Northwest Flow Snow Events

Winter Weather Prep Seminar – December 2001

Modified December 2005

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Prepared for a forecaster training seminar at WFO GSP

Goals

- Increase awareness of Northwest Flow Snow Events
- Identify situations in which snow will occur in the southern Appalachians during periods of northwest flow
- Improve forecasting

What is a Northwest Flow Snow (NFS) Event?

…snowfall in the southern Appalachians produced - or augmented - by upslope flow caused by low-level northwest winds…

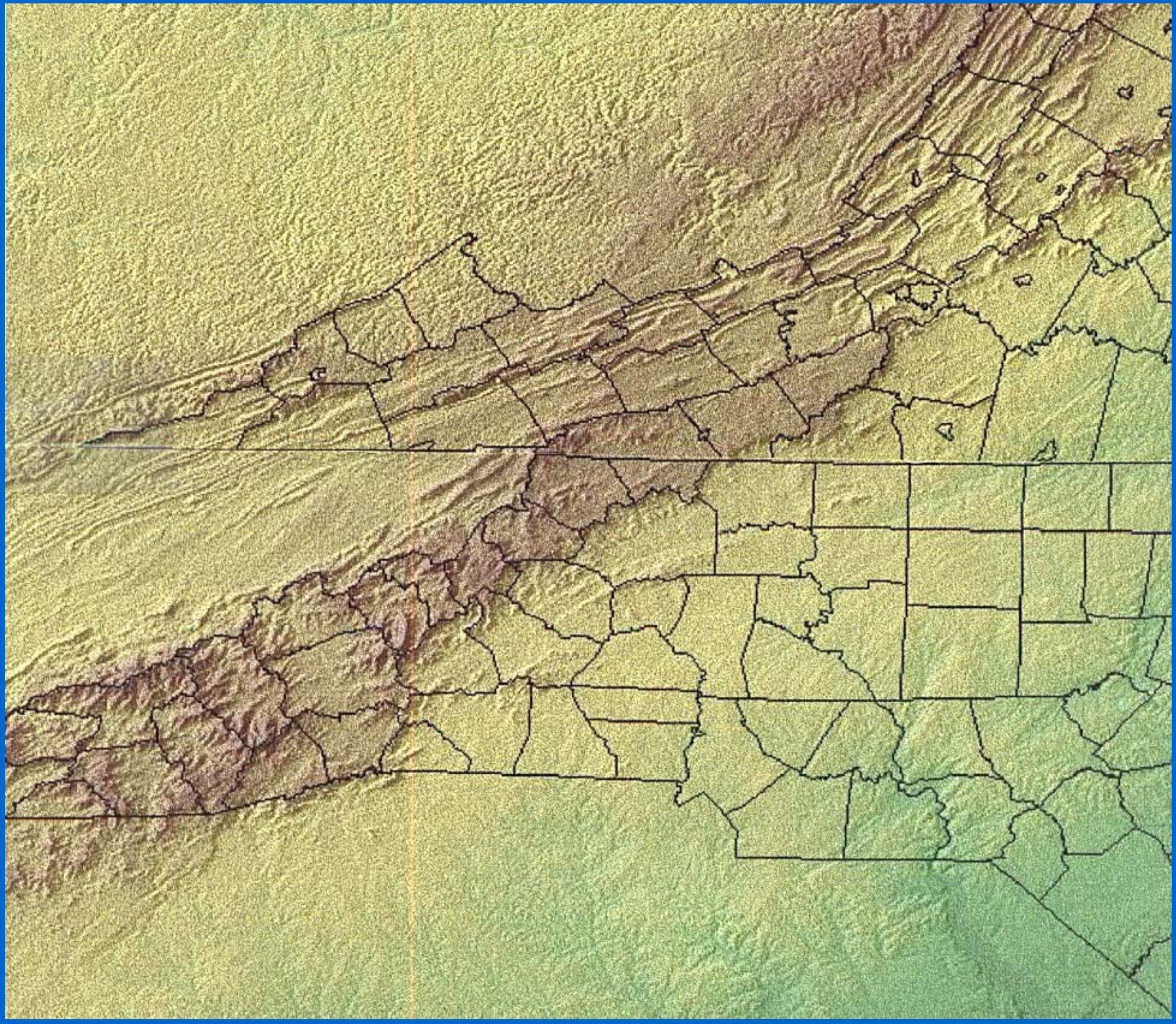
(The snow is often not associated with synoptic scale precipitation.)

Northwest Flow Snow

Depends on:

- Air mass characteristics and synoptic scale pressure pattern
- Local vertical motion caused by terrain
- Microphysical processes in the cloud

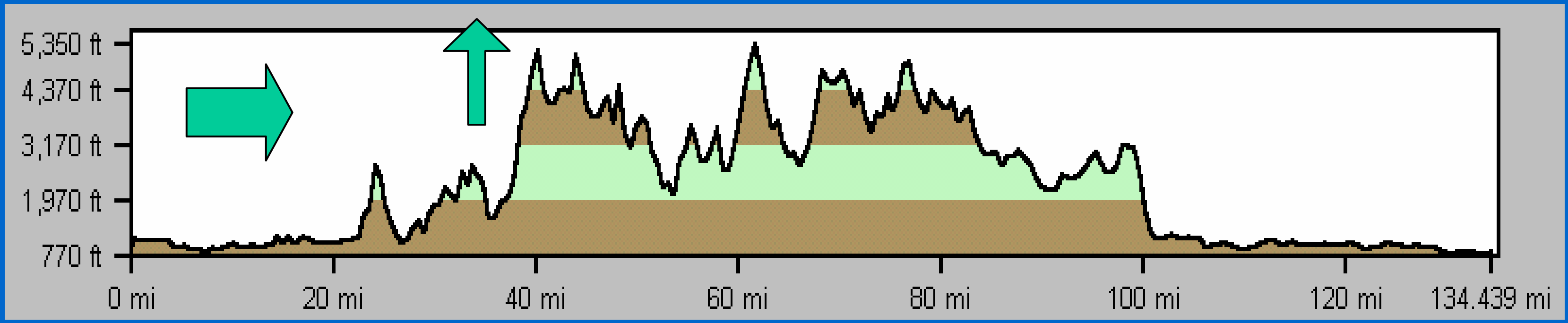
Northwest Flow Snow Study Area



Upslope Flow

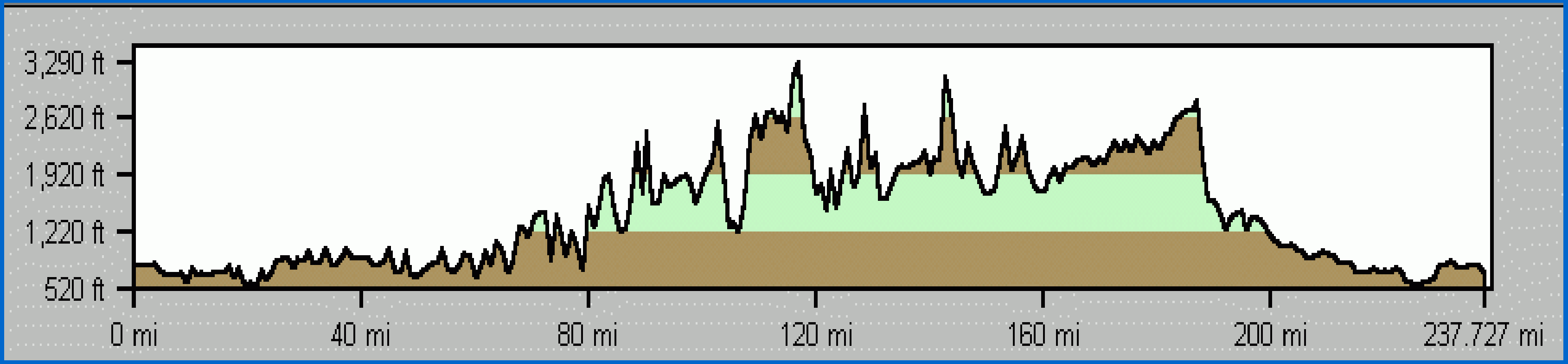
NW Wind Encounters Significant Rise in Terrain

Along the North Carolina / Tennessee border, elevation increases of 4000 ft to 5000 ft over very short distances are common

