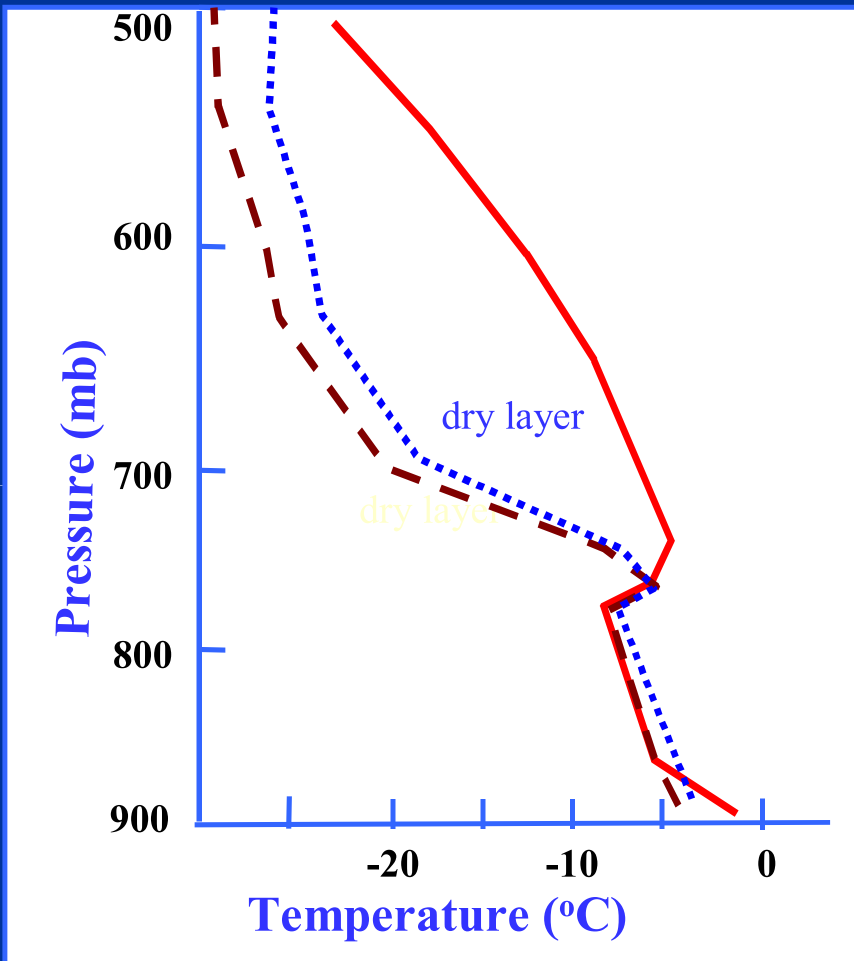
Freezing rain

- Freezing rain can occur with ground temp. >0°C but air temp.<0°C, with freezing on elevated cold sfc (trees, power lines, cars)
- If ground is frozen but air temp. is slightly above 0°C then freezing rain can occur (ice accumulation on ground), at least temporarily
  - check soil and road sensor temps.
- Ice storm (>.25"of ice) usually requires:
  - surface temp. of 30°F or less
  - influx of colder (low level CAA) or drier air (evaporative cooling), or extremely cold and/or dry initial low-level air and cold soil temperatures to offset latent heat of freezing

Freezing Drizzle

- Typical Characteristics of sounding
  - weak upward vertical motion
  - strong inversion with a deep dry layer above inversion (no seeding of ice from above) and a shallow moist layer below inversion
  - surface temperatures <0°C
  - entire sounding may be below freezing with cloud top temperatures within the low-level cloud deck between 0°C and -10°C

