Snow forecasting

Another inch with the vort!

Hydro-meteorological Prediction Center

Snow Forecasting

- Things to think about when forecasting snow and snowfall amounts
- How to forecast precipitation type
- snowfall accumulations
- A few empirical forecast techniques
- Synoptic and mesoscale aspects of heavy snow
- Case studies

Forecasting snow requires

- knowledge of the numerical models
  - must resolve which model has best storm track
- knowledge of whether the pattern the model is forecasting favors a major snowstorm or a minor one.
- an assessment of whether the model is handling the mesoscale structure correctly.
- knowledge of the model low-level temperature biases.
  - For example, the models often warm the low level temps too quickly across northern Maine

To forecast snowfall amounts

1 -- Need to forecast liquid equivalent (qpf)

2 -- Determine rain/snow line, precipitation type

3 -- Then determine whether surface temperature will allow snow to accumulate

4 -- Finally, predict snow to liquid equivalent ratio

The physical reasons that determine the amount of snow that falls over any location are

- The vertical transport of moisture into the system
  - vertical motion and moisture
- The efficiency of the precipitation processes (cloud physics)
- Size of the area of precipitating clouds
- Propagation, are new snow producing clouds developing upstream

Precipitation type

- is dependent on the vertical temperature structure
  - mechanisms that can change the vertical structure include:
    - evaporation
    - melting
    - thermal advection
    - vertical motion
    - solar radiation (especially during spring)
- Is dependent cloud physics (freezing rain vs snow)

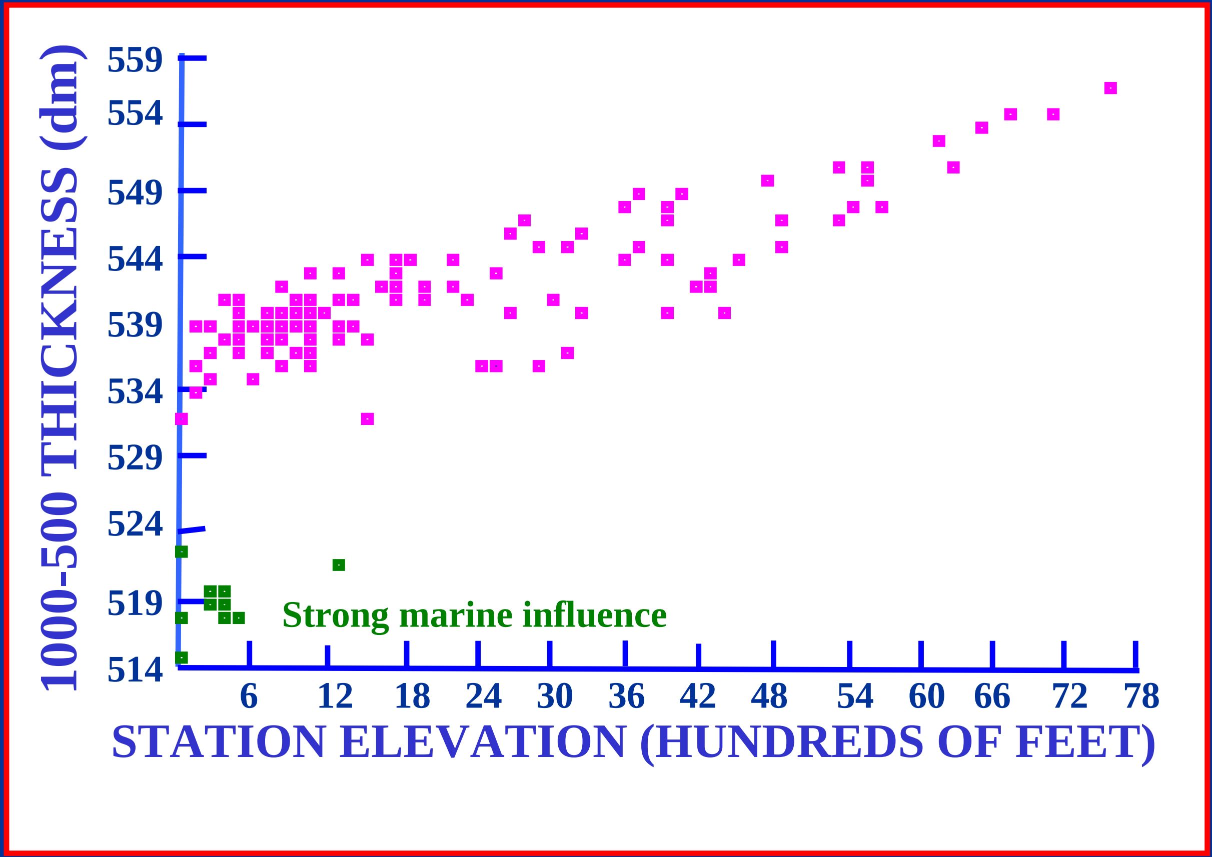
Traditional ways to forecast precipitation type