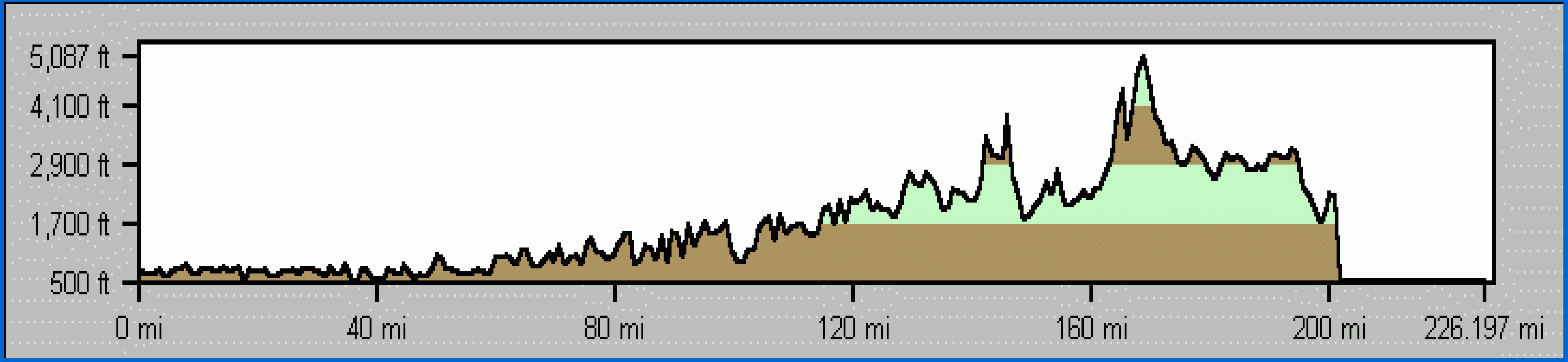


Knoxville NC Mountains Greenville

Blacksburg CWA



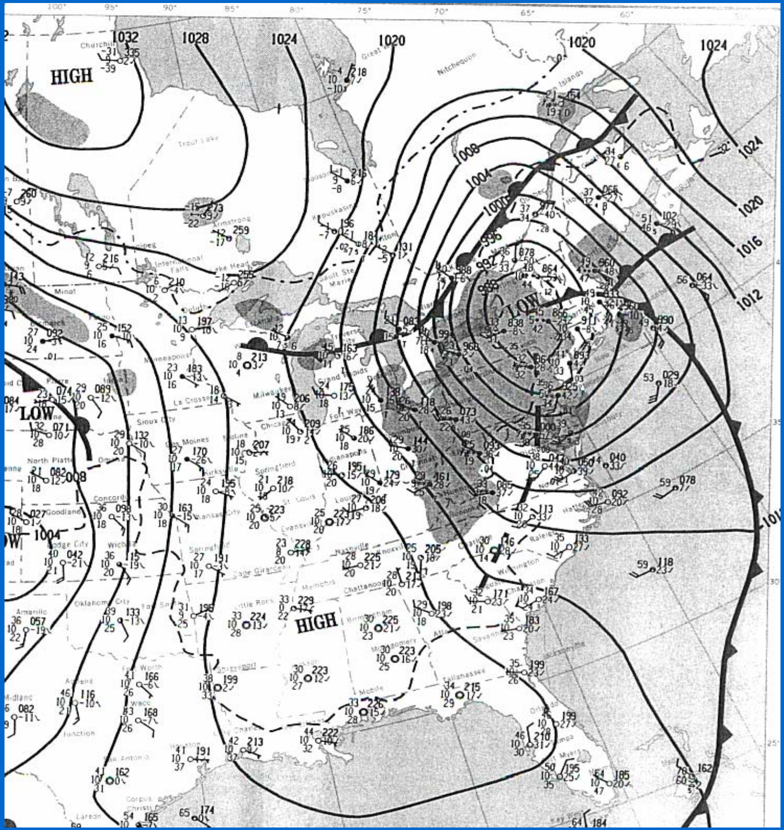
WV VA Mountains NC



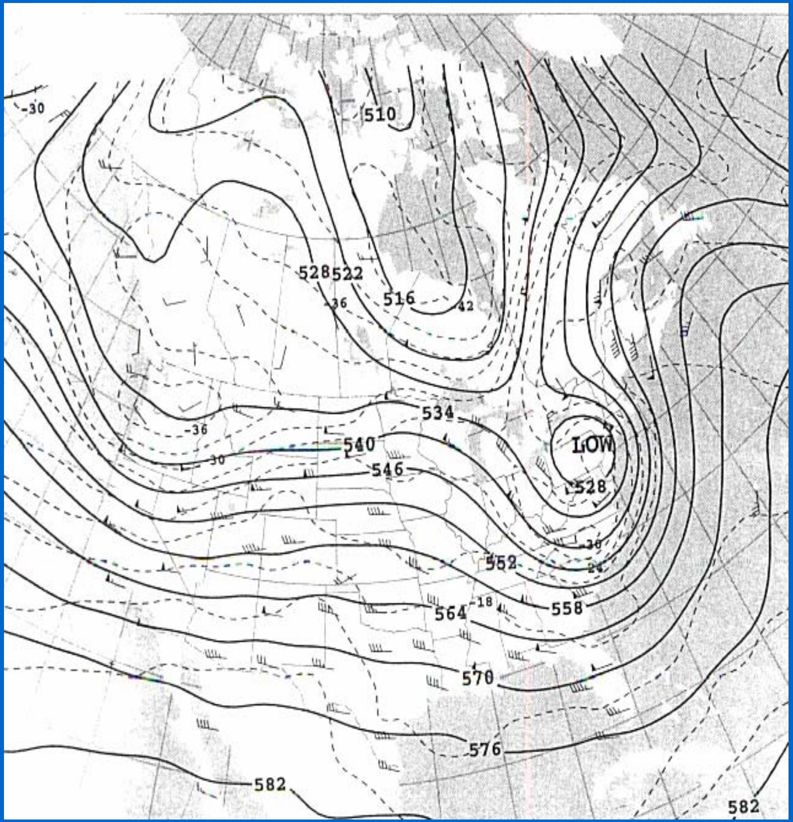
KY WV / VA / NC Mountains NC

Typical Surface and Upper Air Maps

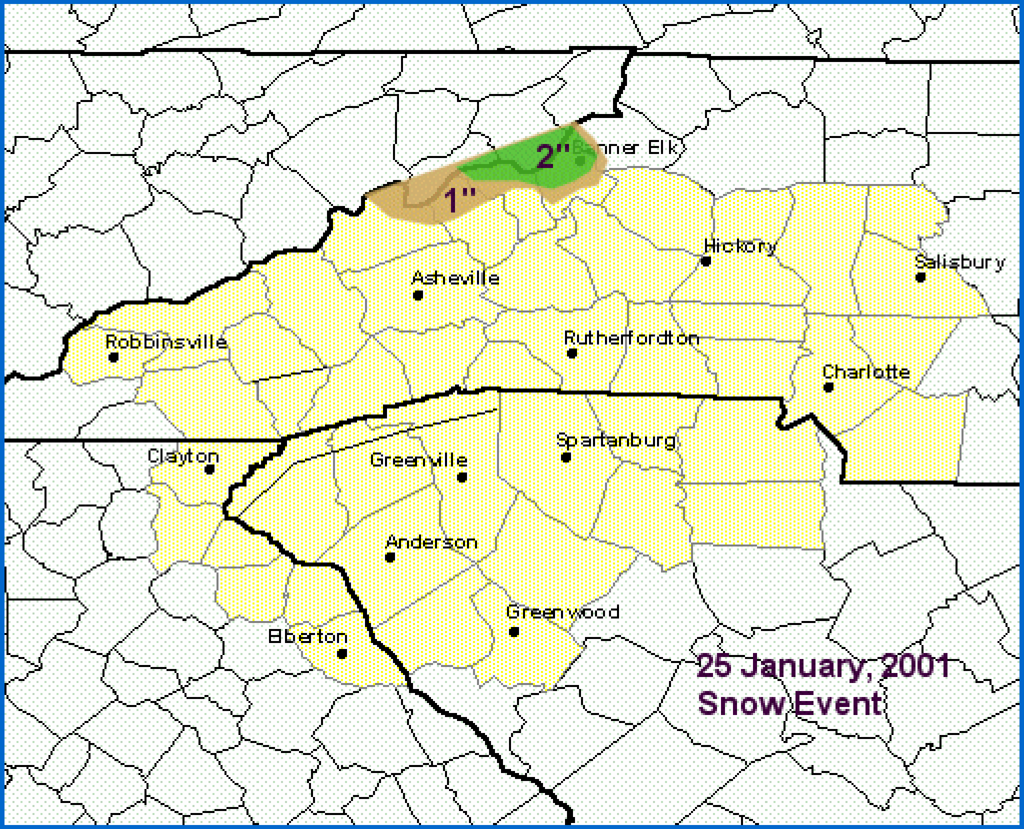
Surface



500 mb

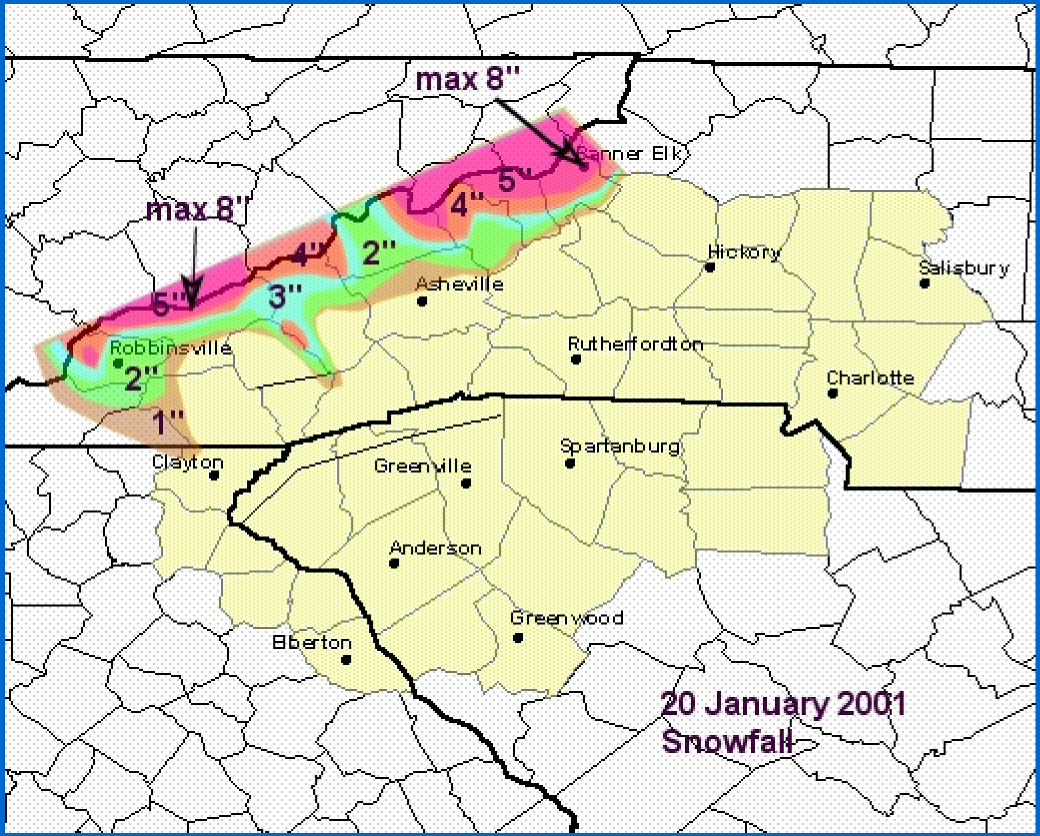


Example of Snow Distribution



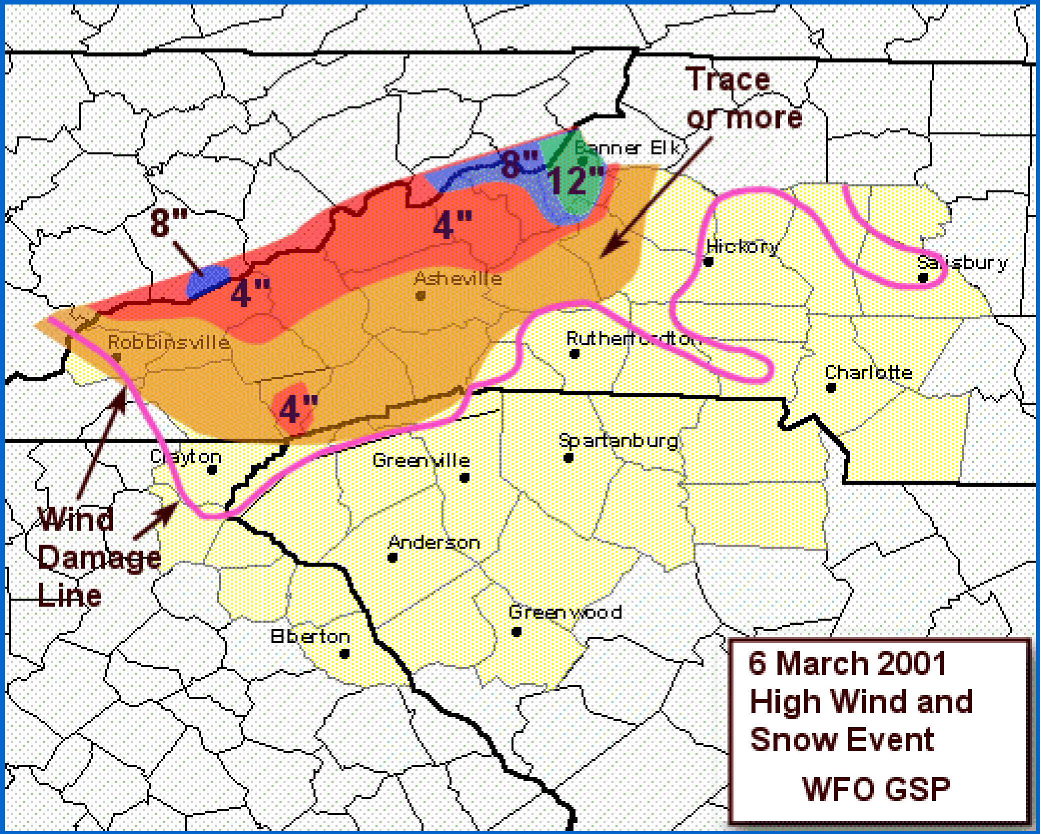
A minor event – Counties in GSP CWA most susceptible to NW Flow snow

Example of Snow Distribution



Typical distribution of snow flurries and snow showers during NW flow event in which moisture (windward cloud field) extends along entire range of Appalachians. Note the proximity of the snow to the TN/NC border.

Example of Snow Distribution



Typical snowfall distribution during an event consisting of deep moisture and terrain-induced upward motion augmented by a short wave embedded in the northwest flow.

Primary Characteristics of Northwest Flow Snow Events

- Often not associated with extratropical cyclone precipitation shield
- Forced primarily by low-level orographic lift
  - Consider component of wind orthogonal to mountains
  - Terrain-induced vertical motion proportional to wind speed

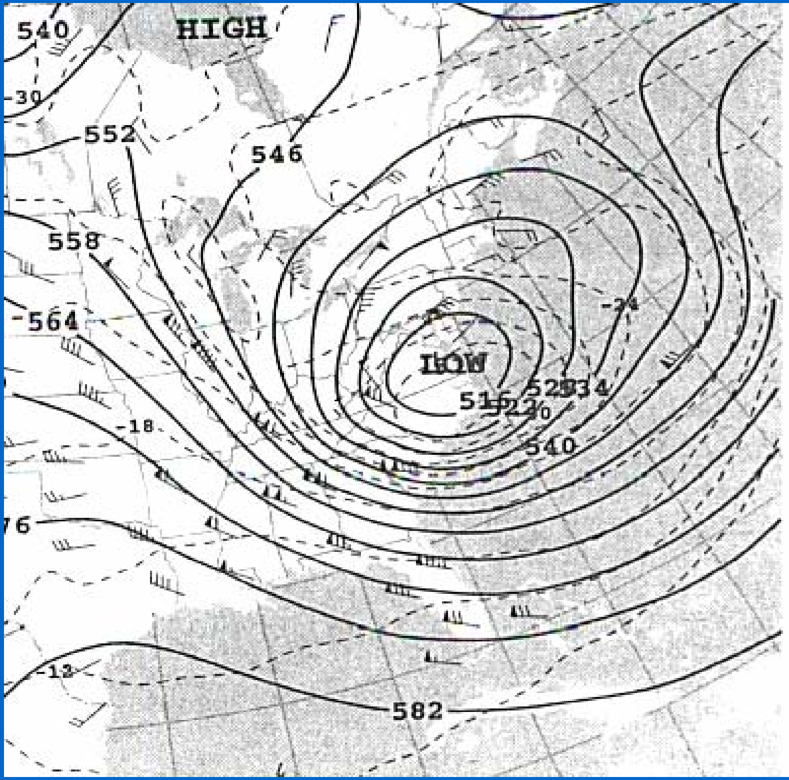
Primary Characteristics

- Occasional augmentation of snowfall by forcing that can be identified using QG diagnostics

- Snowfall pattern quite irregular and accumulation highly variable
  – Sometimes only flurries
  – Sometimes warning criteria accumulation

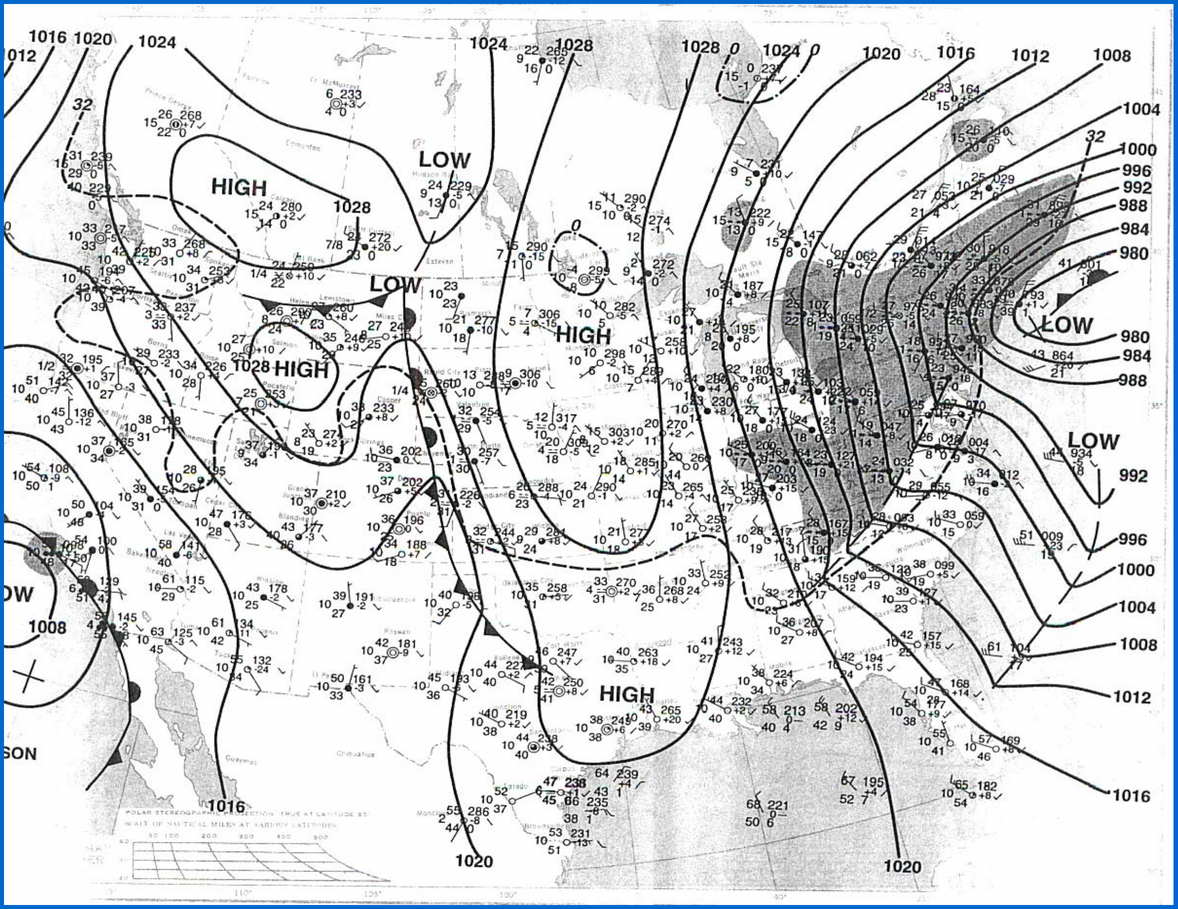
Map Types

- Favorable synoptic scale patterns include:
  - Northwest wind (preferably with cyclonic curvature) at 500 mb or below with trough or deep cut-off low east or northeast of CWA



Map Types

– Surface high pressure system over central United States building into southeastern states



Upward Motion - ❄ Equation?

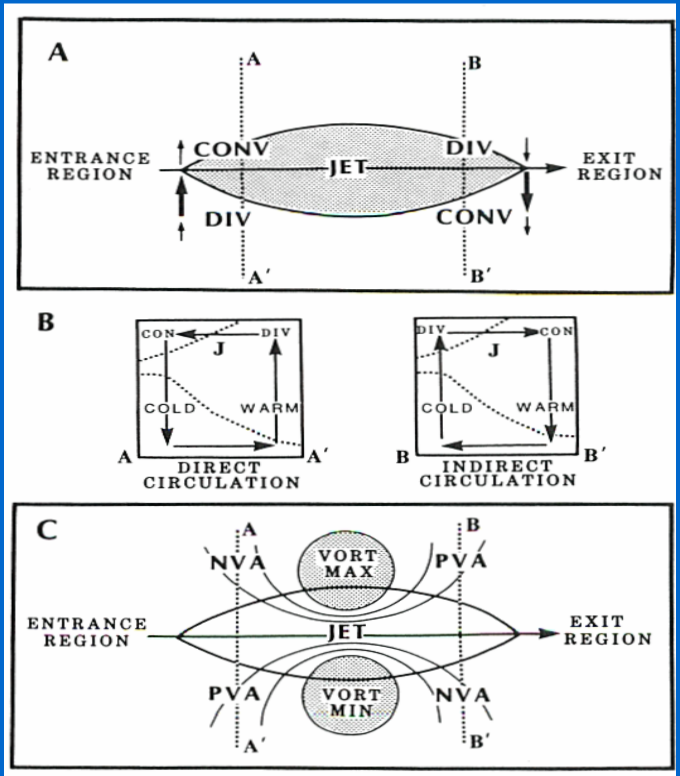
❄ 🔔 Laplacian of temperature advection
+
Differential Vorticity Advection

- During Northwest Flow Events, QG forcing often does <u>not</u> favor upward motion and precipitation
  - NW Flow Snow usually occurs in environment dominated by cold air advection
  - NW Flow Snow frequently (but not always!) occurs in environment lacking differential cyclonic vorticity advection

Be Alert!

- Jet streak or short wave trough approaching southern Appalachians in northwest flow can enhance precipitation (evident as a vorticity maximum at 500 mb)

Always keep in mind the vertical and horizontal accelerations that occur in the vicinity of jet streaks.



(Kocin and Uccellini, 1990)

Northwest Flow Snow Categories

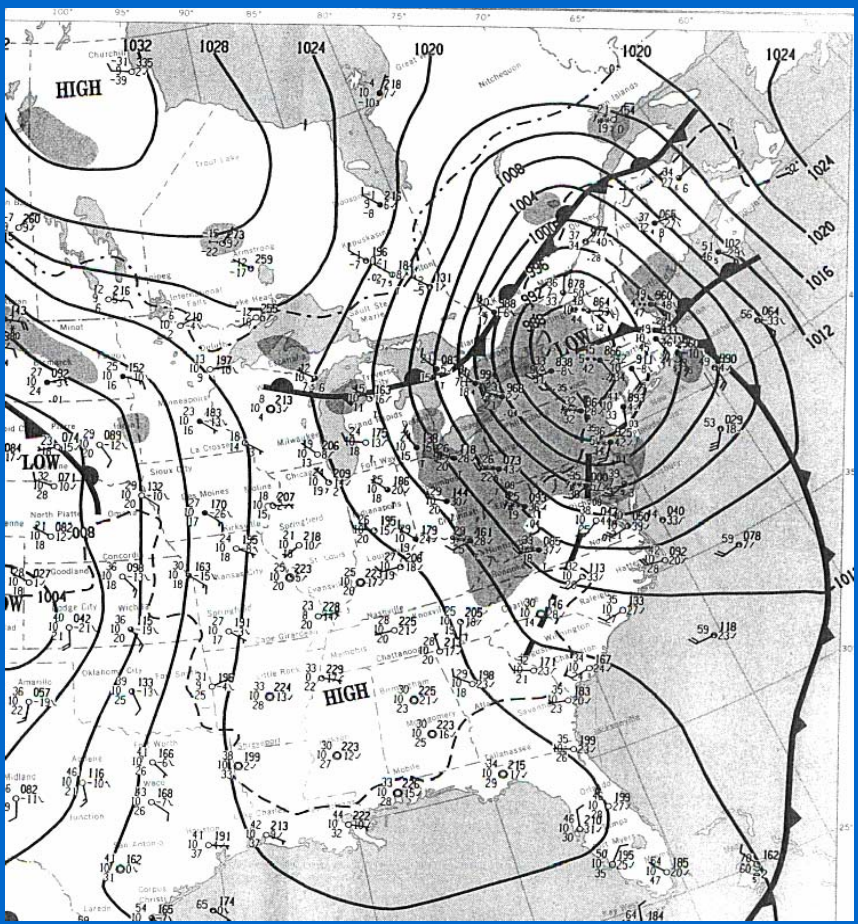
- **Type I –** Post Frontal
- **Type II –** Comma Head (“Wrap-Around”)
- **Type III -** Cut-Off Low