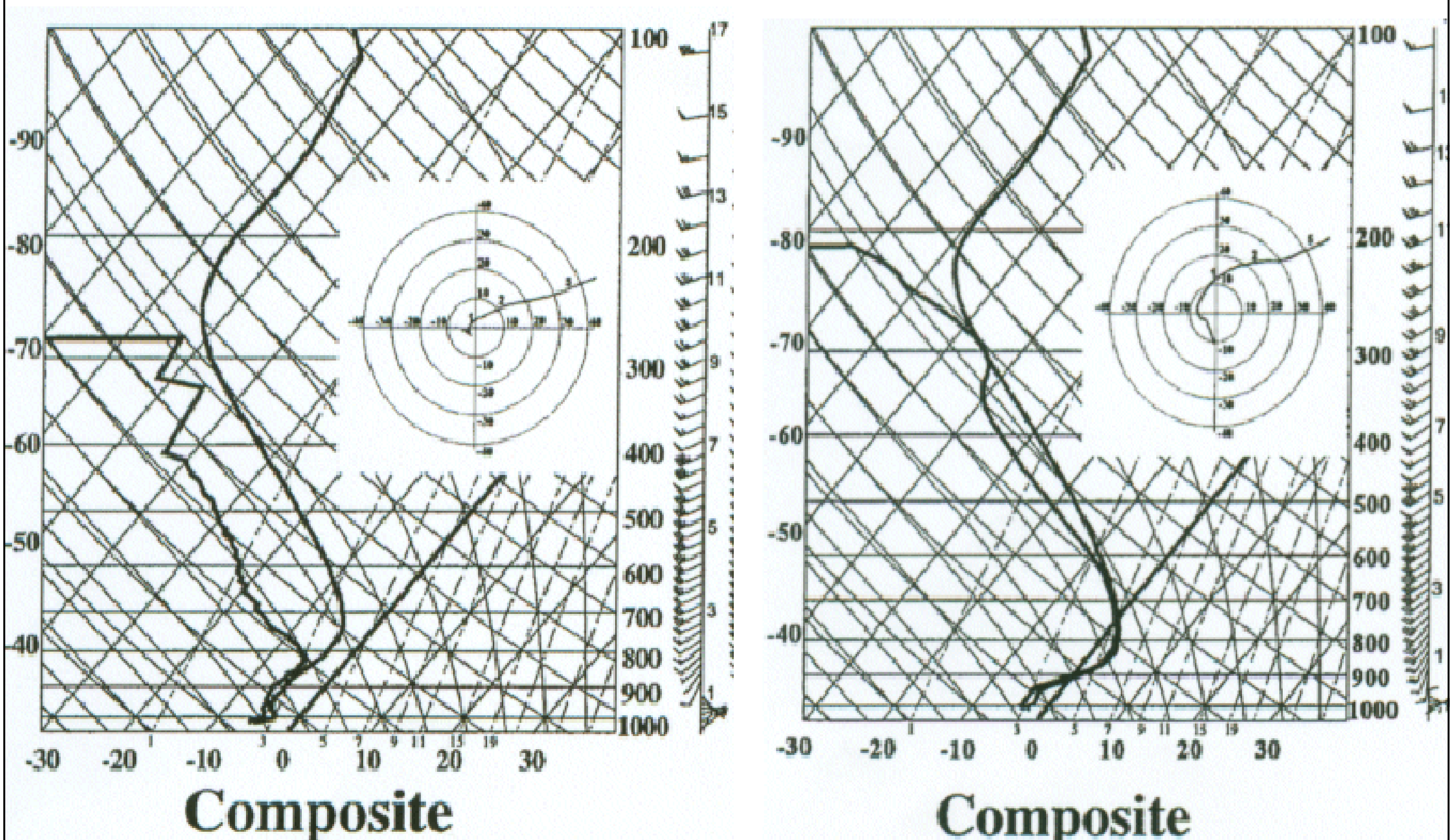
Freezing drizzle



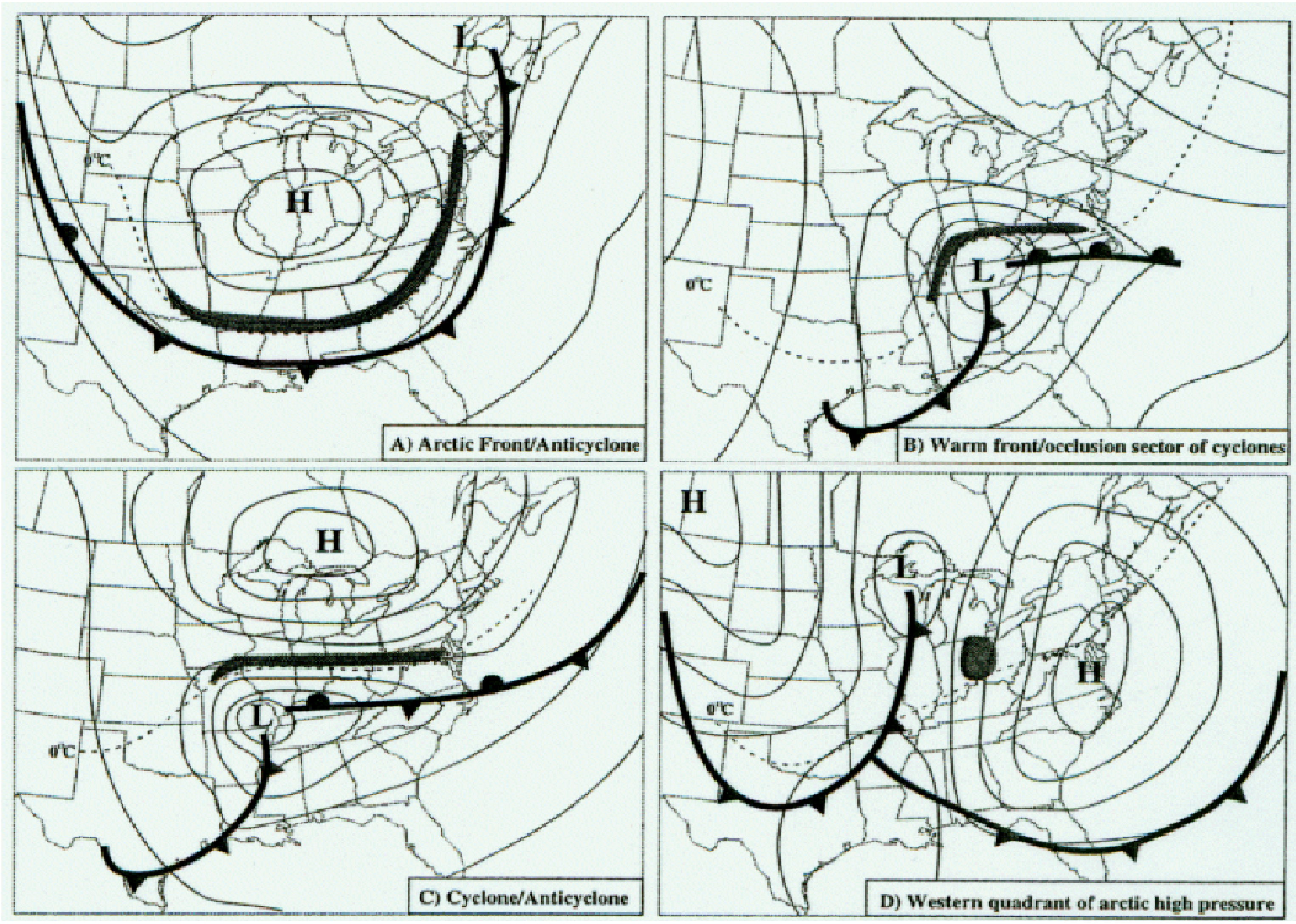
Sounding from Rapid City, SD at 00 UTC 12 March 1976. Temperature (red line), dewpoint (dashed), frost point (blue dots).

- Bocchieri (1980) and Young (1978) found that 30% and 40% of freezing rain (usually drizzle) did not have a layer that was above freezing on the sounding.
- Huffman and Norman (1988) notes for this type of freezing rain event cloud top temperatures within the low- level cloud deck should be in the 0° to -10°C range and that there should be a pronounced dry layer just above the cloud top. A typical sounding for freezing drizzle is shown.

Typical FZDZ sounding on left with FZRA sounding on right (Rauber et al. 2000)



Synoptic climatology of freezing pcpn east of the Rockies



- Four archetypical weather patterns not associated with specific topographic features - FZRA / FZDZ occurred the most with pattern A followed by patterns C, B and the least percentage occurred with D (Rauber et al. 2001)

Surface Based Warm Layer

- If cloud top temperature is colder than –10°C for ice crystal growth and no elevated warm layer (>0°C) is present than pcpn will be rain or snow depending on freezing level
- Freezing level must be at least 1200 ft above sfc to insure that most of the snow will melt to rain before reaching sfc (Penn 1957, McNulty 1988)
- Freezing Level / Chance of Snow

Freezing Level	Chance of Snow
35 mb (290 m, 950 ft)	50%
25 mb (201 m, 660 ft)	70%
12mb (96 m, 315 ft)	90%

- Snow rarely occurs with a surface temp >39°F (snow usually occurs at 35°F or less)

Uncertainty of Pcpn Type

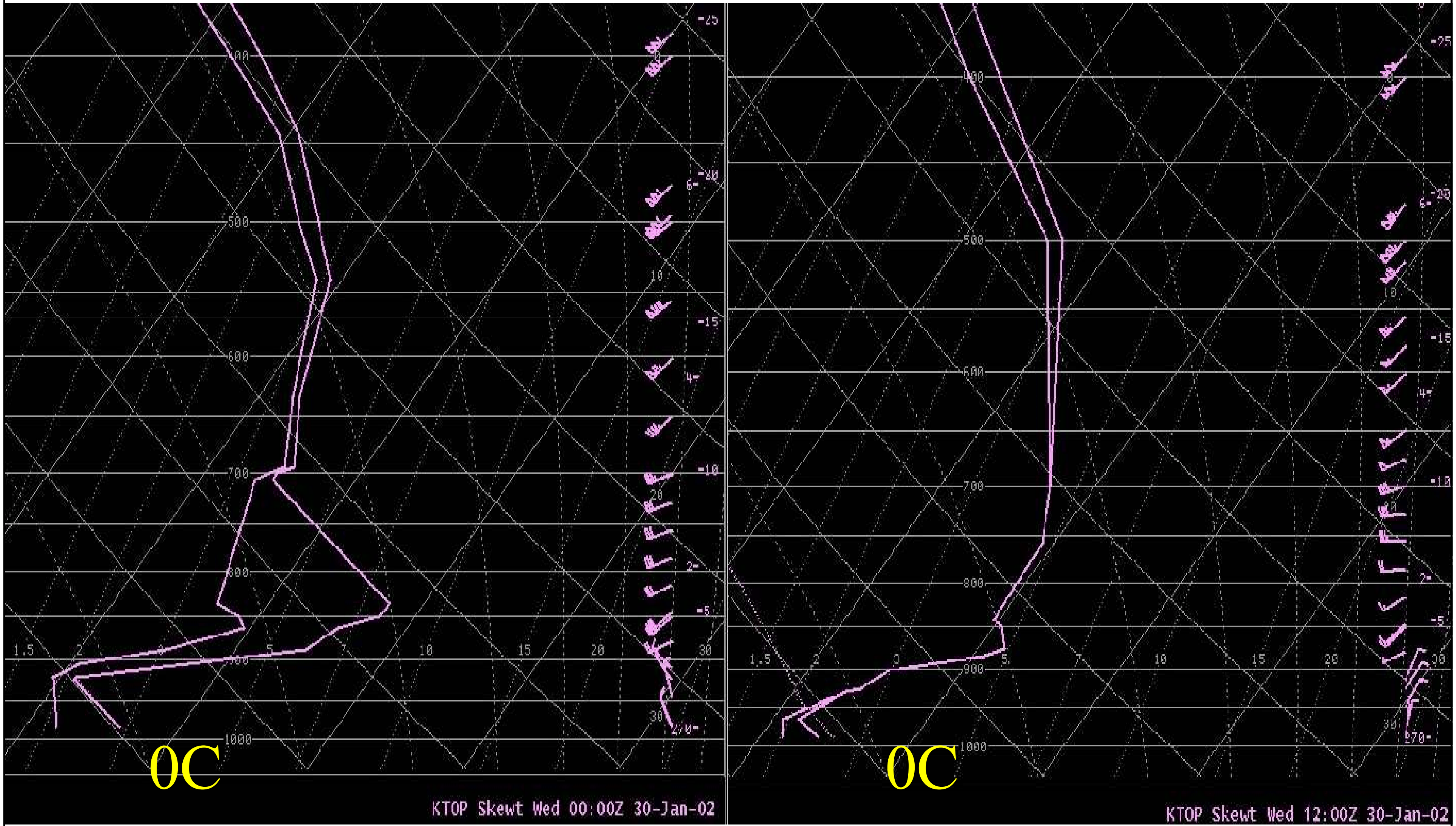
- The melting of a snowflake in a warm layer either elevated or surface based is a function of:
  - size, density and structure of ice crystals
  - fall velocity (related to size & shape of crystal)
  - temperature, depth, lapse rate, and relative humidity of warm layer