- 1000-500 thickness
  - will not resolve thin warm layers
    - warm boundary layer temperature or a warm layer above the surface
- 1000-850 and 850-700 mb partial thickness methods
  - better, but still may miss a very thin warm layer
- soundings and forecast soundings
  - the best method

1000-500 mb thickness

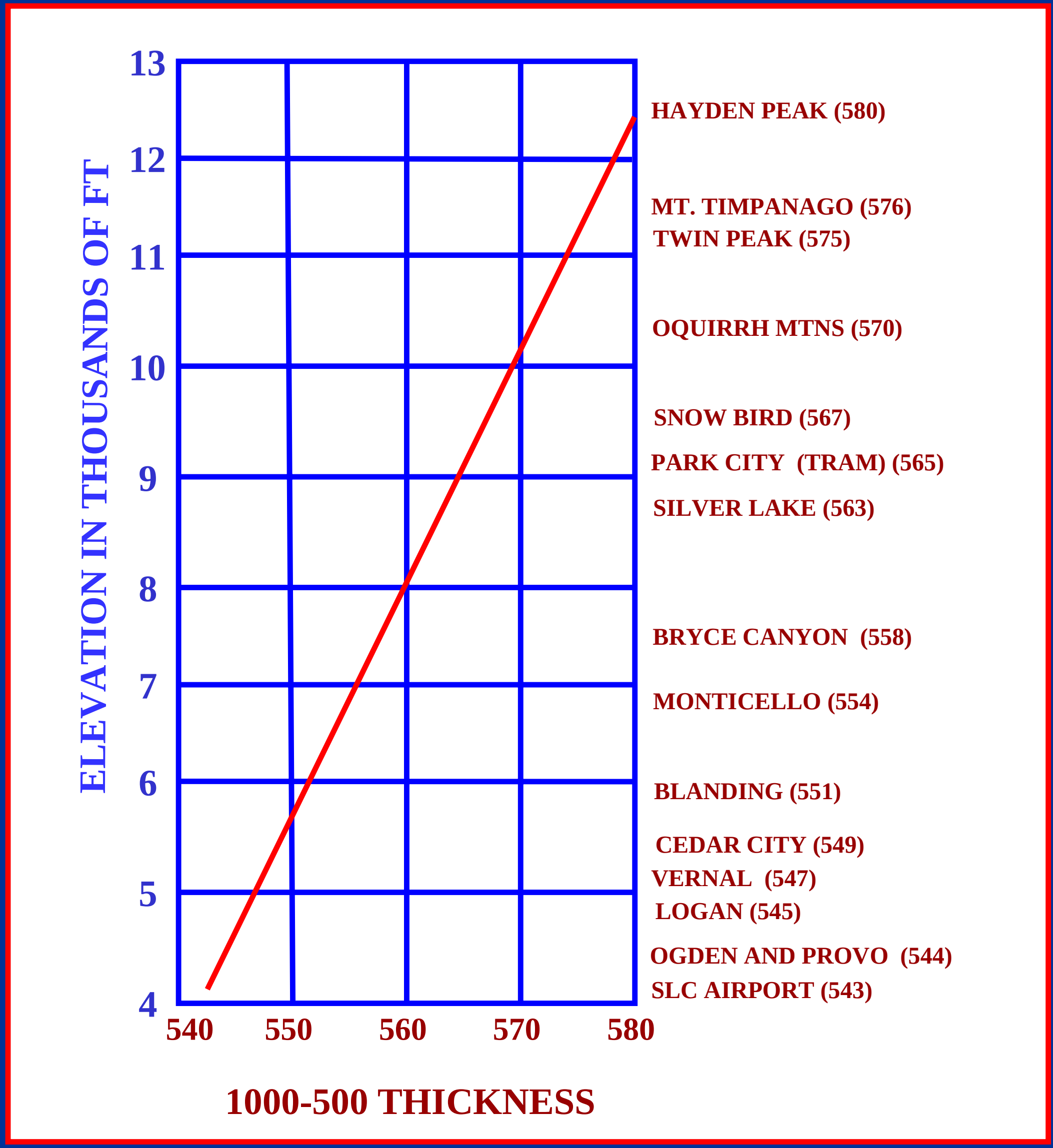
Figure adapted from Glahn et al., 1975

50 % values of 1000-500 mb thickness as a function of station elevation



The critical thickness varies with elevation and with the dominant weather regime (stability of the airmass) that affects the station

THE 50% CRITICAL THICKNESS FOR MOUNTAINS OF UTAH



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

Precipitation type from soundings

This is the best way to determine precipitation type

- Summary of important factors to look at on sounding
  - how warm is warm layer
  - what is the depth of the layer with wet bulb temperatures above zero
  - wet bulb temperature of cold layer
  - depth of cold layer

The warm layer

- If T_w of warm layer exceeds 3 to 4^o C, snow melts completely resulting in rain or freezing rain.
- If T_w is less than 1^o C, only partial melting occurs and snow will usually refreeze.
- If T_w is 1-3^o C usually results in partial melting of snowflakes but then usually refreezes into sleet (or a mixture of sleet and freezing rain depending on the depth of the warm layer.