Type I – Post-Frontal

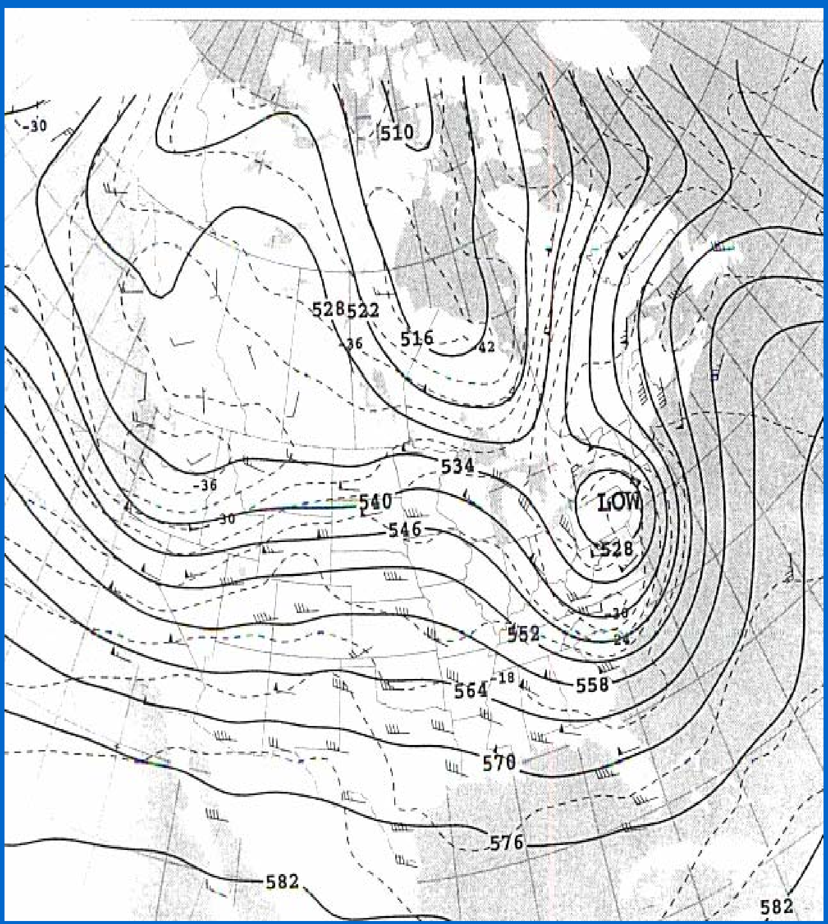
- Low-level wind is northwest (upslope)
- Deepening surface low moving northeast away from CWA
- Synoptic scale precipitation shield is over mid-Atlantic or northeastern states – <u>not</u> over southern Appalachians
- Can evolve from Type II

Post Frontal Event – 3-4 March 1999

Surface



500 mb



Type II – Comma Head - “Wrap Around” Moisture

- Low-level wind is northwest (upslope)
- Trailing edge of synoptic scale precipitation shield associated with departing extratropical cyclone is still over southern Appalachians
  - “Wrap-around” moisture
  - Related to cold conveyor belt ?
- More likely to have contribution from QG forcing
- Can evolve into Type I (Post-Frontal)

Comma-Shaped Cloud Shield

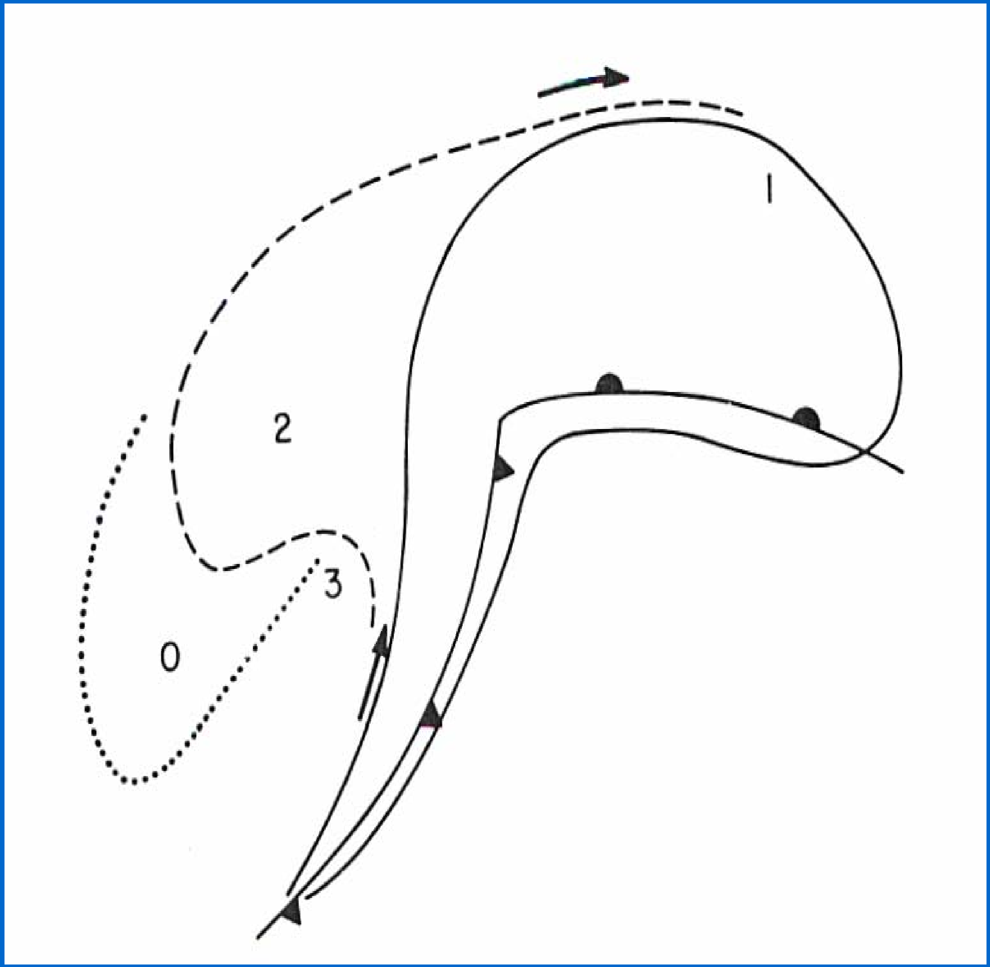
1 Dense middle- and upper-layer cloud

2 Westward extension of cloud canopy

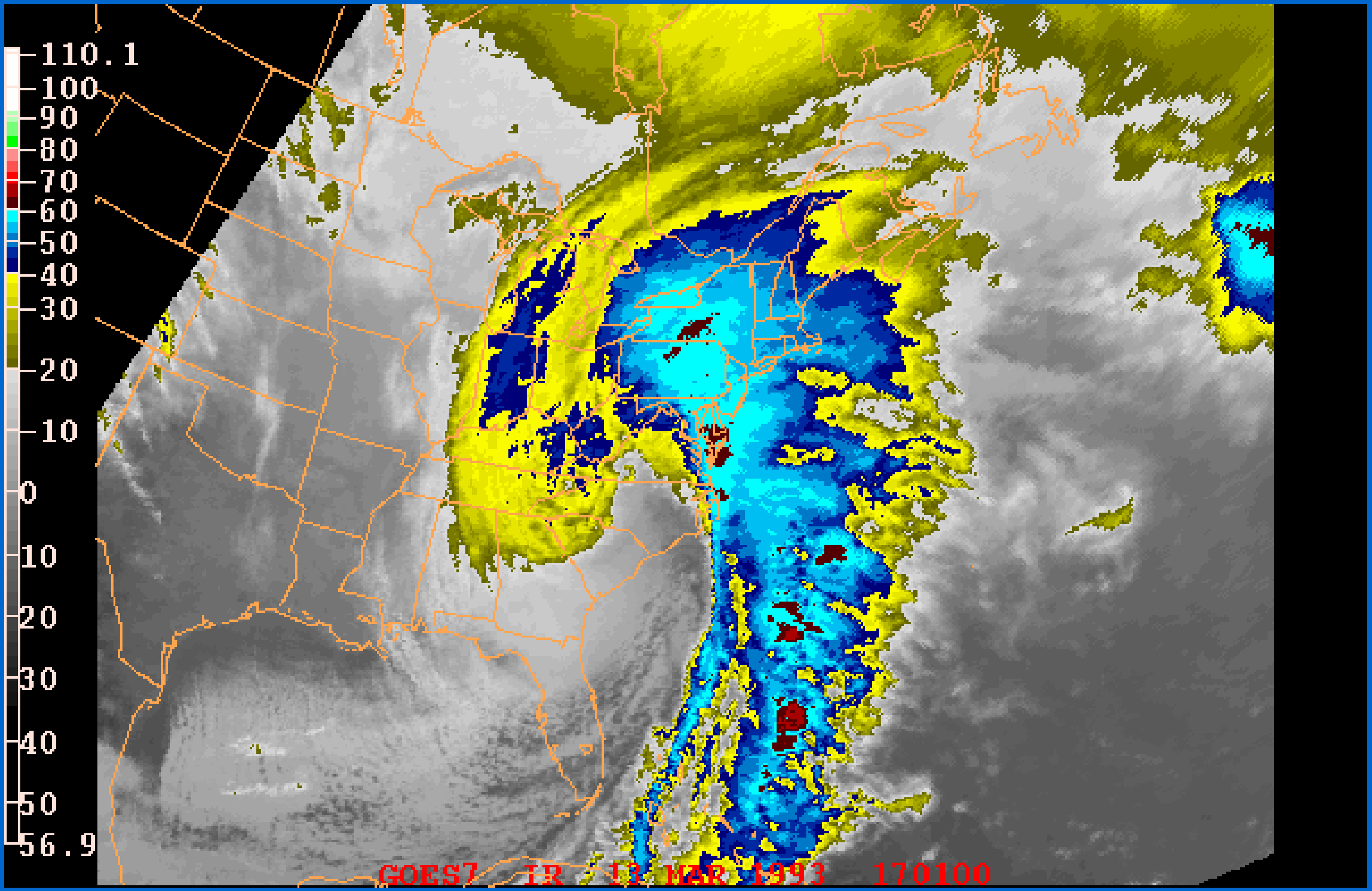
3 Dry slot

0 Thin layer of stratiform cloud. This air enters the poleward side of the cyclone and is diverted equatorward west of the cyclone center.

(Bluestein 1993)

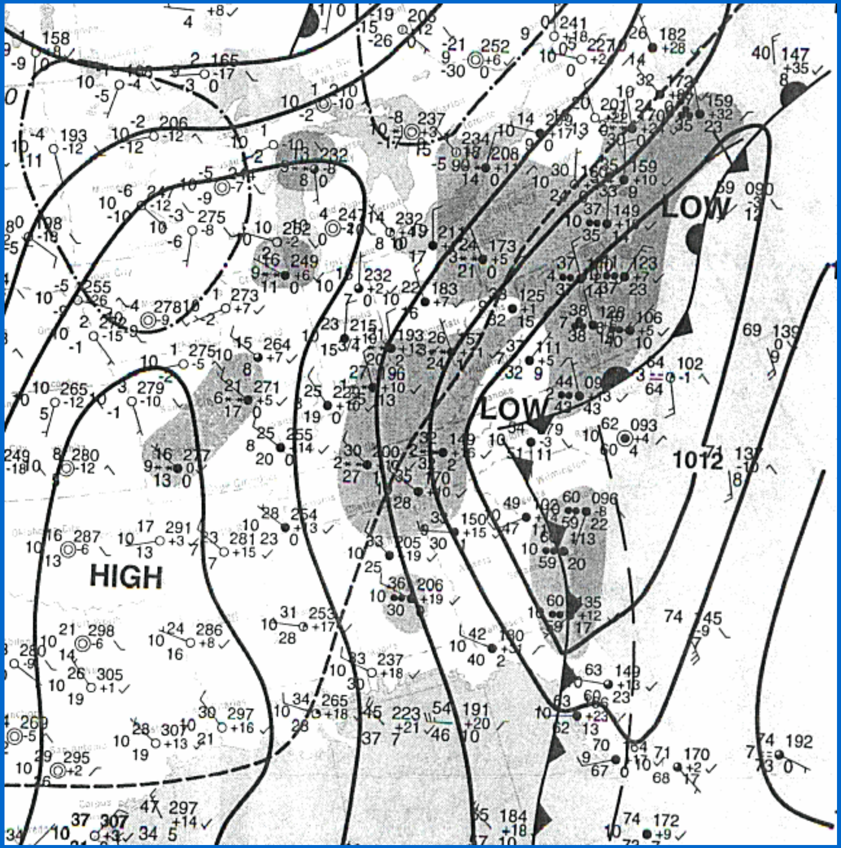


Storm of the Century
March 1993

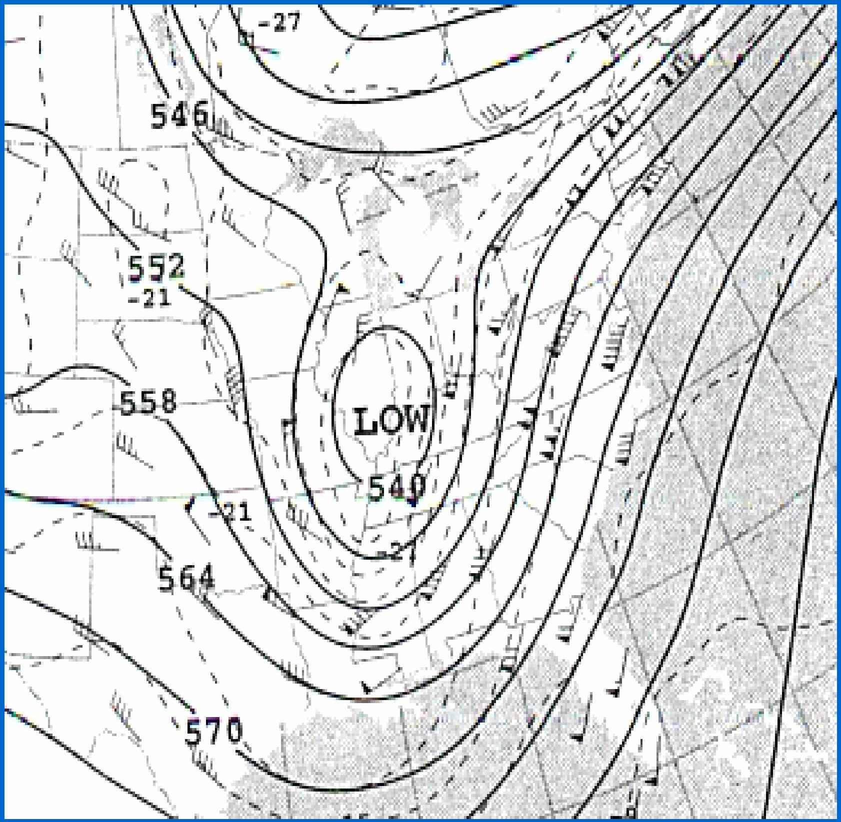


Comma Head ("Wrap-Around") Event – 20 January 2001

Surface



500 mb



Type III – Cut-Off Low

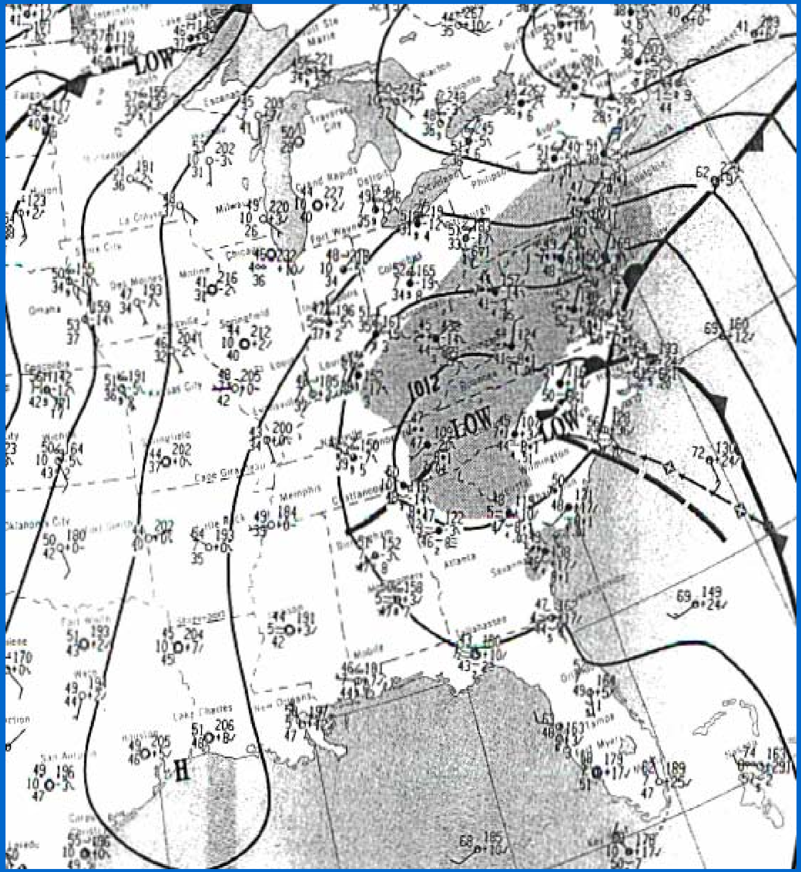
- Not “pure” Northwest Flow snow event
  - Low-level winds across mountains are northwest
  - Snowfall enhanced significantly by synoptic scale forcing due to proximity of low
  - More complex processes involved in precipitation formation
  - Subtype of Type II ?