Diabatic Processes that can Change the Temp. Profile

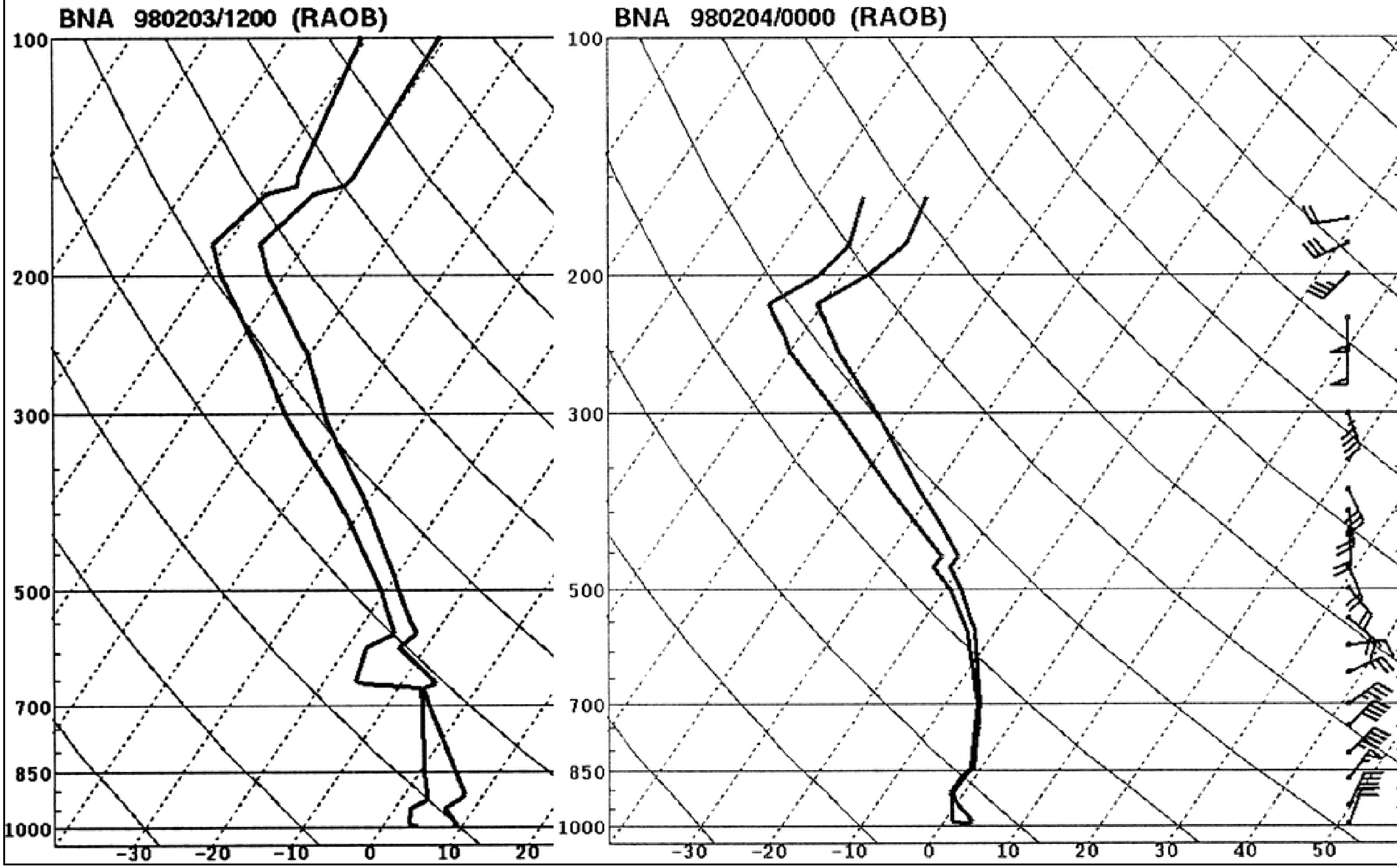
- Evaporative Cooling
  - Use the wet-bulb temperature if precipitation is expected to fall through an unsaturated layer
  - May drop the temperature as much as 5-10°F/hr until the air is saturated and the wet-bulb temperature is reached
- Melting
  - cooling occurs when snow falls through a warm layer (>0°C) and melts; most significant with heavy precipitation
- Solar Radiation – mainly affects the low-level temperatures (diurnal heating/nocturnal cooling)

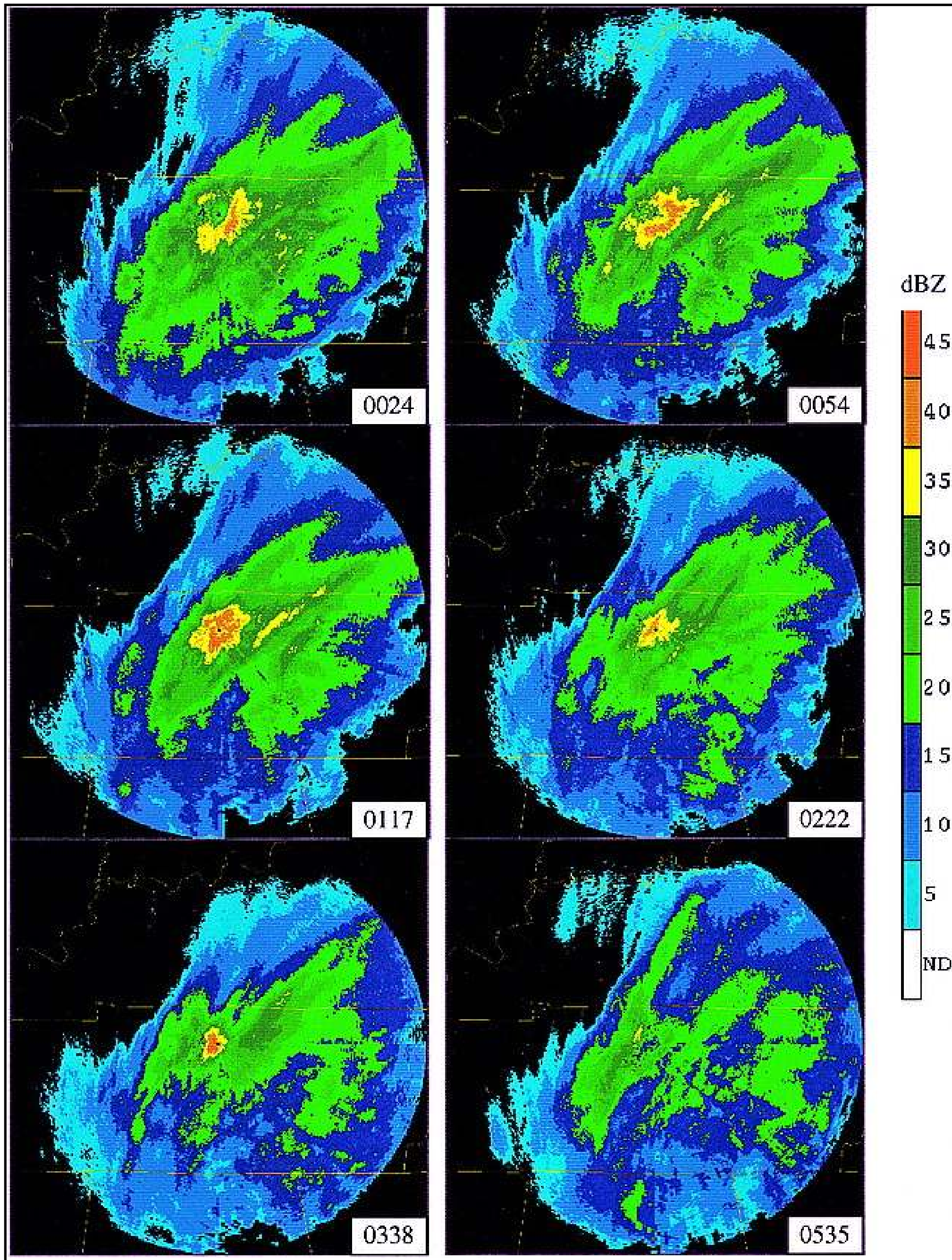
An Example of Evaporative Cooling as Pcpn Falls into a Dry Layer

TOP sounding on right is 12 hours later



“Melting Effect”- rain changing to snow by 02Z at BNA, note 0°C isothermal layer between 850-925 mb on 00z sounding (right) due to cooling as snowflakes melted in sfc based warm layer





Radar bright band shrunk toward radar with time as the top of the melting layer lowered in altitude with time. (Kain et.al 2000)

Time series of base reflectivity images from KOHX (Nashville, TN) WSR-88D radar at 0.5° elevation angle. Note the shrinking with time of the "bright band," or higher reflectivity region roughly surrounding the radar site.