From Stewart and King, 1987

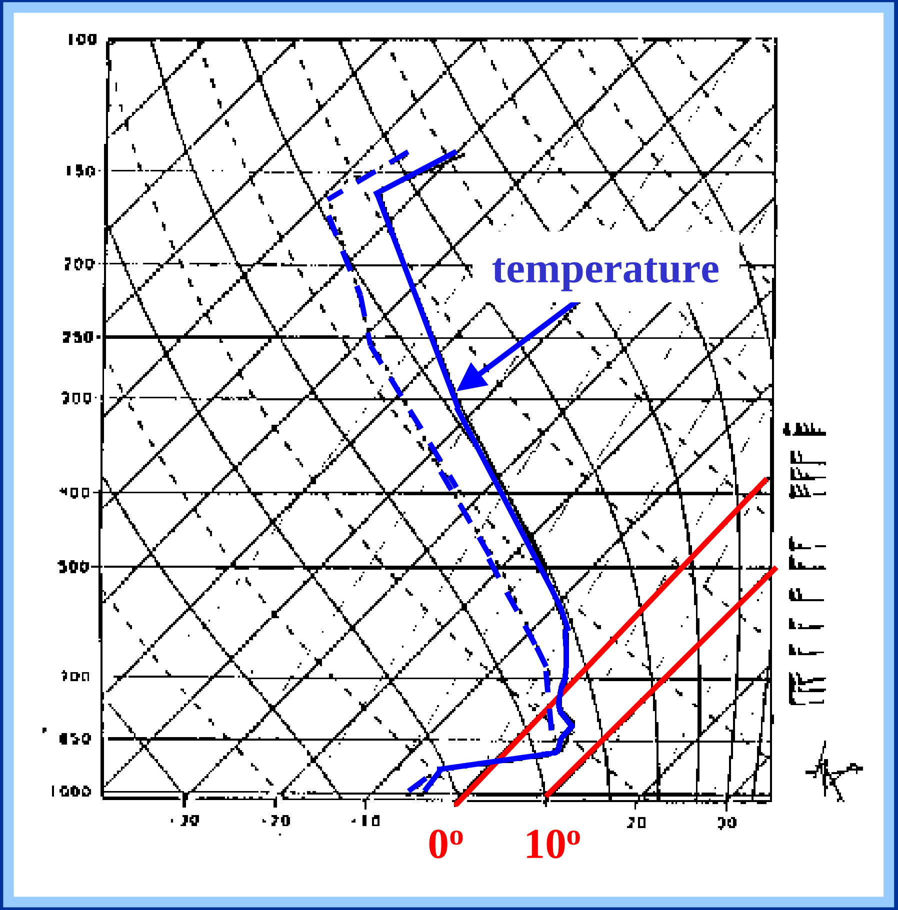
Lower cold layer

- If temperature is less than -10^{o}C, and freezing nuclei are sufficiently abundant and enough time is spent in the cold layer, either snow or sleet can occur.
- If cold layer is warmer than -8^{o}C, droplets remain super cooled if the snow was completely melted (favors freezing rain).
- Depth of cold layer is not nearly as important as the temperature of the cold layer.