Type III – Cut-Off Low
(continued)

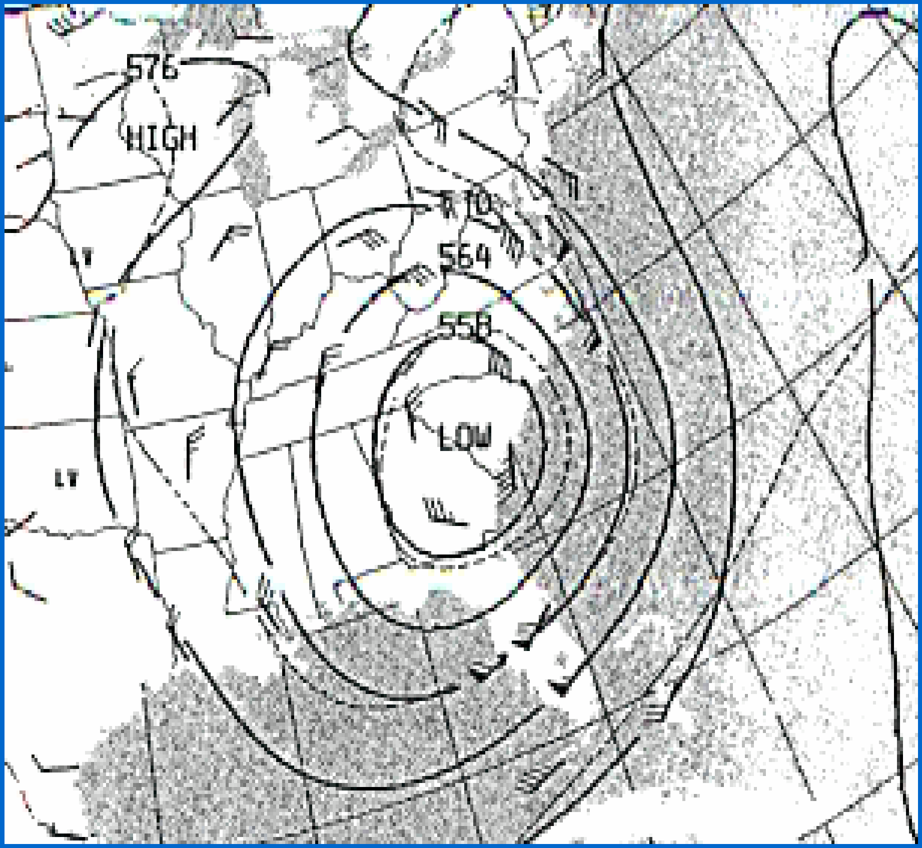
- Nearly stationary cut-off low just east or northeast of CWA
- Can produce long periods of moist, northwest flow
- Most common during late winter and spring

Cut-Off Low – 8 May 1992

Surface



500 mb



WINDEX

Wintertime INstability inDEX

- Probably most common in Type I (post-frontal) events
- A tool for anticipating significant snowfall during periods of an hour or less
- Associated with post-frontal events when surface trough or upper-level forcing is embedded in NW Flow
- Developed for instability snow squalls in New England (Lundstedt 1993)

WINDEX

- Rapid Lifted Index change to more stable
  - Indicative of air mass change rather than parcel stability
- 30^{o} wind shift (veering)
- Increasing boundary layer wind speed
- Temperature difference at least 10^{o} C from surface to 800 mb
- Layer Relative Humidity > 70%
- Can produce snow east of favored areas

Forecasting Tips

- Wind direction and speed of low-level flow
  - Favored direction is perpendicular to terrain
    - Generally NW, but local ridge orientation can result in modification
  - Large scale flow should be cyclonic
  - Not as many significant events in neutral flow
  - Speed in layer encountering mountains should be at least 20 kt

Forecasting Tips

- Moisture
  - “Deep” moisture not necessary
    - Frequently confined to 850 mb and below
    - Moisture above 850 mb indicates greater potential for precipitation
    - Examine moisture characteristics of air in Kentucky and East Tennessee to evaluate snow potential (use “point” soundings in AWIPS and hourly TRI and TYS profiles in BUFKIT)

A Few More Moisture Clues

- Surface dew point depressions < 10°C
- Mixing ratio $\geq$ 2 g kg^{-1} indicates potential for accumulating snow
- Model 850 mb “Moisture Transport Vector” provides guidance on areas most susceptible to precipitation
- Flurries predominate with shallow mean RH and 850 mb temperatures of -2°C to -6°C

…and more

- Onset of snow often with 850 mb RH > 70%
- Ending of snow often with departure of 1000-850 mb mean RH of 70%
- Bands of clouds from Great Lakes sometimes provide moisture source (at least in RNK CWA)

Forecasting Tips:
Temperature Considerations

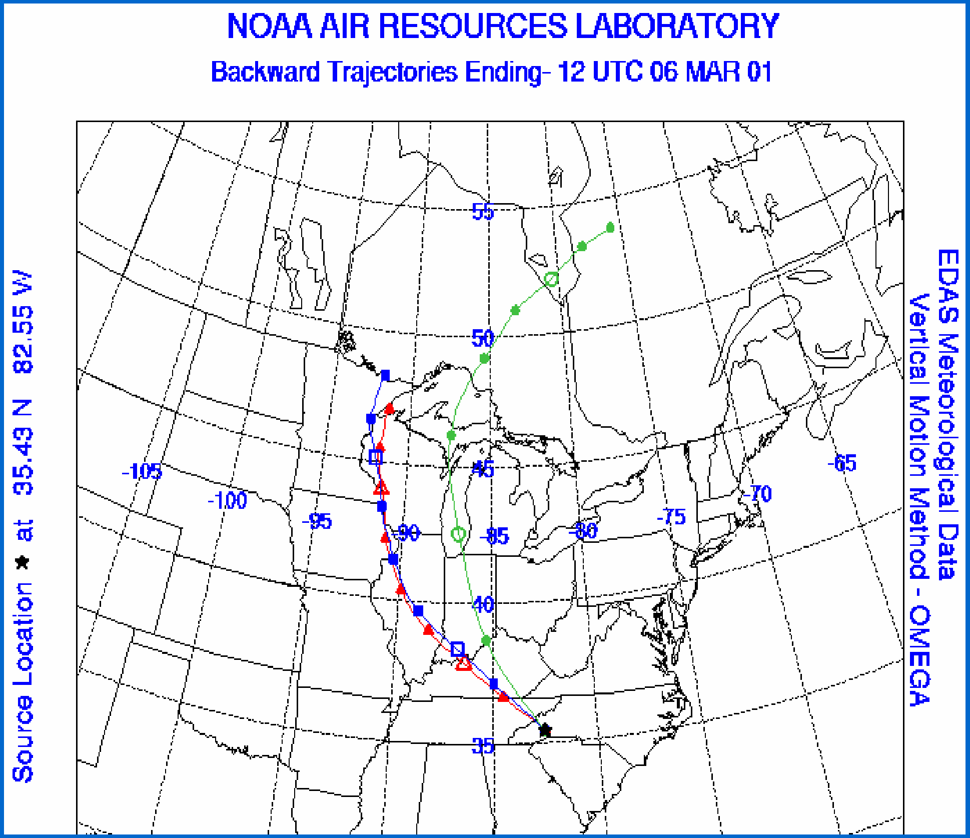
- Frequently observed that 850 mb temperatures are at least –12^{o}C for a significant event (not the case 17 Apr 2001)

- Unstable lapse rates promote precipitation
  - Contributes to shallow convection
  - Lapse rates in layers below 700 mb during 17 Apr 2001 event were approximately 9^{o}C per km

Great Lakes Influence
Maybe ?

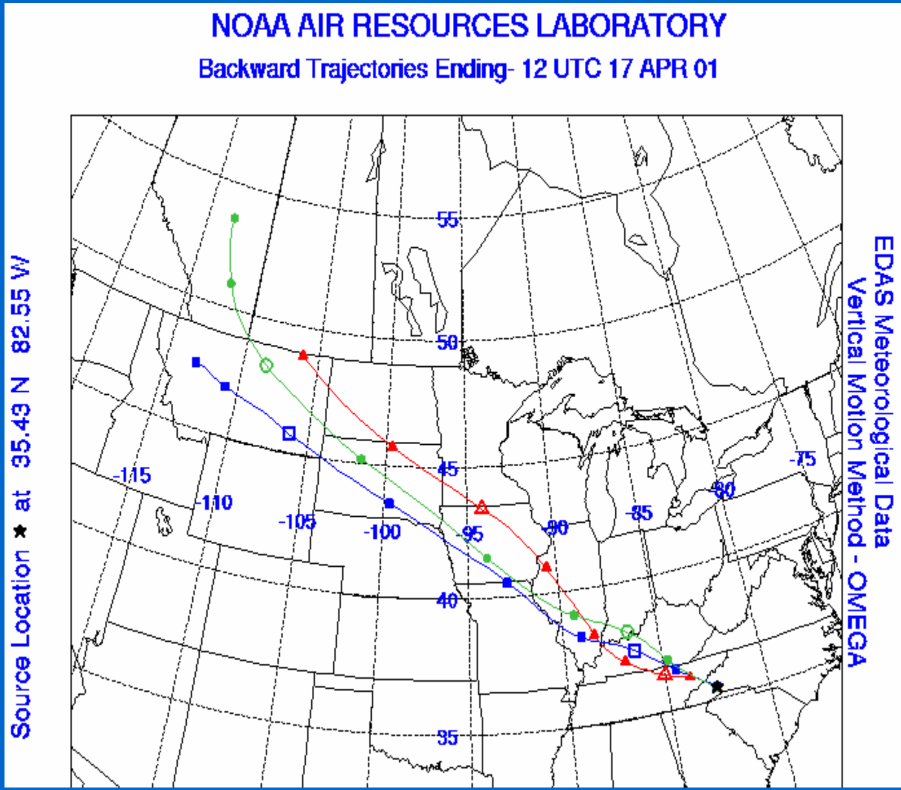
- Air flow from Great Lakes region does sometimes occur during Northwest Flow Snow events

- 6 March 2001



Great Lakes Influence

Maybe Not!

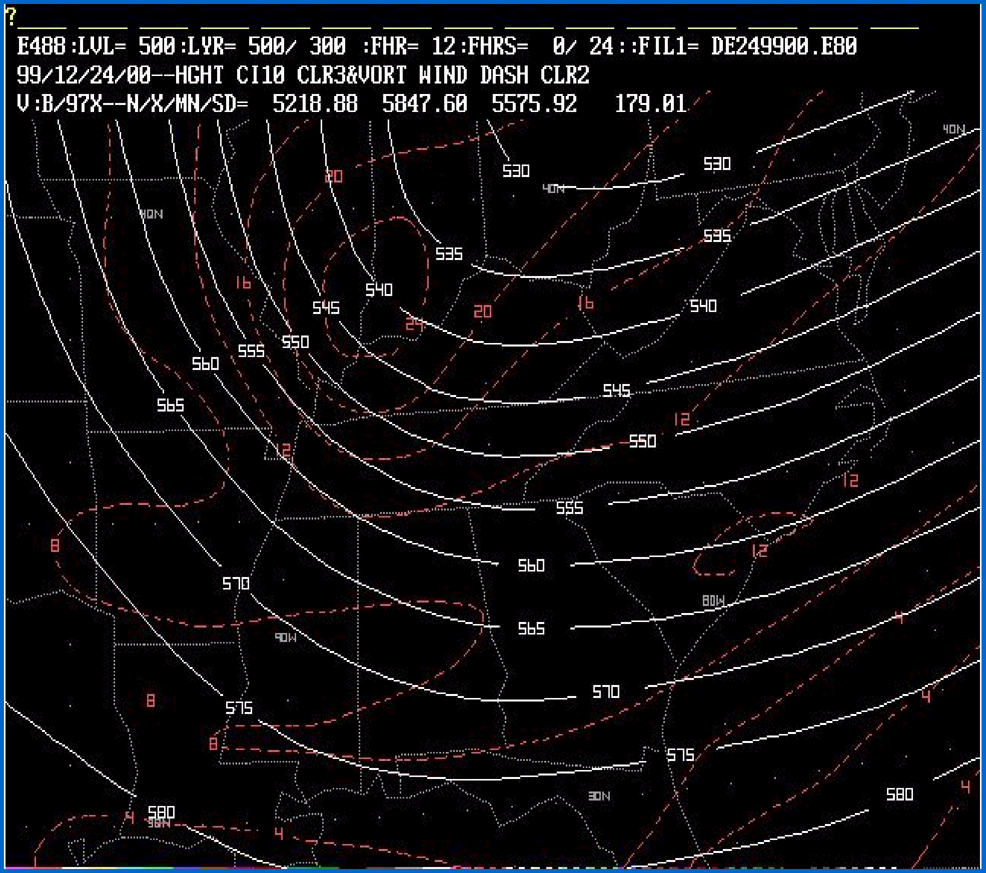


- Air flow from the Great Lakes region is <u>not</u> required for significant NW Flow snow
- 17 April 2001

What’s Upwind?

- Large field of stratus and stratocumulus (especially with snow showers and snow flurries) across KY and TN indicates sufficient moisture for Northwest Flow snow in southern Appalachians
- Most favorable cloud coverage exists when stratus/stratocumulus extend into northern MS, northern AL, and northwest GA
- Vorticity Maximum?

Vorticity Maximum



- Post frontal snow enhanced when short wave trough or wind maximum in NW flow approaches mountains (appears as vort max)
- When accompanied by colder cloud tops, snowfall rates can be significant for short periods of time (WINDEX)

Cloud and Precipitation Physics

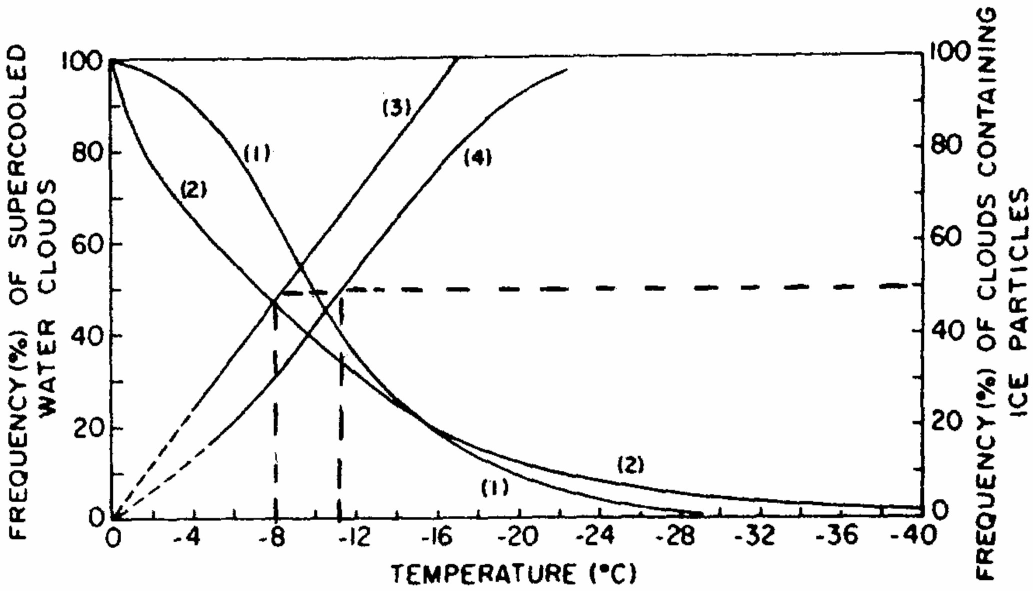


Fig. 2-1. Variation of the frequency of supercooled clouds and of clouds containing ice crystals. Curves 1 and 2 pertain to ordinate at left. Curves 3 and 4 pertain to ordinate at right. (1) Peppler (1940), Germany, all water clouds; (2) Borovikov *et al.* (1963) ETU, all water clouds; (3) Mossop *et al.* (1970), Tasmania, mixed clouds; (4) Morris and Braham (1968), Minnesota, mixed clouds.