Consider the "Melting Effect" when:

- Low level temperature advection is weak
  - little to no WAA
- Steady rainfall of at least moderate intensity is expected for several hours
  - cooling due to melting will be strongest where precipitation rates are the highest
  - if model underestimates QPF (intensity/duration of pcpn) it will also underestimate the cooling due to melting
- Borderline rain/snow situation
  - surface temps not far from freezing/freezing level not too high

Other Mechanisms that can Change the Temperature Profile

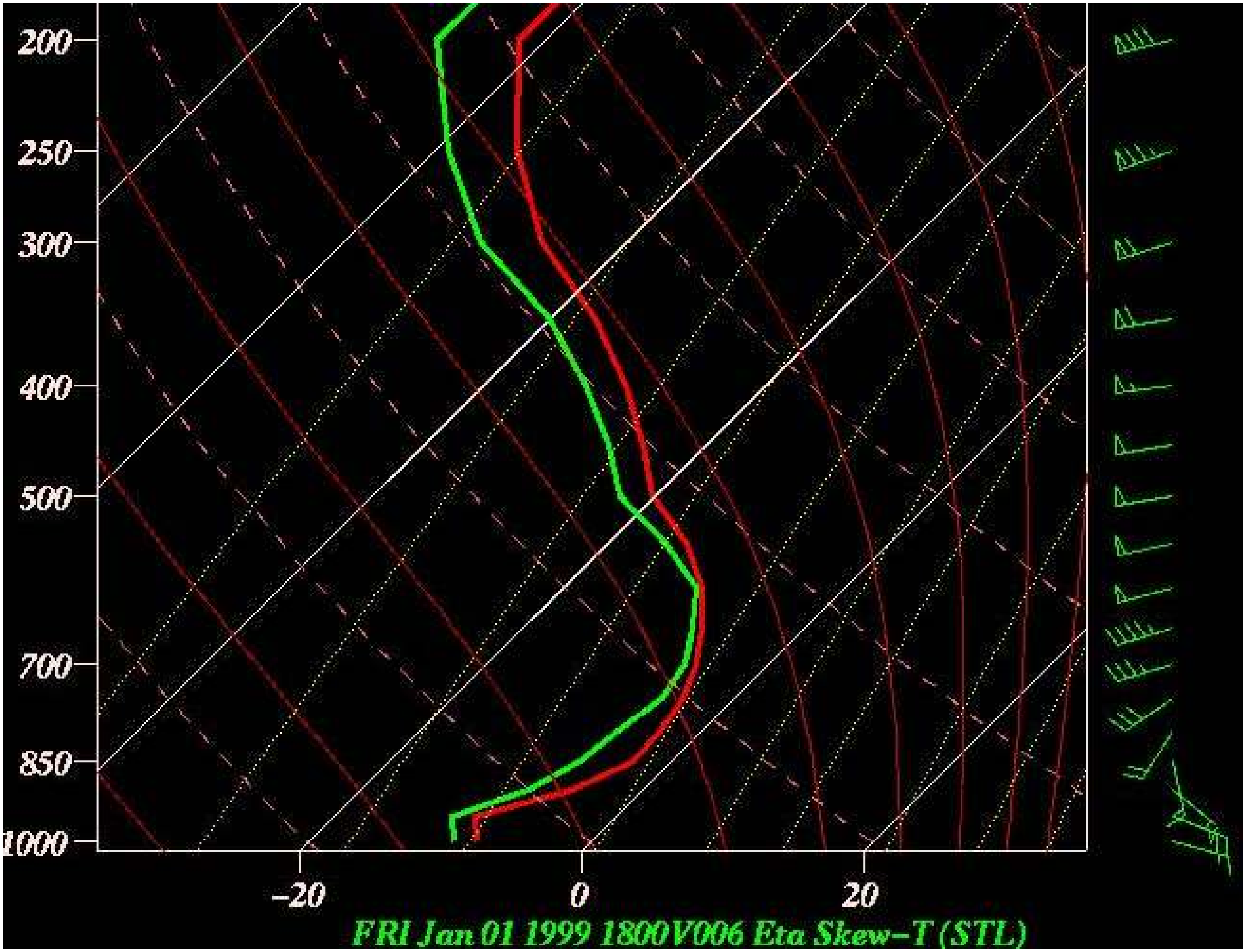
- Pseudo-adiabatic cooling due to upward vertical motion
- Thermal Advection
  - strong WAA will create or advect in an elevated warm layer
  - WAA will not only warm the air but also is a forcing for upward vertical motion, pseudo-adiabatic lift will cool the layer, slowing the rate of warming
  - CAA combined with strong upward vertical motion due to forcings other than WAA (ie. PVA increasing with height, jet streak and/or frontogenetical circulations) & weakly stable or unstable conditions (CSI/elevated upright convection) can cause a rapid change over to snow

Pcpn Type and Intensity

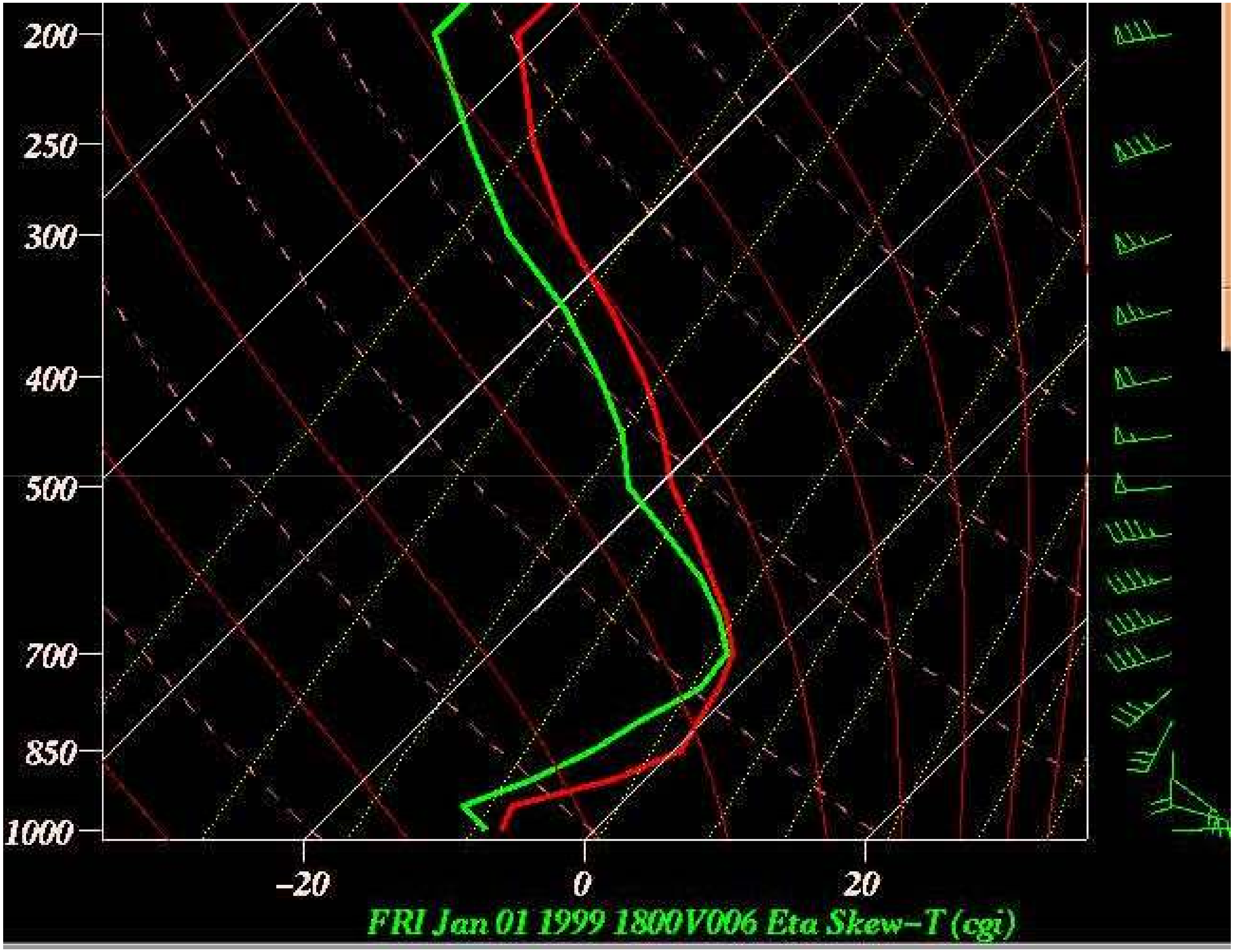
- Light (freezing) rain/drizzle can change to sleet/snow whenever the intensity of the pcpn increases (stronger upward vertical motion) due to one or a combination of these effects of stronger upward vertical motion:
  - increased pseudo-adiabatic cooling
  - increased depth of cloud (colder cloud top)
  - larger snowflakes (take longer to melt)
  - increased cooling due to melting with heavier pcpn
- Watch out for elevated convection!
  - can change FZDZ to +SN

January 1-2, 1999 Case

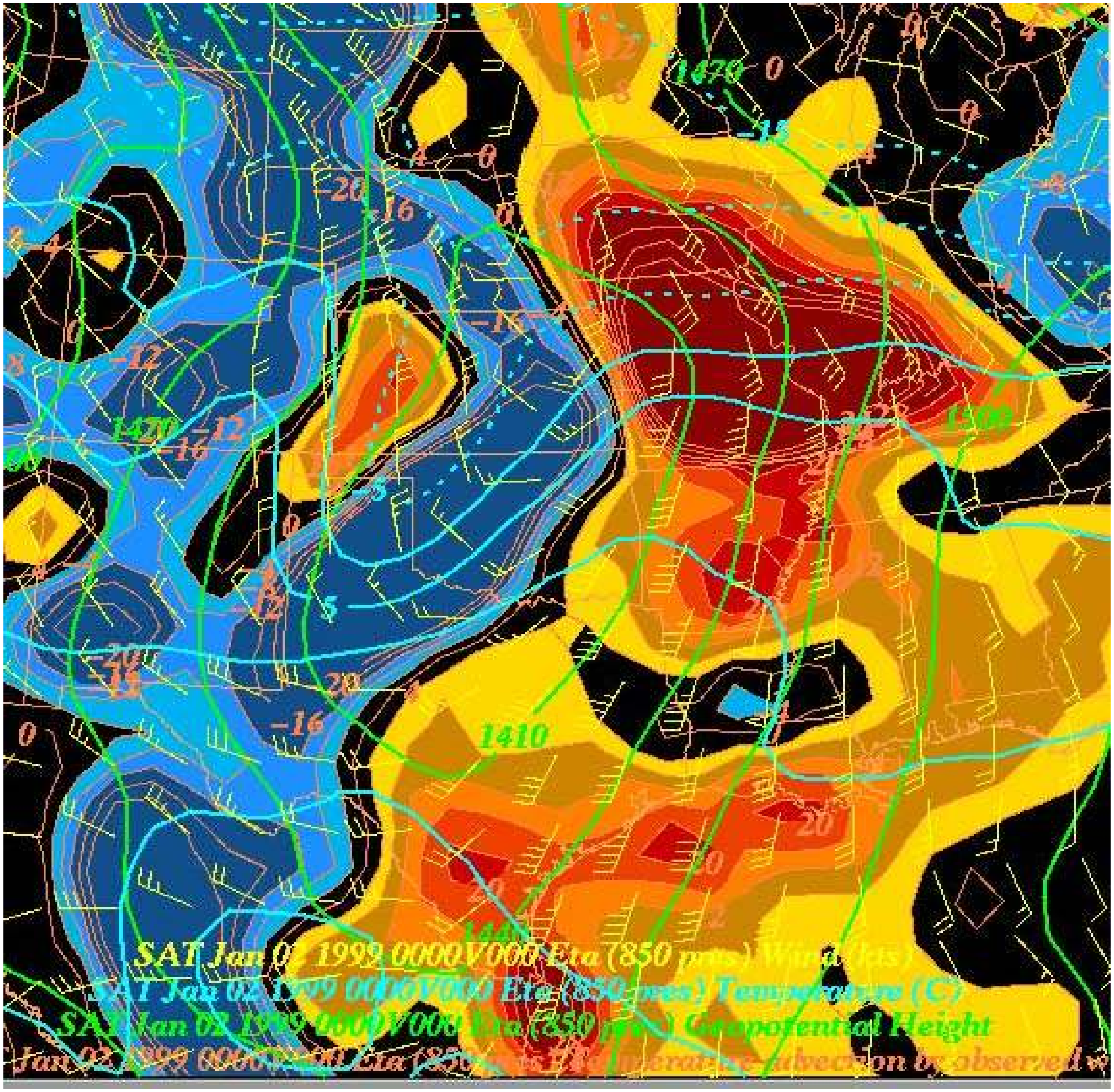
- Major winter storm brought heavy snow to northeast MO, and a mix of snow, sleet and freezing rain to east central & southeast MO
- UIN : 12-13 inches, all snow
  STL : 6-9 in., snow began at 17z Jan 1, changed to snow/sleet at 23z, freezing rain & sleet at 08z Jan 2, then back to snow at 11z
  CGI: snow began around 18z Jan 1, changed to freezing rain at 20z, than to rain at 06z Jan 2
- 45-60 kt LLJ brought strong temperature and moisture advection to MO ahead of a developing 850 mb low