(Pruppacher and Klett, 1980)

Cloud and Precipitation Physics

Probability of Ice in Cloud as a Function of Temperature	
$-4^{o}C$	No Ice
$-10^{o}C$	60% Chance Ice Exists
$-12^{o}C$	70% Chance Ice Exists
$-15^{o}C$	90% Chance Ice Exists
$-20^{o}C$	Near 100% Chance Ice Exists

(Baumgardt 2000)

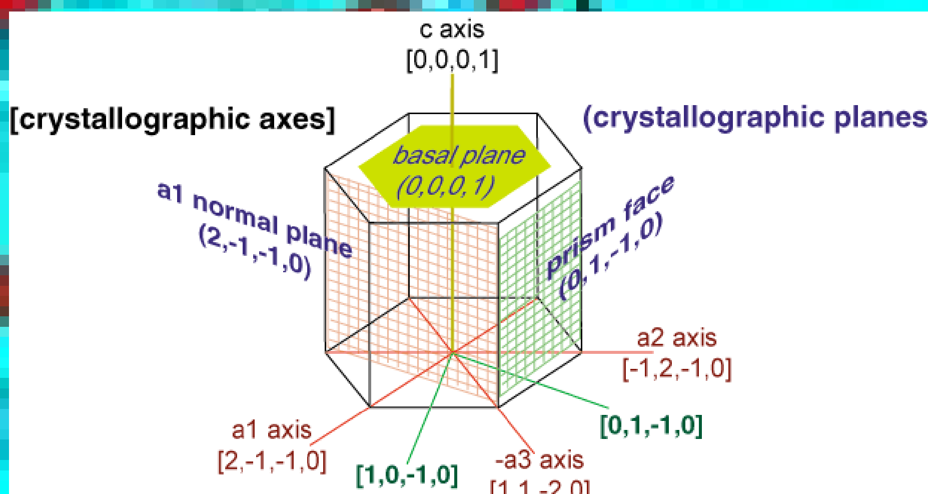
Cloud and Precipitation Physics

- Clouds should extend to –15ºC (✂ 2 or 3 degrees) for most efficient generation of snowflakes (refer to Nakaya diagram)
  - Optimum production of dendritic snow crystals
  - Optimum diffusive growth rates of ice
  - Nakaya IR enhancement curve in GSP AWIPS

Image: Jerzy Rutkowski (jerzyrut@uni.lodz.pl)

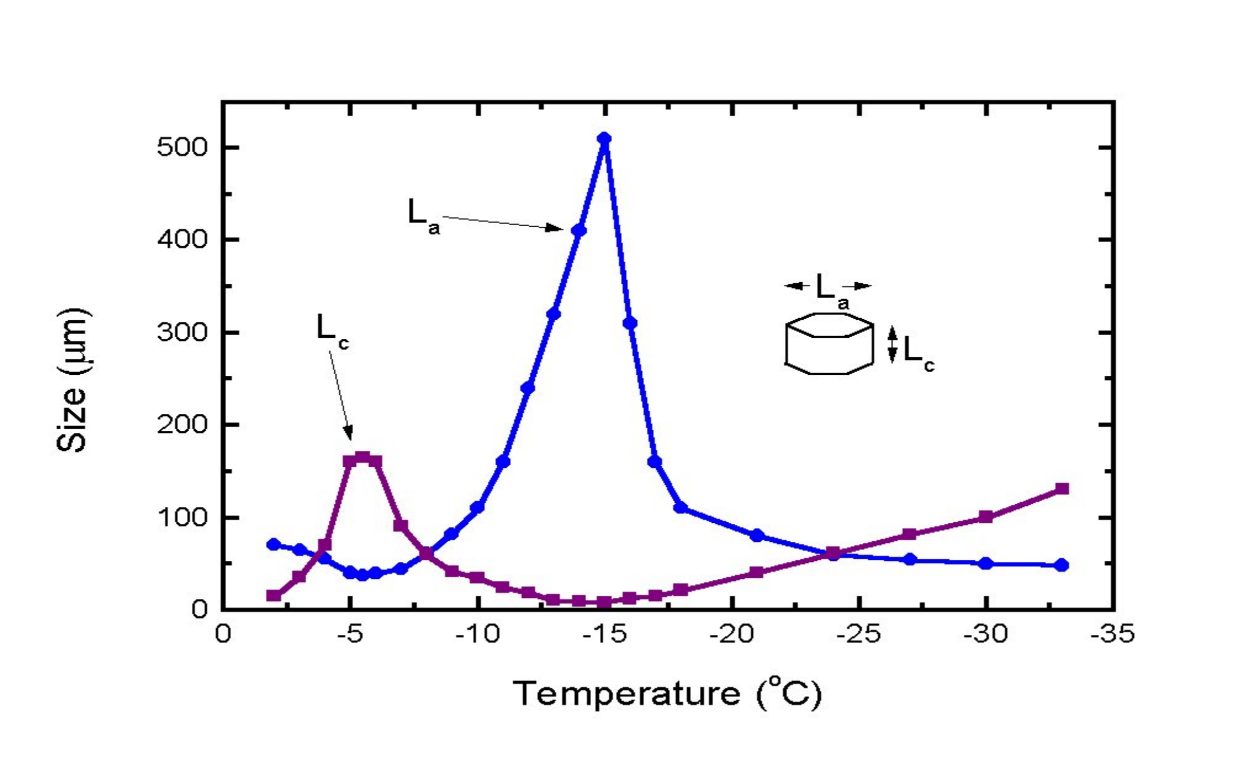
Why Dendrites at –15°C?

Most common form of ice crystal is the hexagonal prism.



http://www.its.caltech.edu/~atomic/snowcrystals/

Crystal Faces Grow at Different Rates Depending on Temperature



Near –15°C, growth rate of $\mathbf{L_a}$ is at a maximum while growth rate of $\mathbf{L_b}$ is at a minimum. Result – Hexagonal Plate, but …

http://www.its.caltech.edu/~atomic/snowcrystals/

Plates Quickly Evolve Into Dendritic Crystals Because of *** Mullins – Sekerka Instability ***

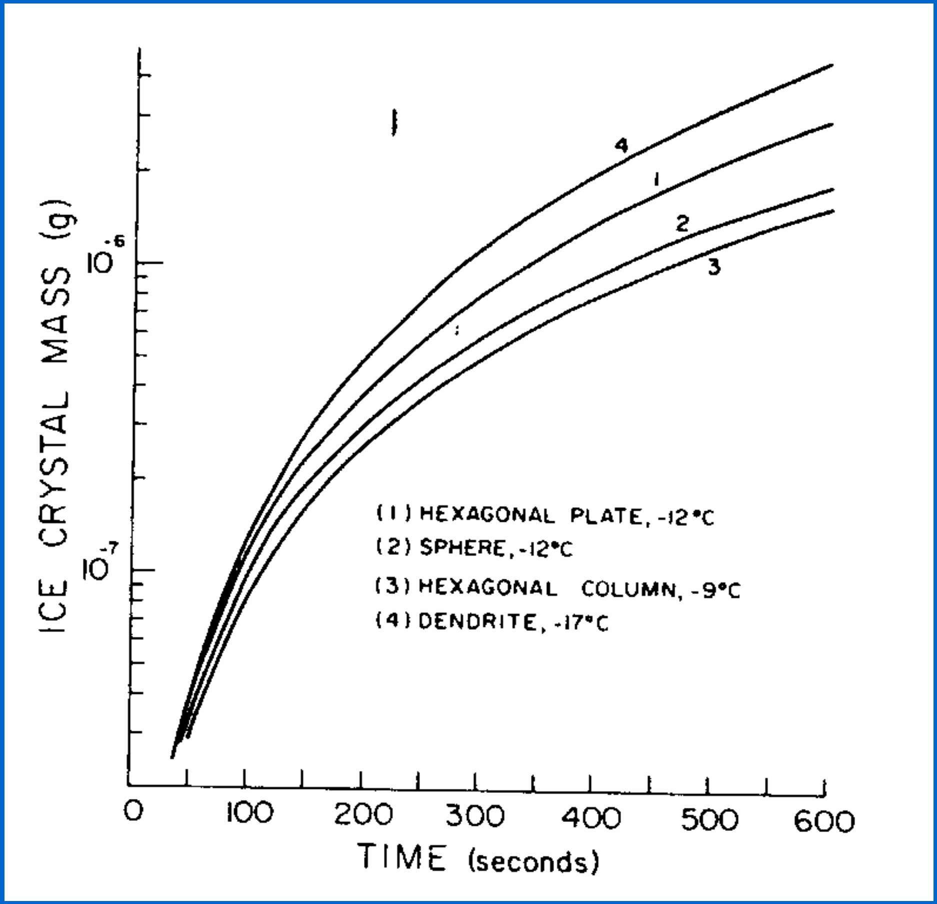
As the crystal grows larger, the corners grow most rapidly by diffusion resulting in six arms. As the arms grow, their edges grow rapidly. … and so on and so on. This produces the dendritic, or tree-like, pattern.

http://www.its.caltech.edu/~atomic/snowcrystals/

Growth Rate of Ice Crystals by Diffusion

Differences in growth rates are initially small.

Dendrites quickly assume greater mass than other crystal types.

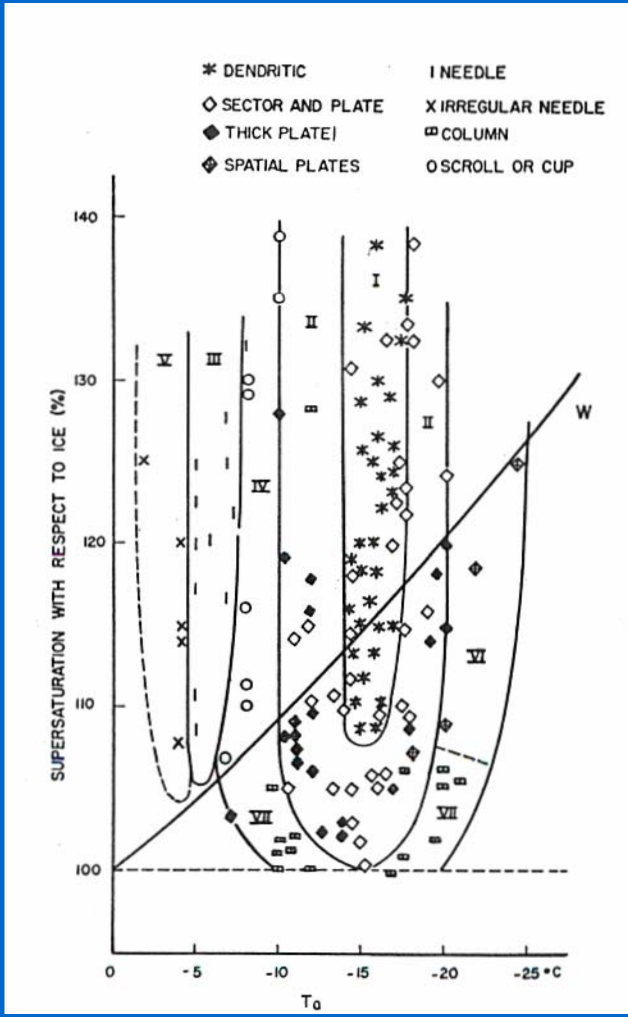


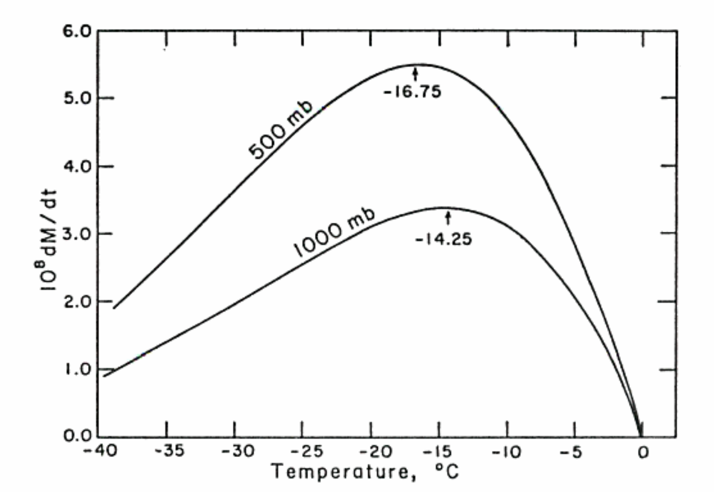
(Pruppacher and Klett, 1980)

Nakaya Diagram

and

Growth Rates of Ice Crystals





Growth rates as a function of temperature for ice crystal in water-saturated cloud at 1000 mb and 500 mb. Temperatures of maximum growth rate are indicated.

⇐ Nakaya Diagram

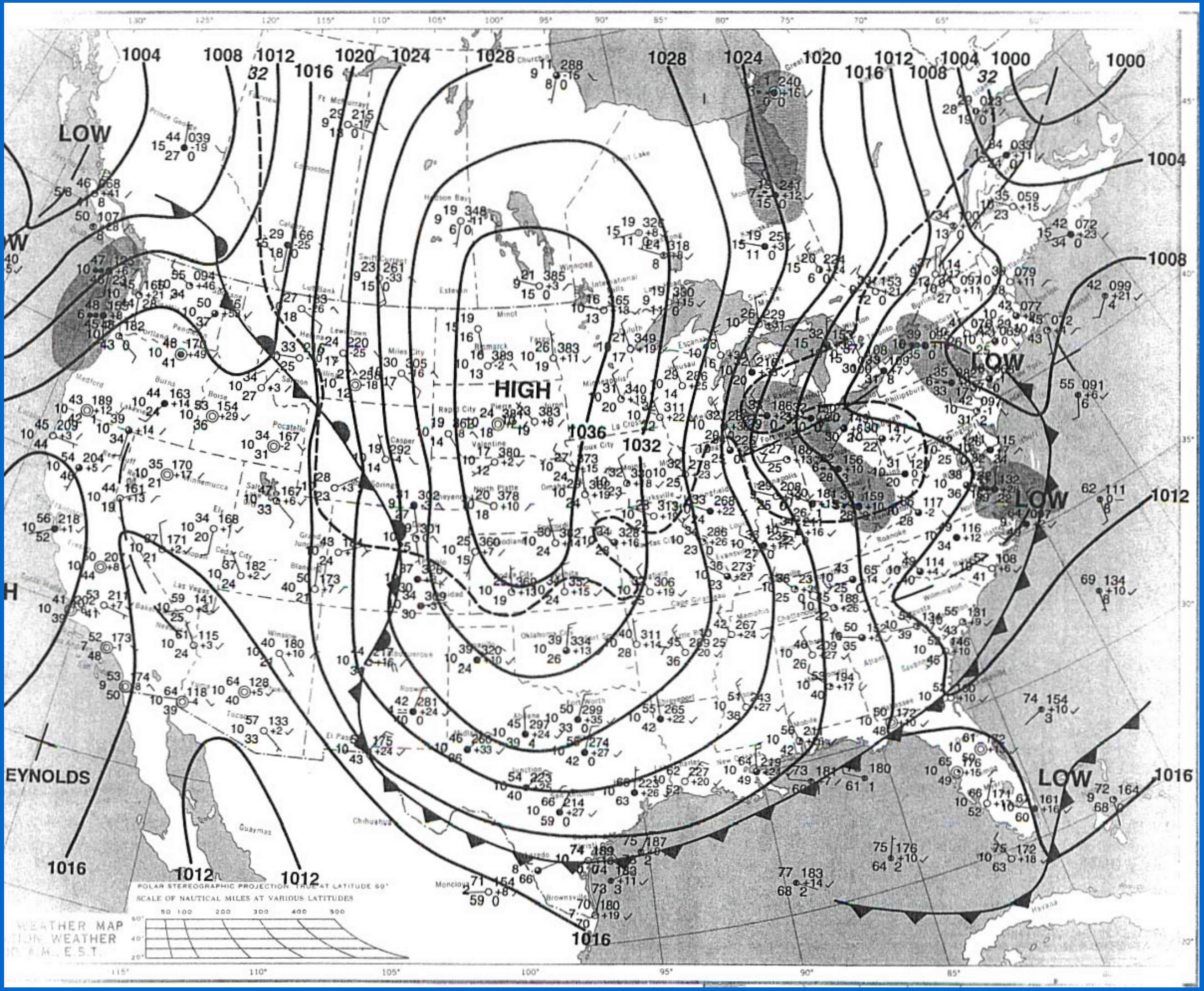
(Byers 1965)