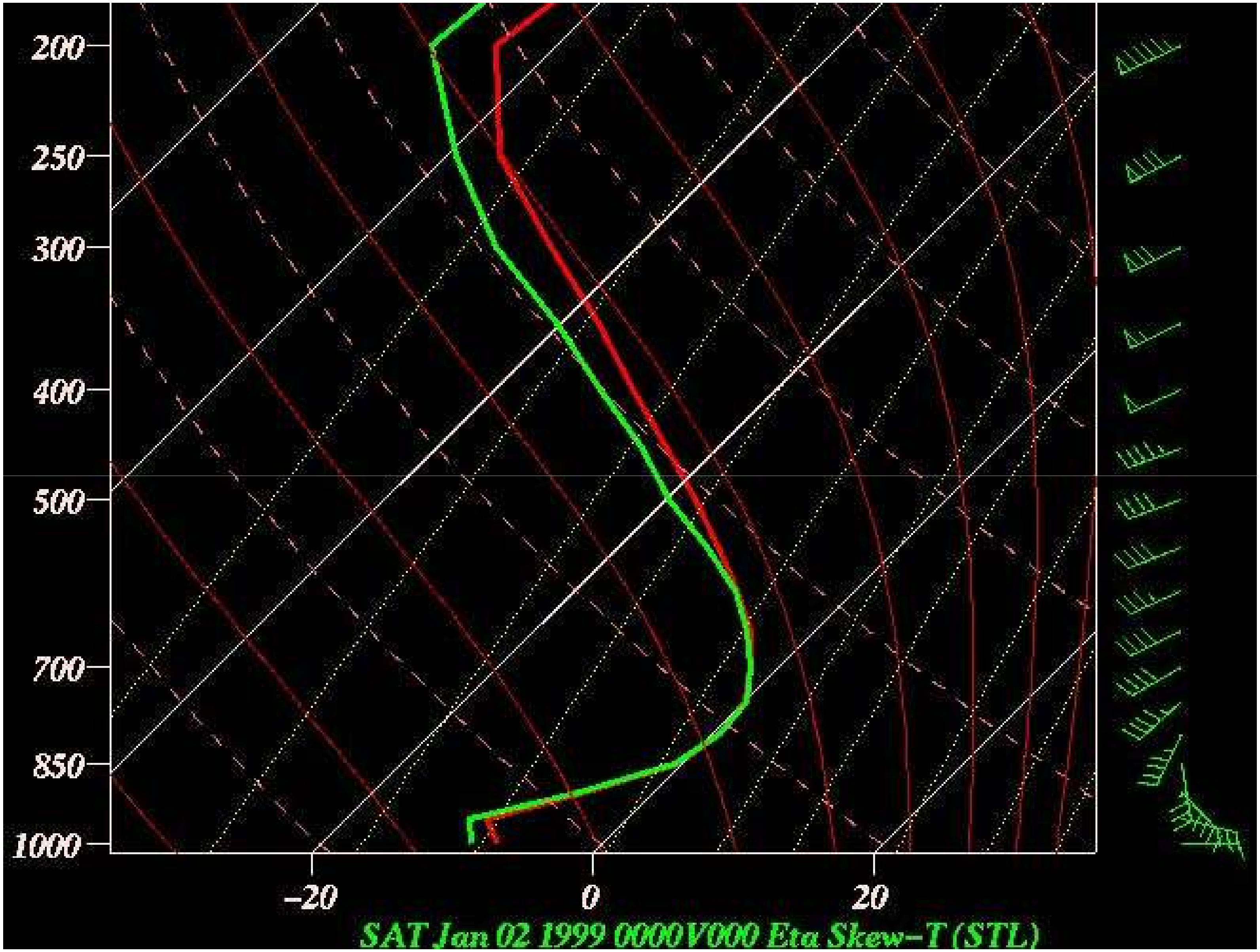
Snow occurring at noon in STL



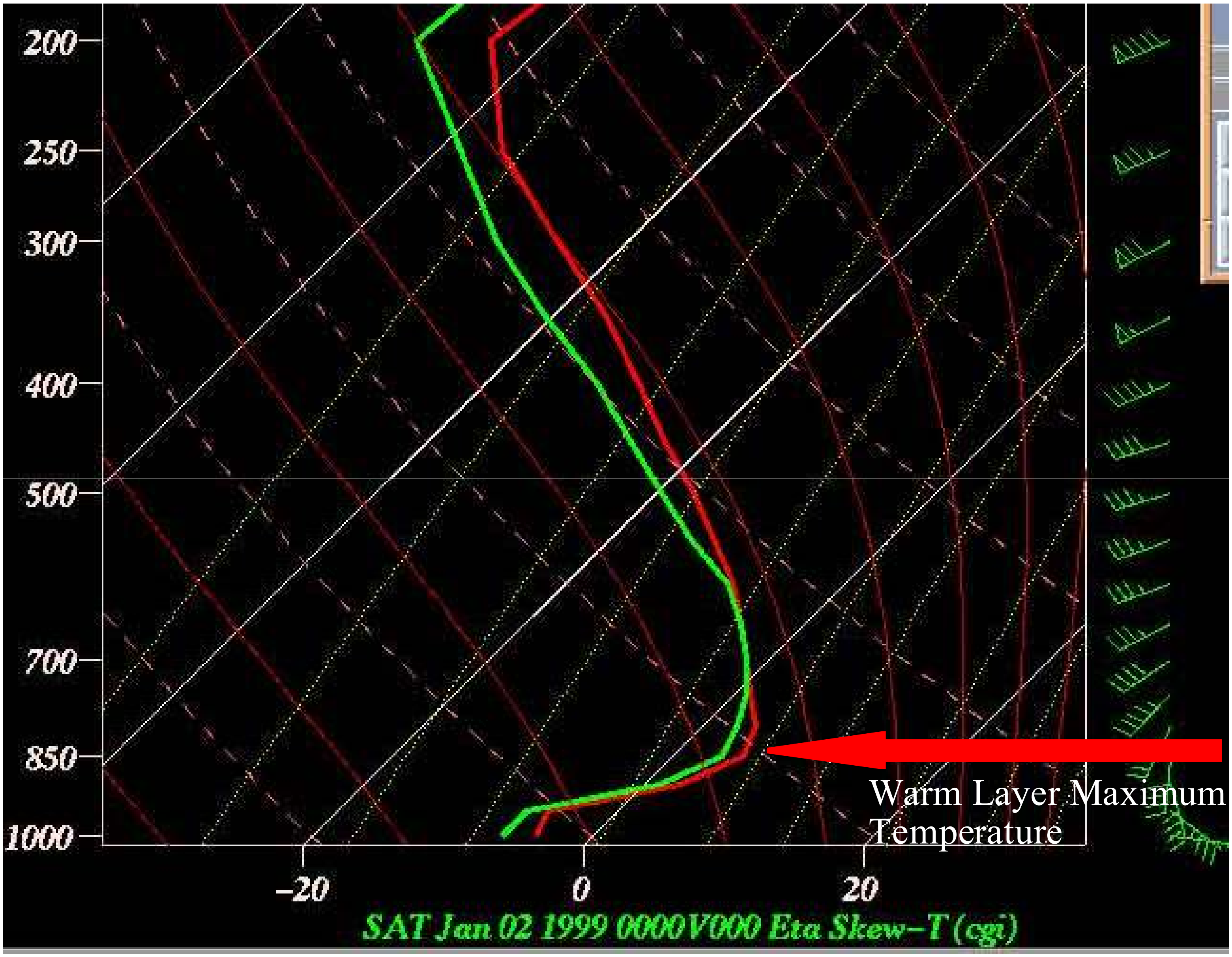
Snow occurring at noon in CGI



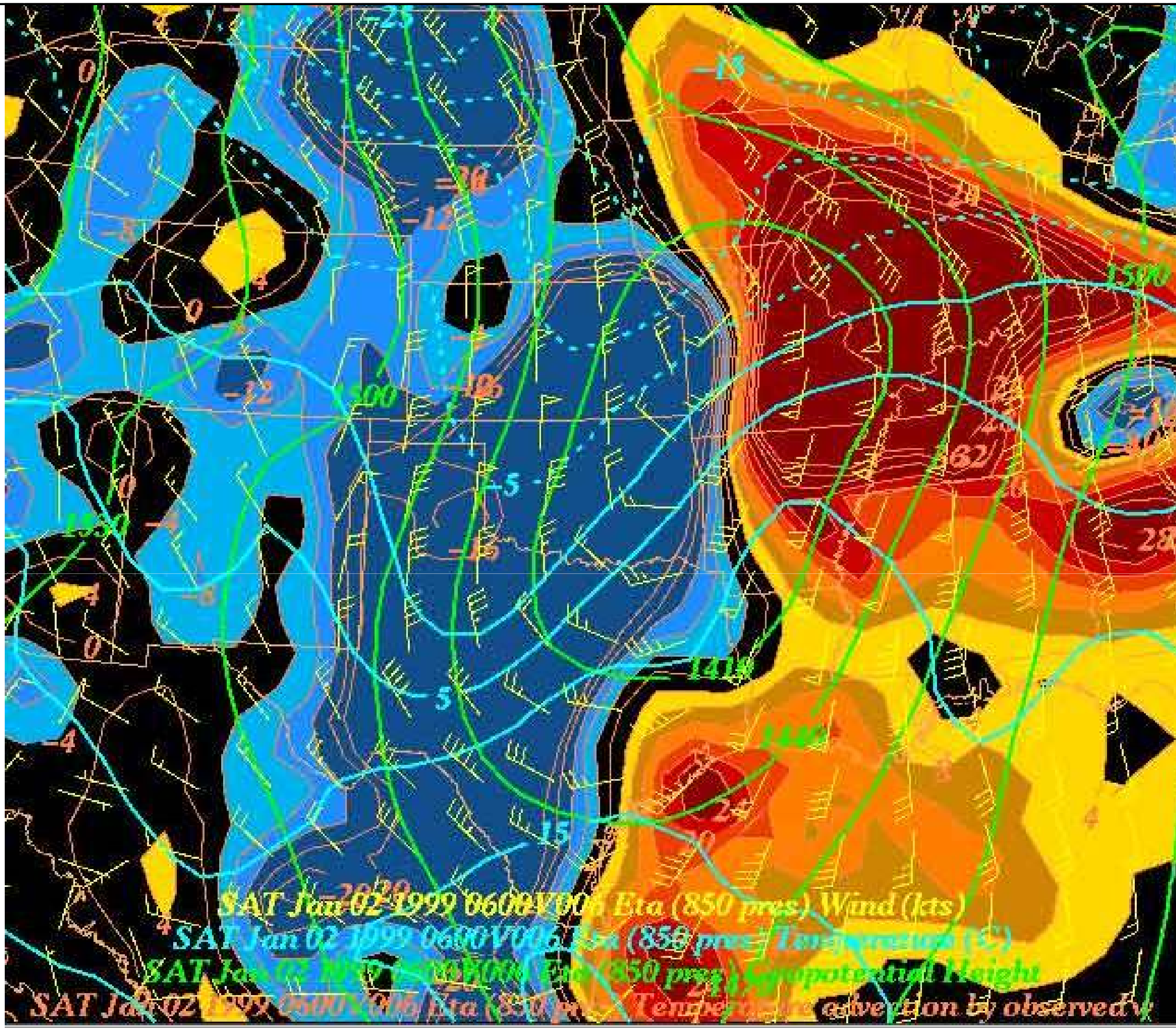
Strong WAA ahead of developing 850 mb low



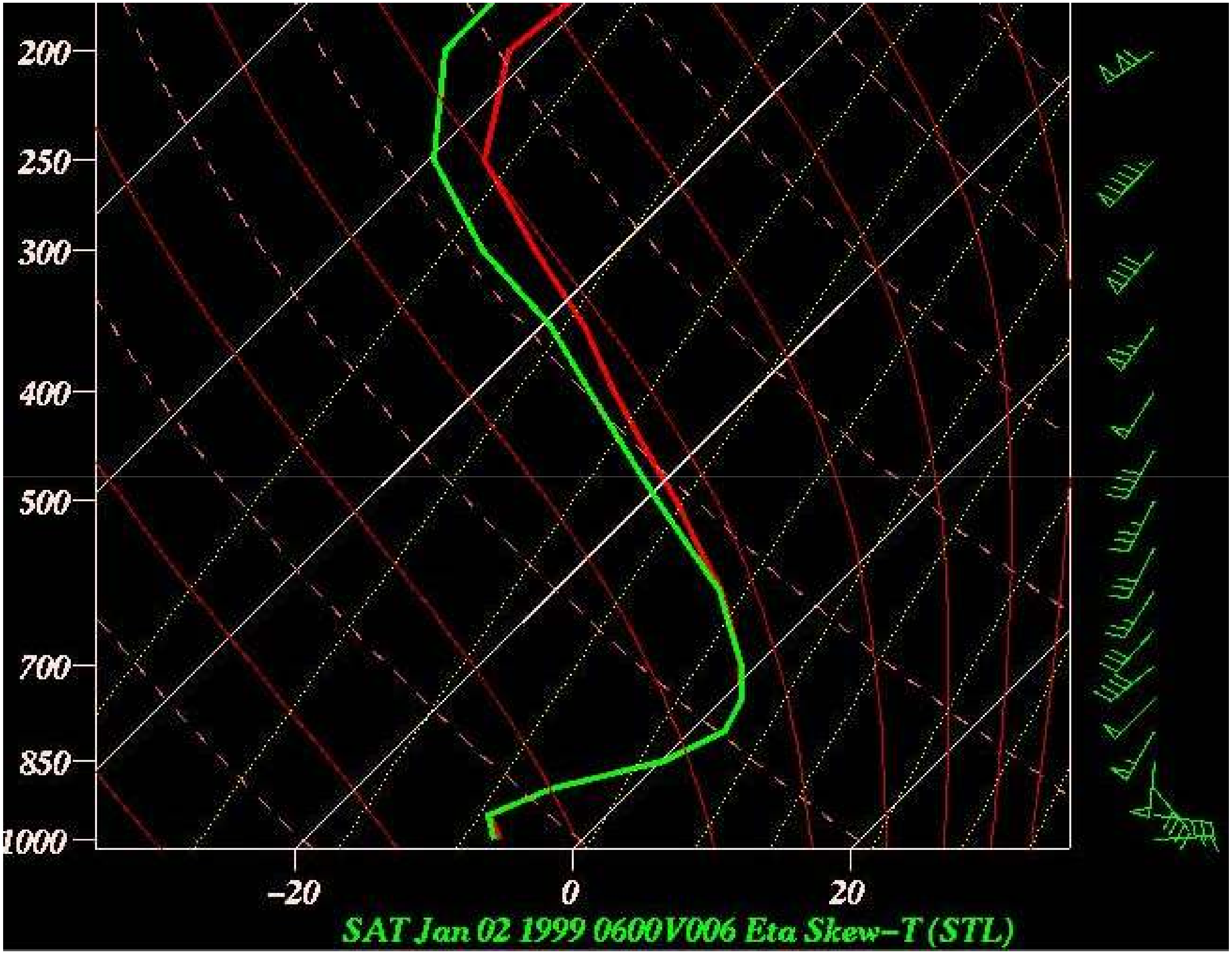
A mix of snow & sleet occurring at STL at 6 pm