Event Review

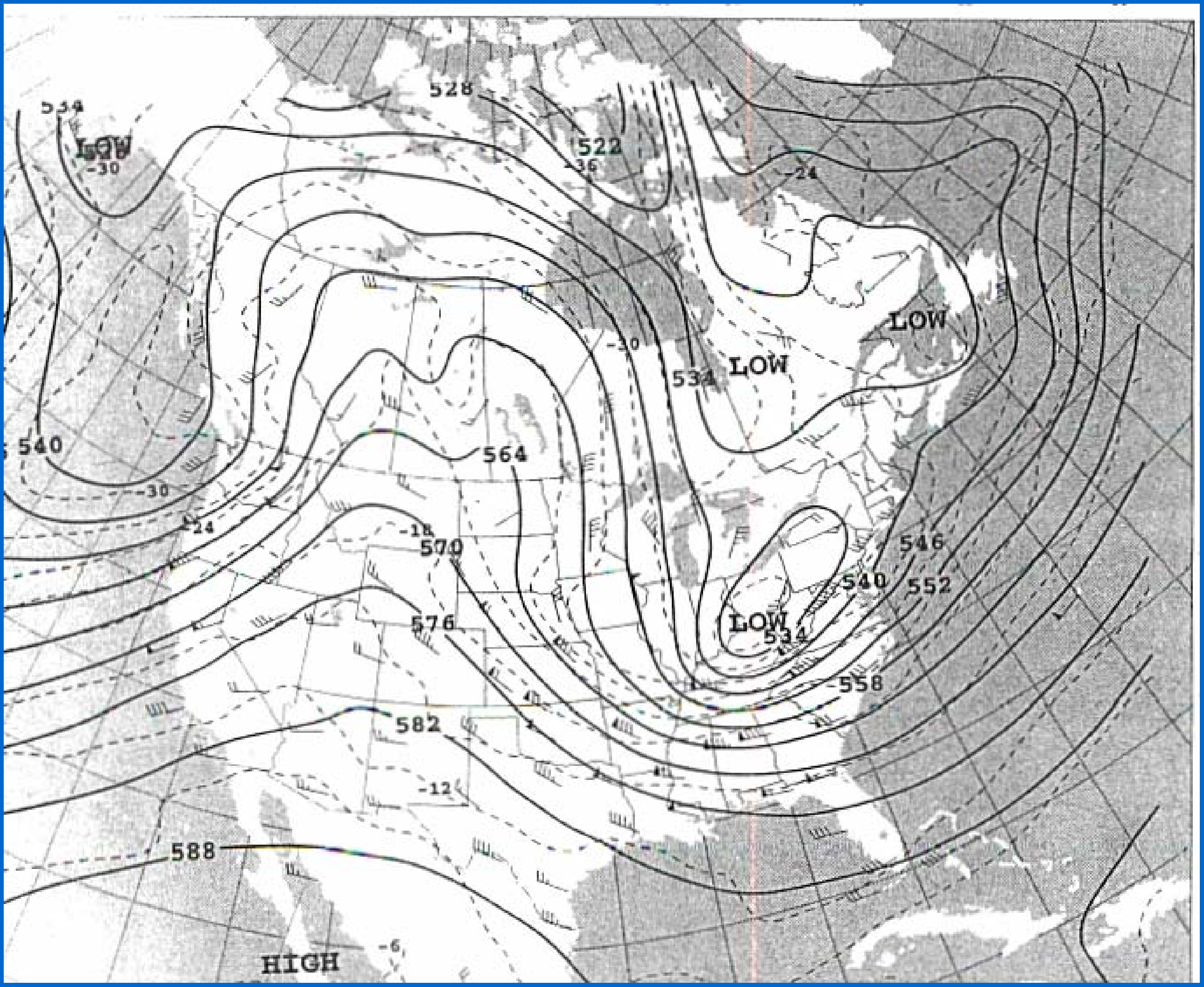
17 April 2001

- Post-frontal Event
  - Cold front offshore
  - Upper-level trough
  - 2” – 4” inches of snow in parts of mountains
  - Snow flurries and snow showers in foothills and Piedmont

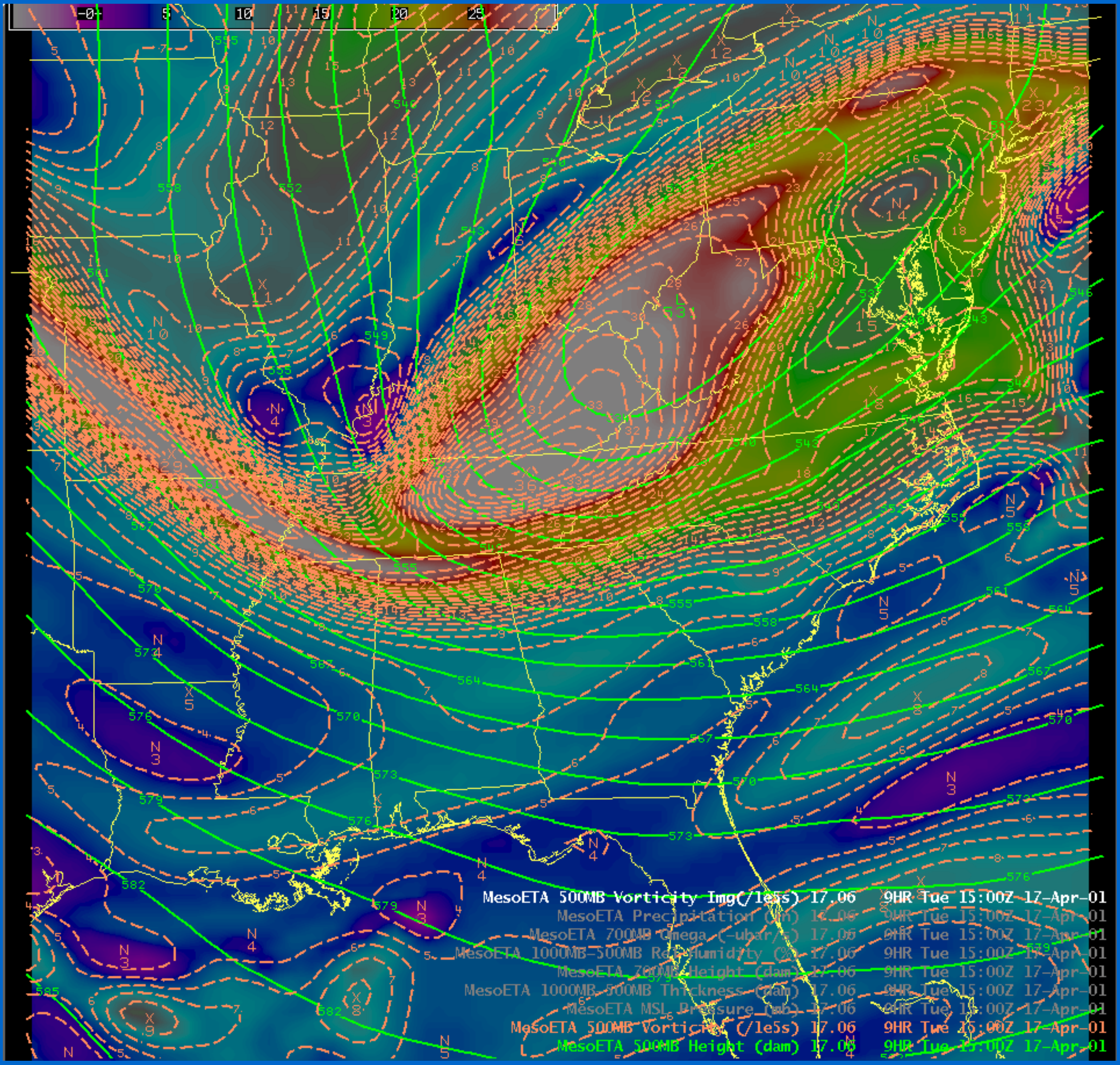
Surface Analysis – 12Z



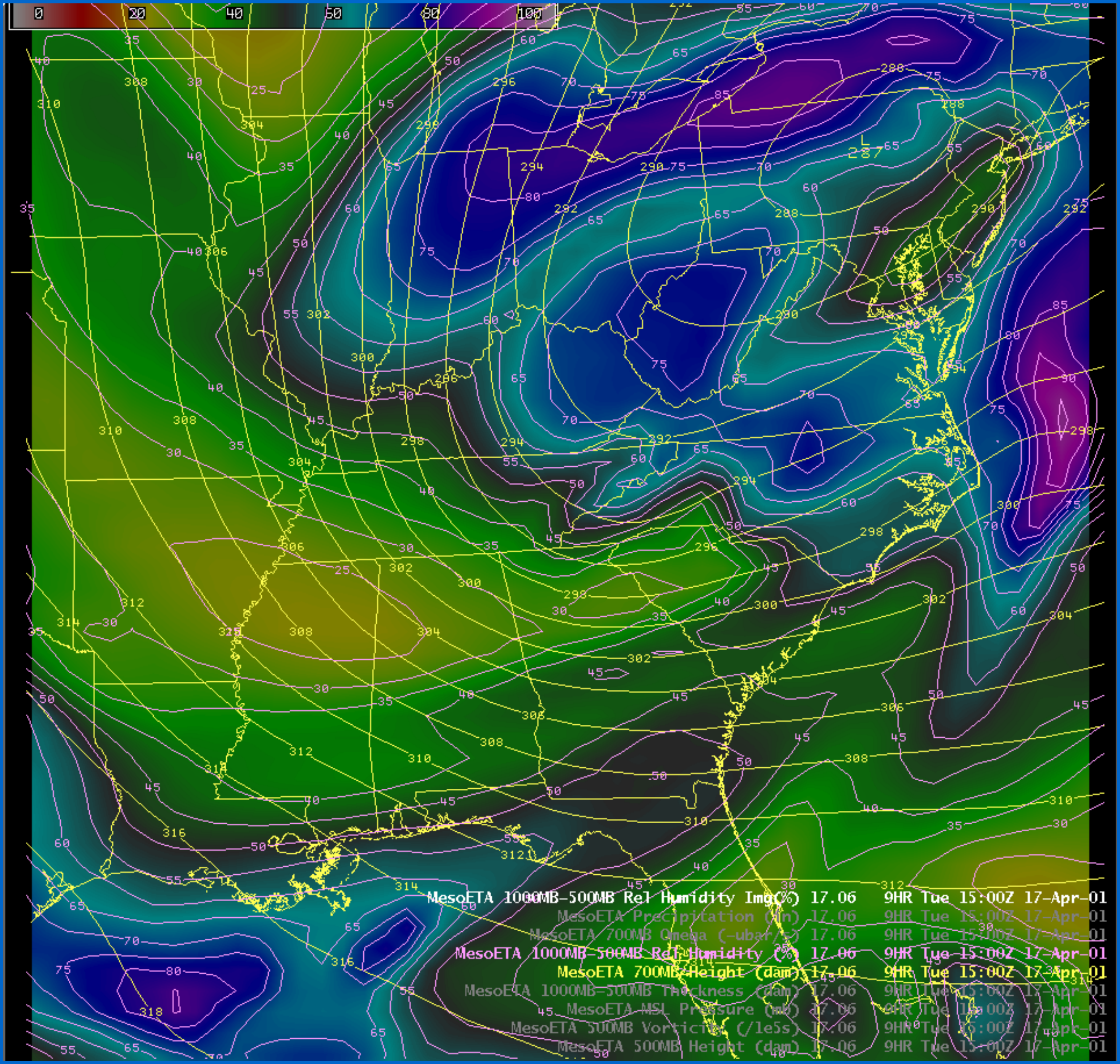
500 mb Analysis – 12Z



500 mb – 15Z


MesoETA 500MB Vorticity Img(/1e5s) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA Precipitation (in) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 700MB Omega (-ubar/s) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 1000MB-500MB Rel Humidity (%) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 700MB Height (dam) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 1000MB-500MB Thickness (dam) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA MSL Pressure (mb) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 500MB Vorticity (/1e5s) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 500MB Height (dam) 17.06 9HR Tue 15:00Z 17-Apr-01

700 mb – 15Z


0
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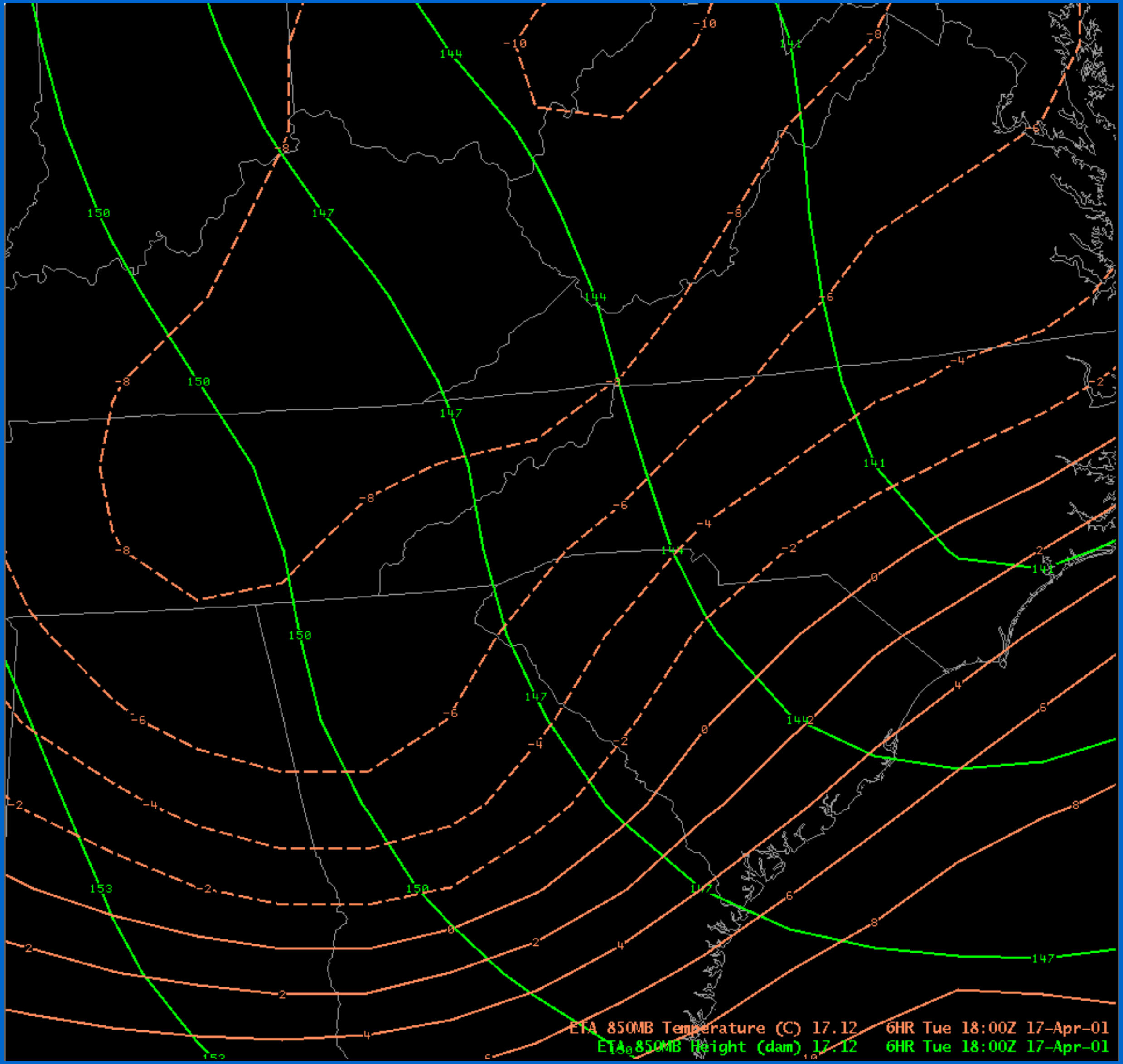
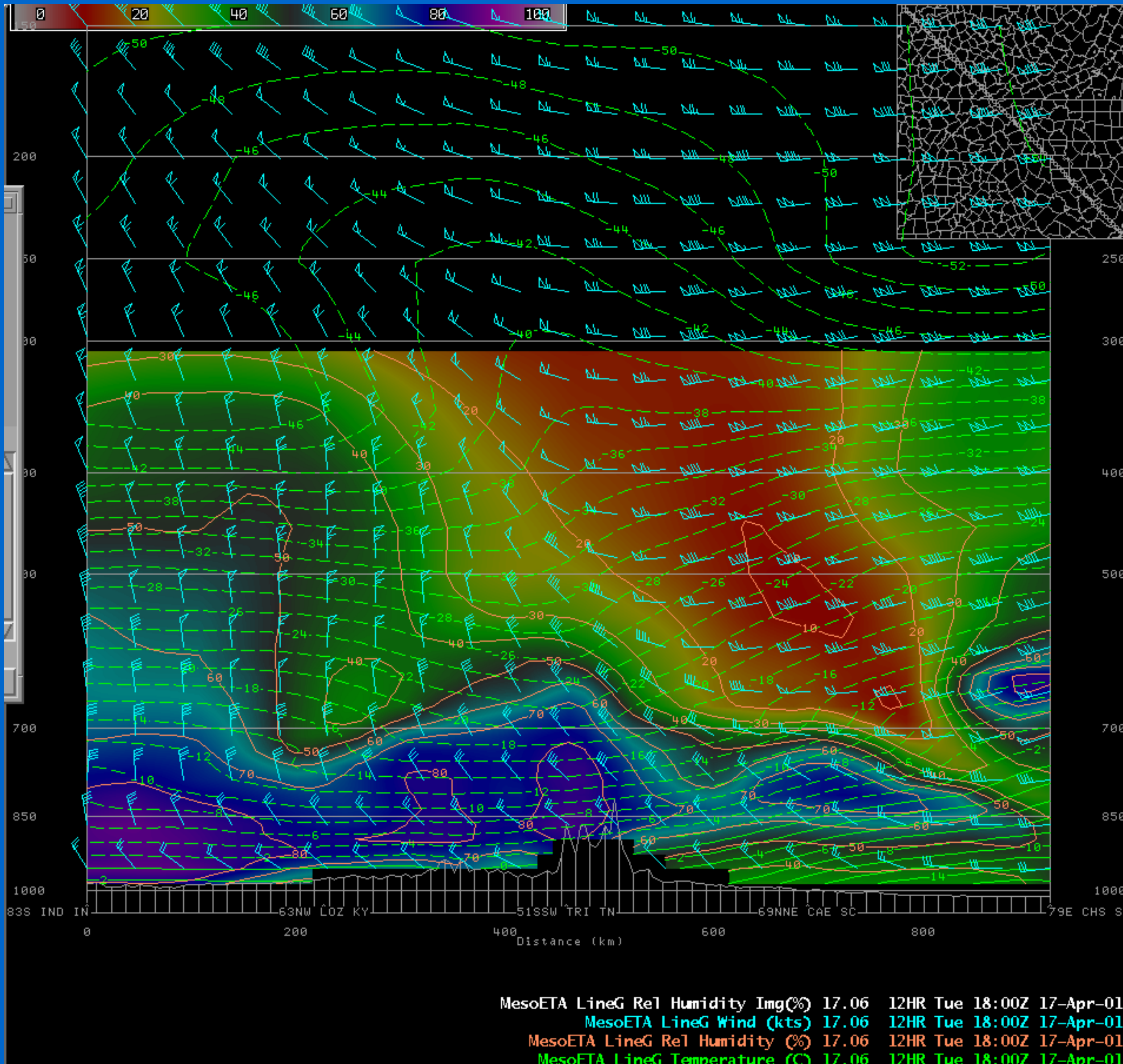
MesoETA 1000MB-500MB Rel Humidity Img(%) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 1000MB-500MB Rel Humidity (%) 17.06 9HR Tue 15:00Z 17-Apr-01
MesoETA 700MB Height (dam) 17.06 9HR Tue 15:00Z 17-Apr-01

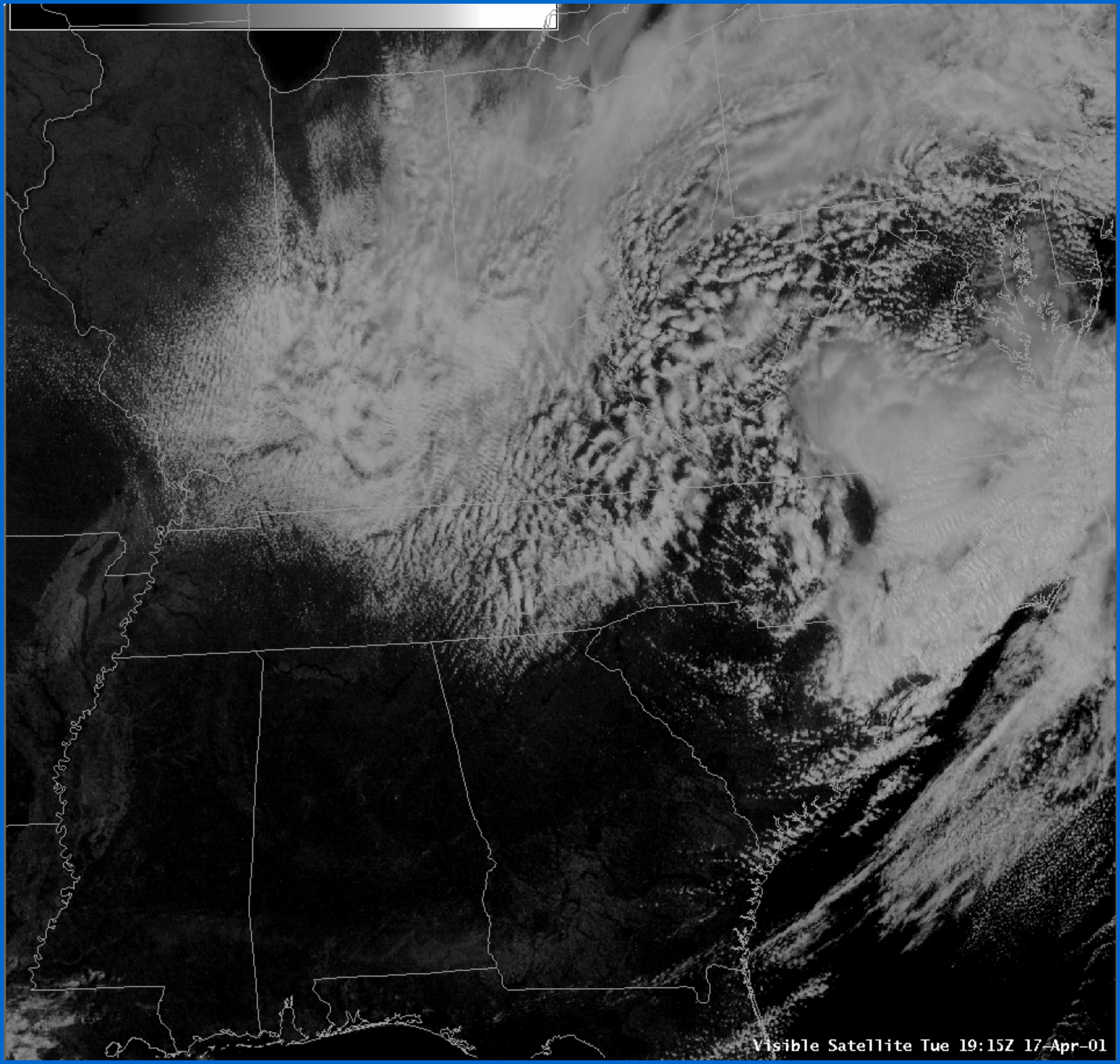
850 mb – 12Z


ETA 850MB Temperature (C) 17.12 6HR Tue 18:00Z 17-Apr-01
ETA 850MB Height (dam) 17.12 6HR Tue 18:00Z 17-Apr-01

NW-SE Cross Section – 18Z



Visible Satellite Imagery – 1915Z



IR Satellite Imagery (Nakaya Curve) – 1545Z

Light Blue…….. 0.0°C

Darker Blue… -10.0°C

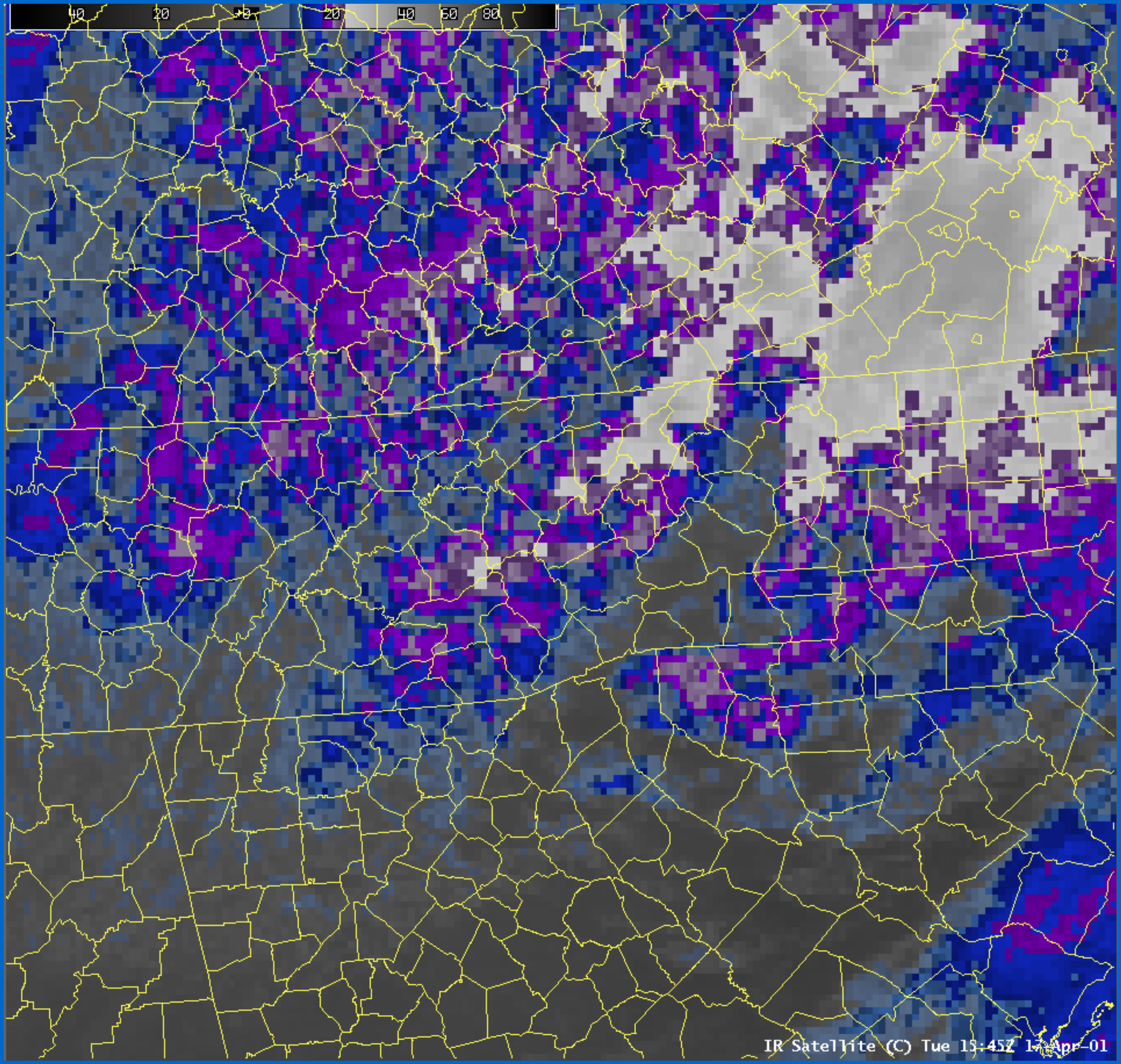
Dark Blue…… -13.0°C

Purple……….. -17.5°C

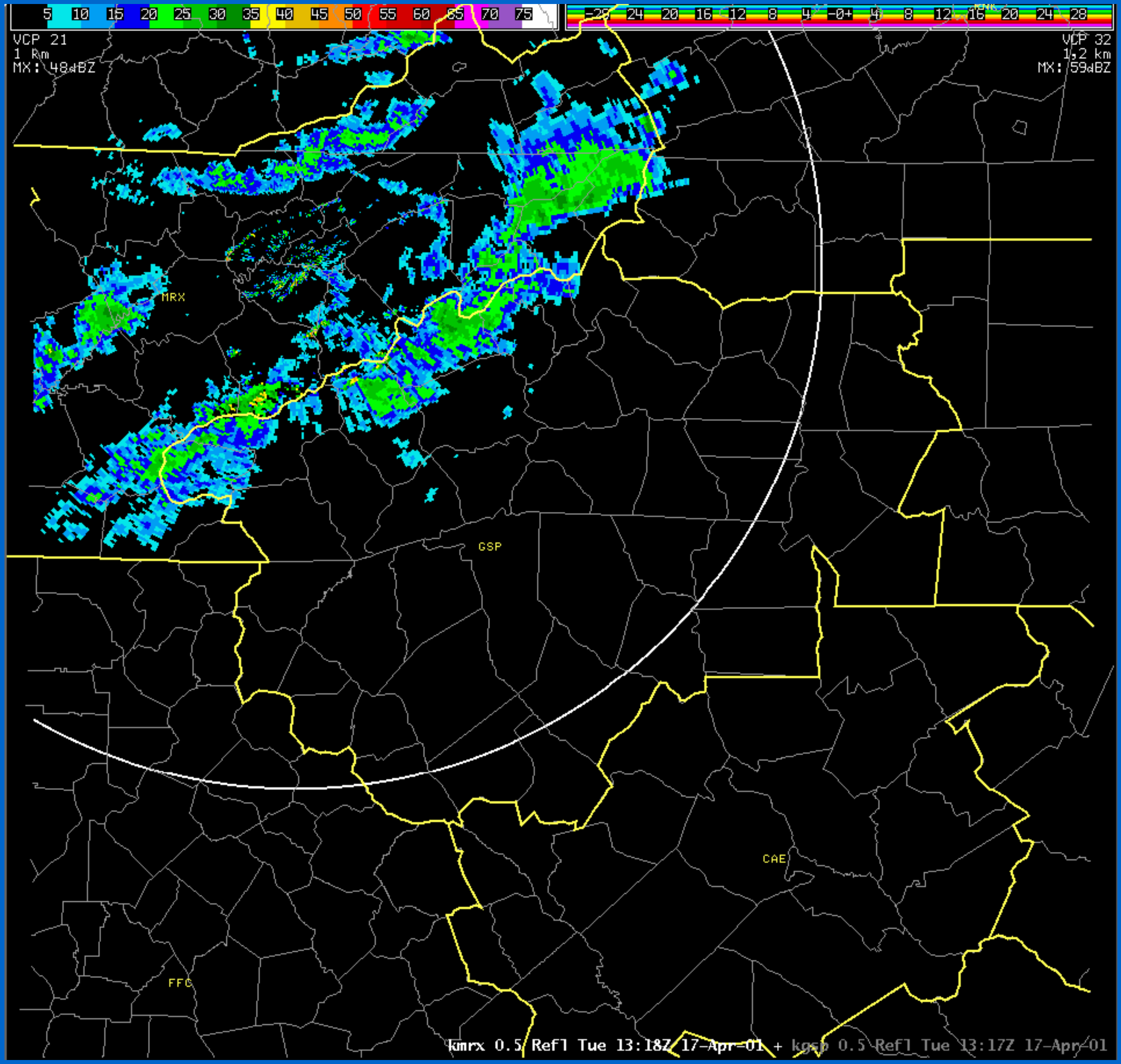
Light Purple…. -20.0°C

Light Gray……-23.0°C

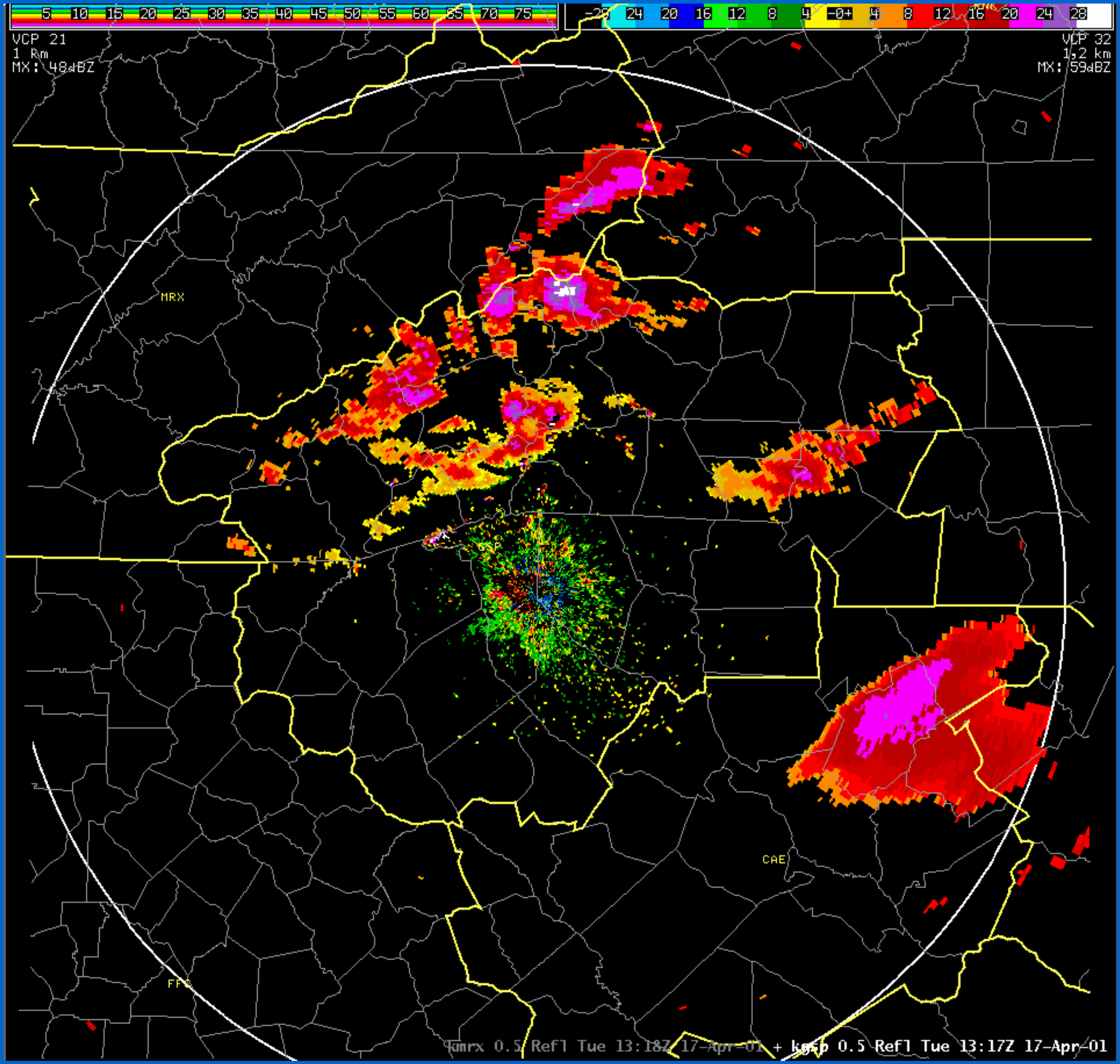
Dark Blue Highlights temperatures within +/-2°C of -15°C