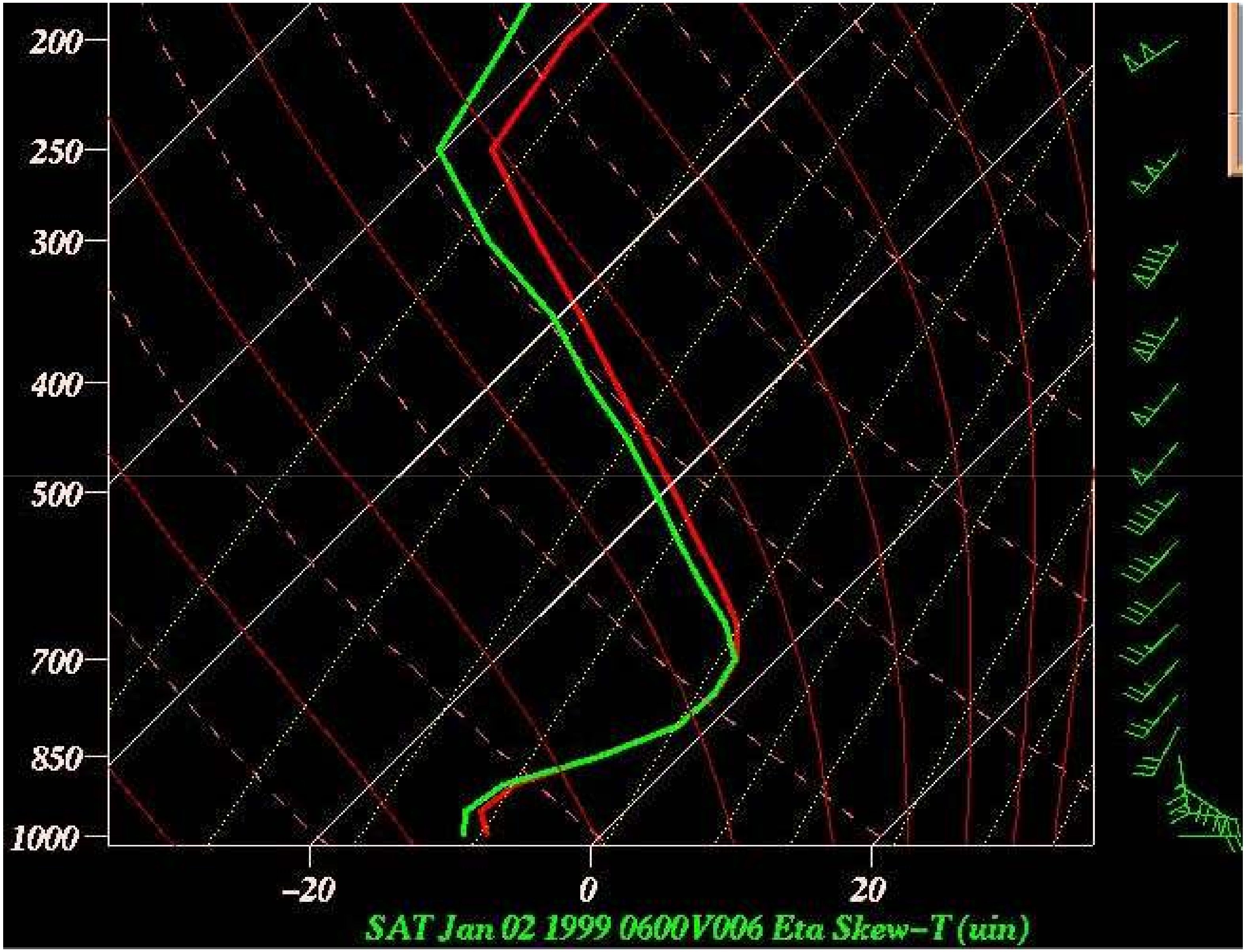
Freezing rain occurring at CGI at 6 pm



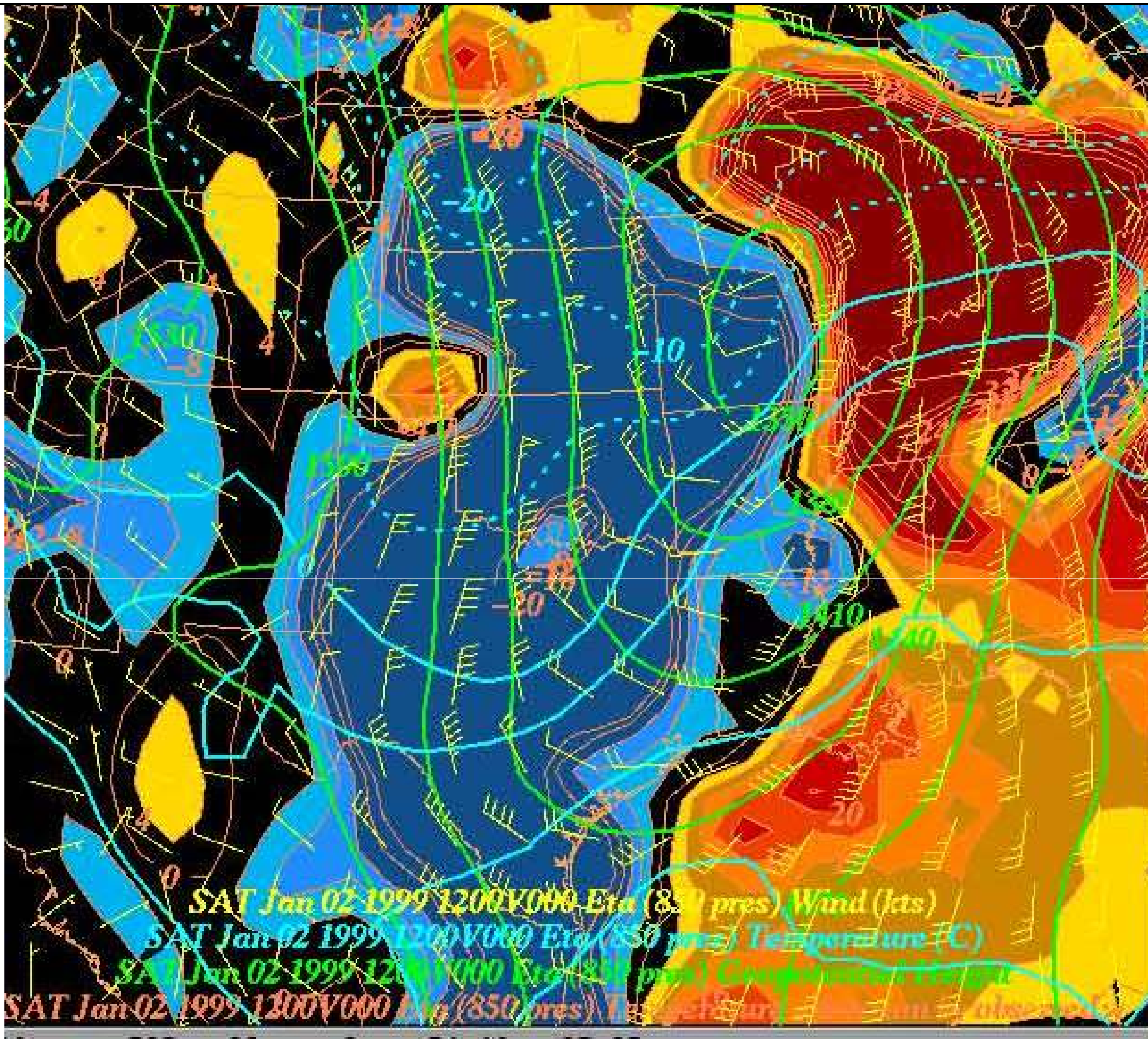
Strong WAA over ern MO IL e-ne of 850 mb low



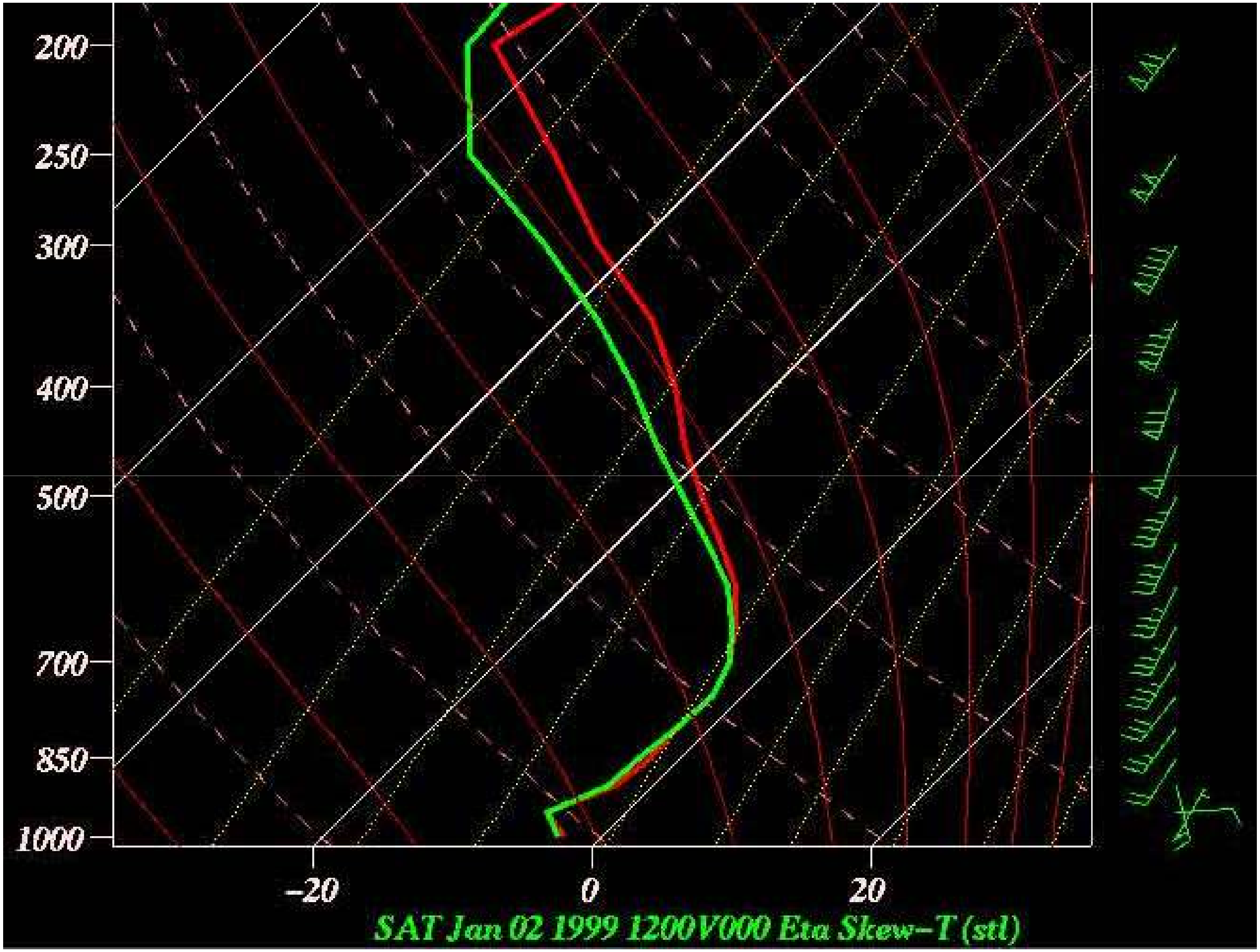
A mix of snow & sleet occurring at STL at midnight



Snow at UIN at midnight



850 mb low just sw of STL, WAA shifted e-ne into IL



Light snow occurring at 6 am in STL

Concluding Remarks

- First examine partial thickness
- Look at current (RAOBS, ACARS, LAPS) and forecast soundings (RUC, ETA, GFS on BUFKIT) nearest forecast location.
- Is cloud top temperature cold enough for ice crystal activation and growth (-10°C or less)?
- Is there an elevated or surface based warm layer present to melt the snowflakes?
  - determine maximum temperature of elevated warm layer or freezing height of sfc based warm layer
- What is the minimum temperature of a surface based cold layer (also sfc and ground temp.)?

Conclusion (cont.)

- Use BUFKIT Program to help you determine p-type & check for the "Cross Hair" Signature
- Examine the current and forecast synoptic and mesoscale environment to determine how the temperature profile may change with time:
  - expect evaporative cooling until saturated
  - cooling due to melting snowflakes in warm layer (could erode warm layer if pcpn heavy – elevated convection)
  - horizontal thermal advections (WAA, CAA)
  - pseudo-adiabatic cooling due to upward vertical motion (what are the magnitude and types of forcing mechanisms present)
- Look for temperature profile trends in model forecast soundings

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