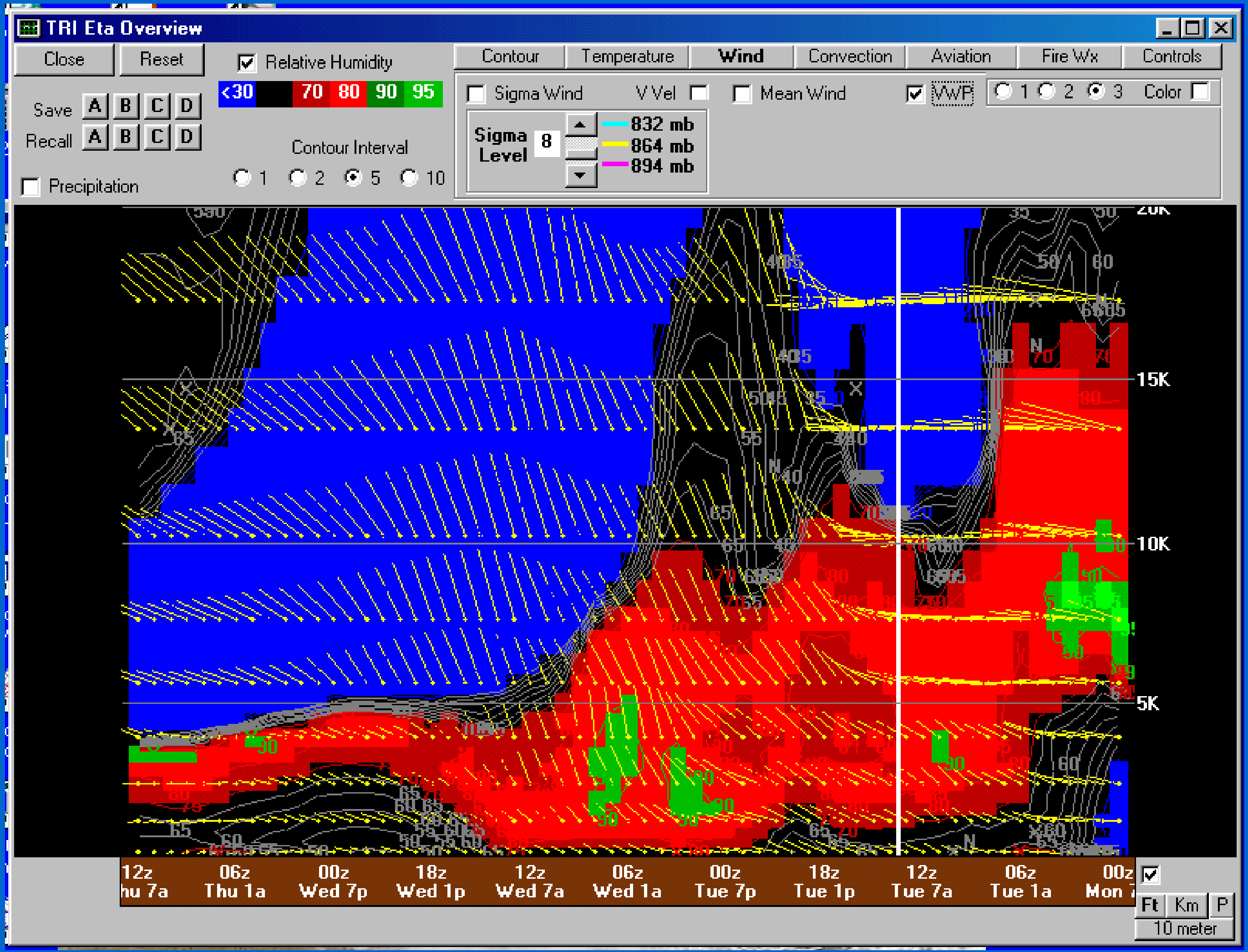
KMRX – 1318Z


5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
-28 24 20 16 12 8 4 -0+ 4 8 12 16 20 24 28
VCP 21
1 km
MX: 48dBZ
VCP 32
1,2 km
MX: 59dBZ
MRX
GSP
CAE
FFC
kmrx 0.5 Refl Tue 13:18Z 17-Apr-01 + kgsp 0.5 Refl Tue 13:17Z 17-Apr-01

KGSP – 1317Z


VCP 21
1 km
MX: 48dBZ
VCP 32
1.2 km
MX: 59dBZ
MRX
CAE
kmrx 0.5 Refl Tue 13:18Z 17-Apr-01 + kgsp 0.5 Refl Tue 13:17Z 17-Apr-01

TRI Overview (Meso Eta Model)
17 April 2001



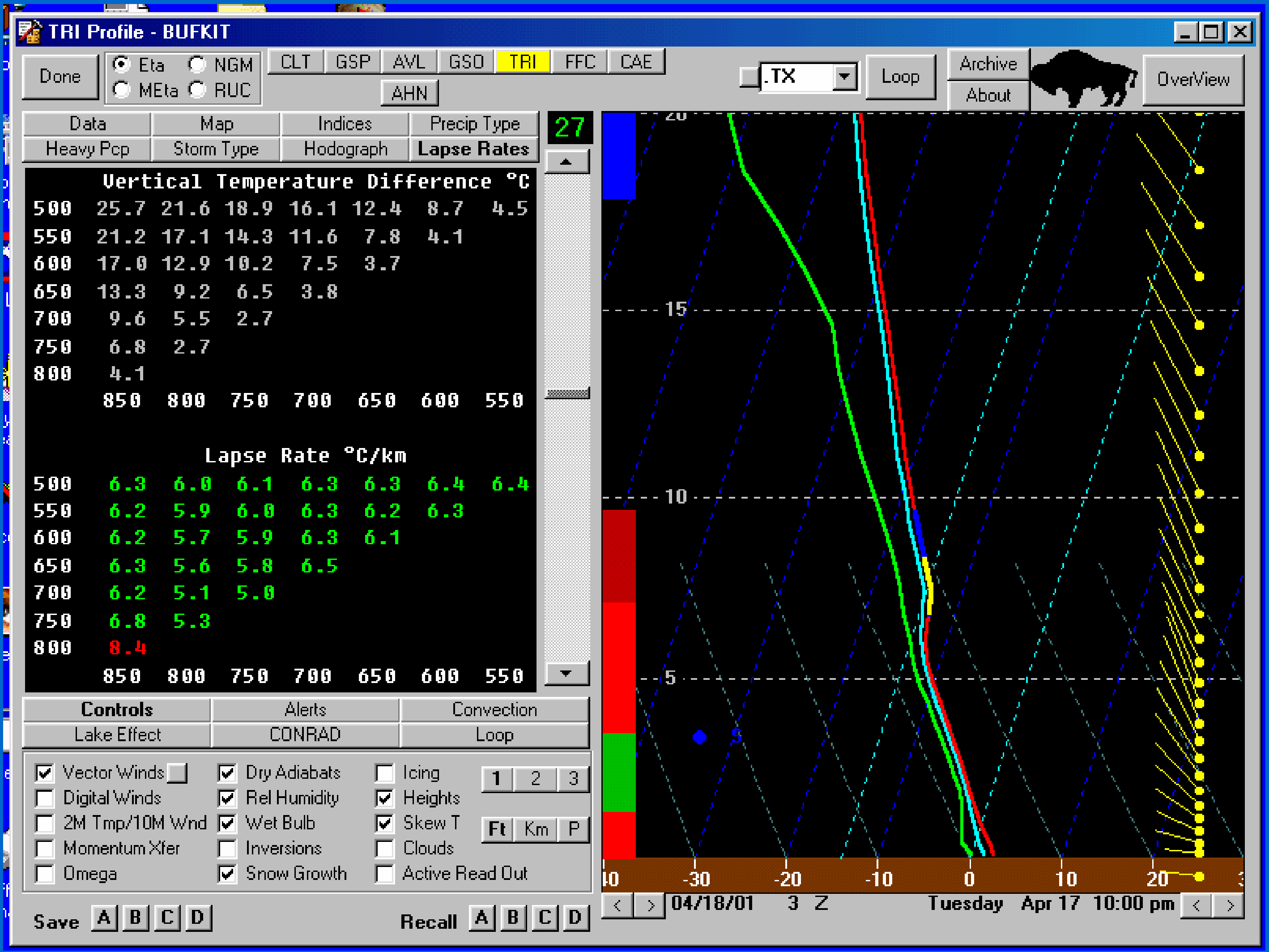
Items Worth Noting

TRI – 17 April 2001

- Overview – Time Section
  - Deep moisture in this case (> 70% RH as high as 10 – 15 K ft)
  - Periods during which mean RH > 90% existed in some layers
  - Snow was occurring before winds aloft shifted to NW

Remember: TRI is a desirable site to examine because the data are good indicators of moisture, wind, and temperature characteristics of the air mass that will be lifted over the mountains.

Vertical Temperature and Moisture Profiles at TRI
1200 UTC – 17 April 2001

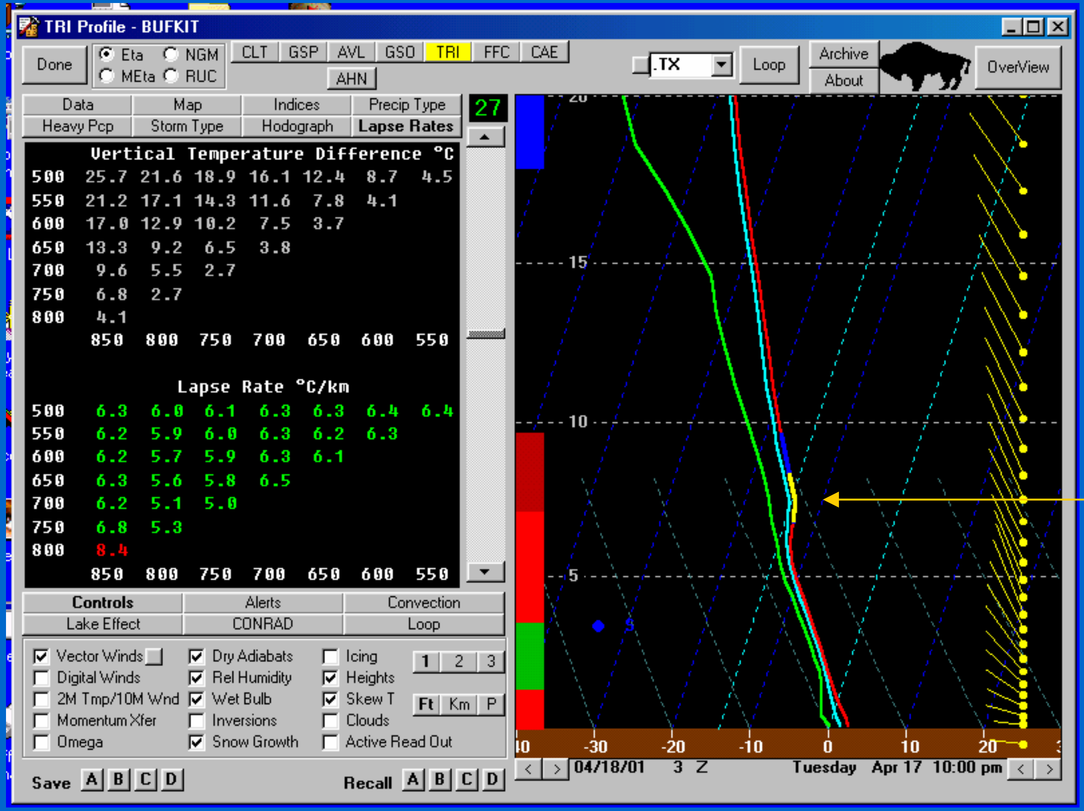


Items Worth Noting

TRI – 1200 UTC - 17 Apr 2001

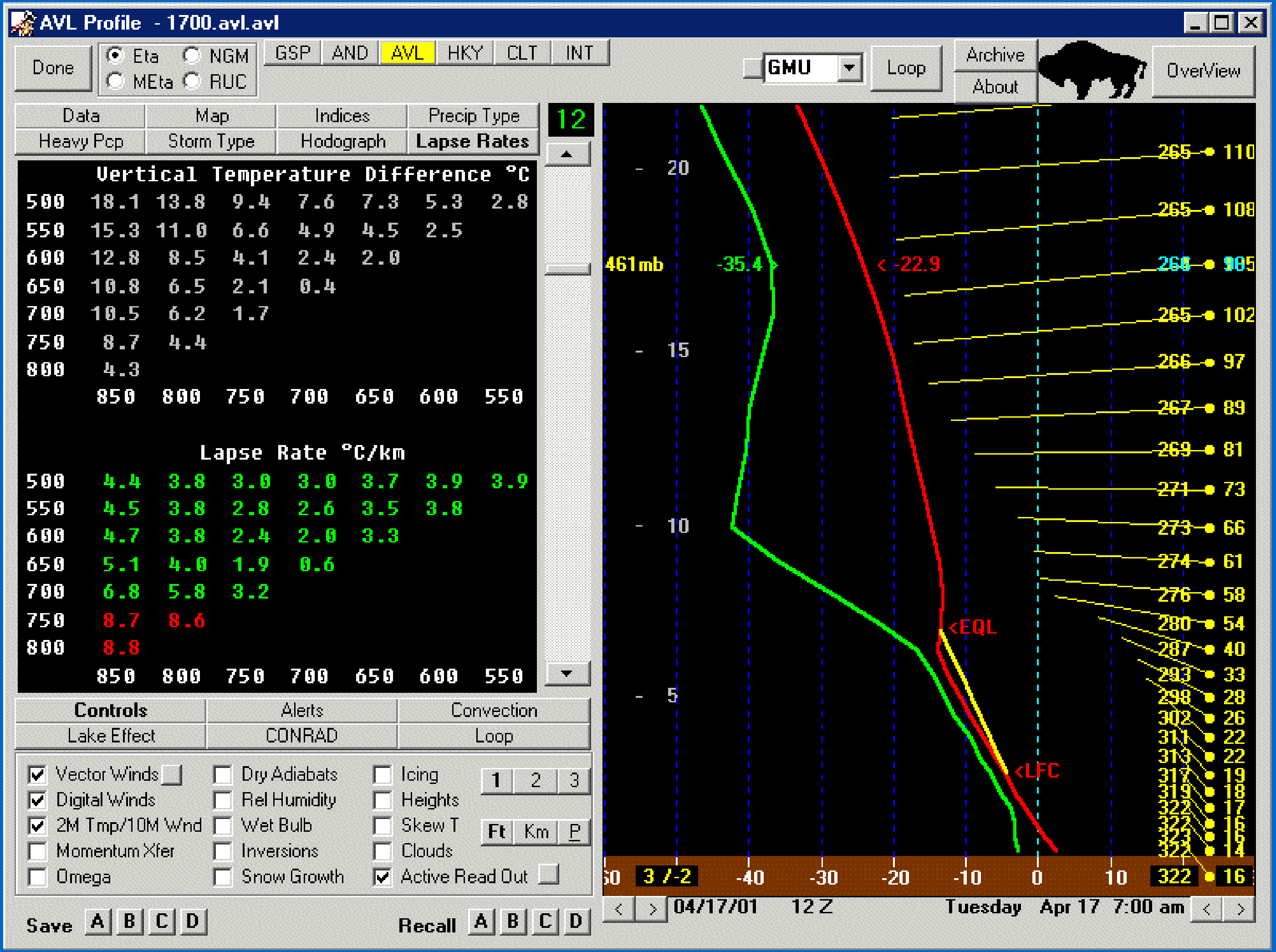
- Vertical Temperature and Moisture Profiles
  - Favorable temperature for snowflake formation near top of moist layer (Check "Overview" display)
  - Steep lapse rate in lower troposphere

Lapse Rates



Temperatures for snowflake growth

Temperature and Moisture Profiles at Asheville
Meso Eta Model 12-hr Forecast – VT 12Z



Asheville Weather

SPECI KAVL 171640Z 36020G26KT 1 1/4SM -SN FEW013 SCT026 BKN034 02/M02 A2999 RMK AO2 PK WND 01026/1638 RAB1557E19B36E40SNB19 P0000

SPECI KAVL 171644Z 36018G26KT 310V010 1/2SM FG FEW008 BKN017 BKN034 00/M01 A2999 RMK AO2 PK WND 01026/1638 RAB1557E19B36E40SNB19SNEMM P0000 $

METAR KAVL 171654Z 32014G25KT 300V360 3/4SM -SN BR BKN013 BKN033 01/00 A2999 RMK AO2 PK WND 01026/1638 RAB1557E19B36E40SNB19 SLP156 P0000 T00110000 $

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Northwest Flow Snow Summary

- Snow in southern Appalachians produced – or augmented – by upslope flow
- Usually following passage of cold front or low pressure system
- Highly variable accumulations
- Most common in Tennessee border counties
- Occurs during periods of cold air advection

Northwest Flow Summary

- Relatively shallow moist layer
  - Frequently 850 mb and below
  - Extensive cumulus/stratocumulus west of mountains (with flurries and snow showers)
- “Snow Growth” temperatures required in-cloud
- For significant NFS events… Do snow growth temperatures, high RH, and omega maximum coincide? (Waldstreicher 2001)
  - Not really investigated yet. Perhaps there is a unique, shallow “cross hair” signature in which the omega maximum is terrain-induced.

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The End