From Stewart and King, 1987

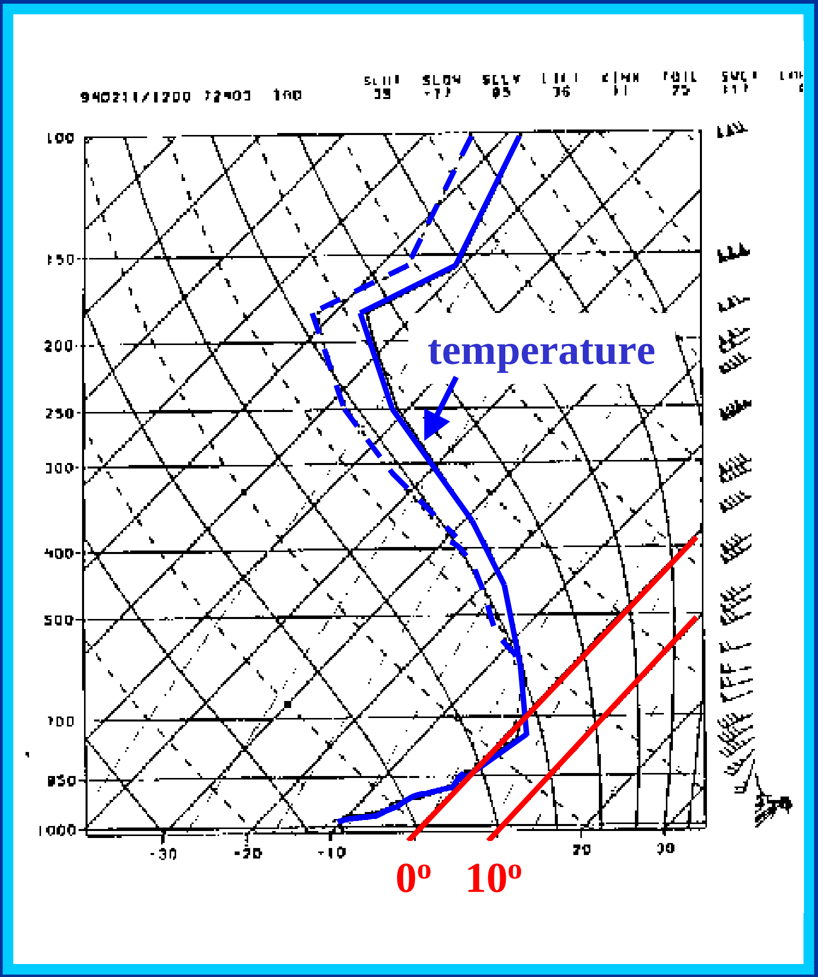
A freezing rain sounding

Note that temperature of the warm layer is above 4^{o}C



An ice pellet sounding

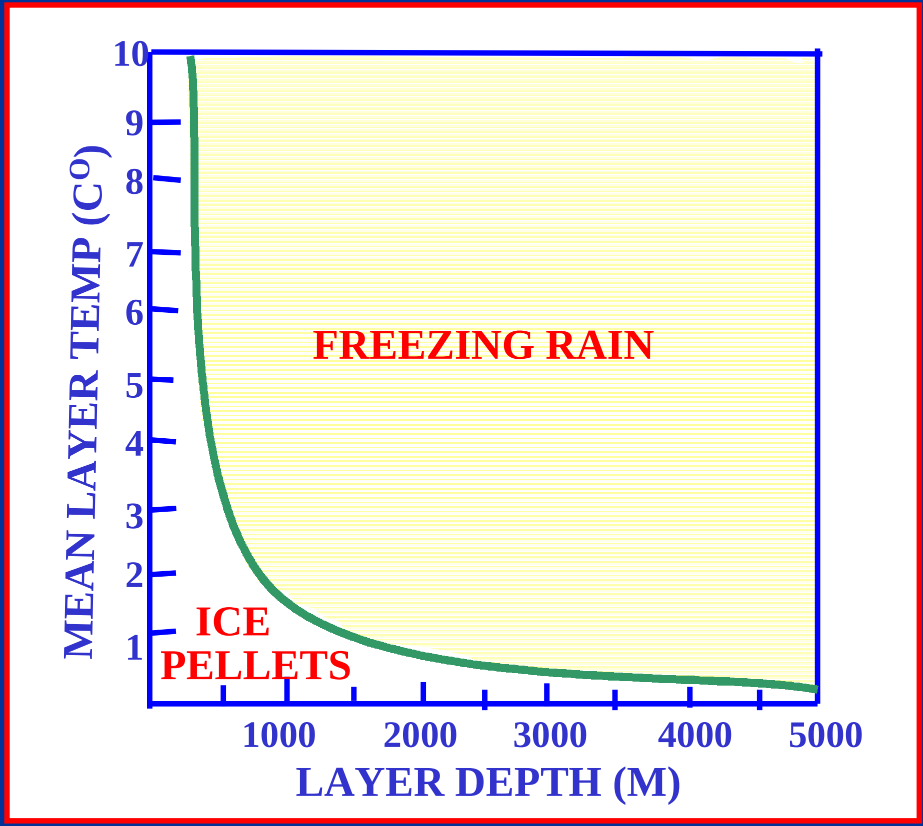
Note temperature of warm layer is 1-3ºC



Unfortunately, a shallow warm layer may show up on a forecast sounding. Use a combination of forecast soundings and MOS guidance to help predict the most likely precipitation type.

FREEZING RAIN OR SLEET

THE TAU TECHNIQUE - Cys et al., 1996



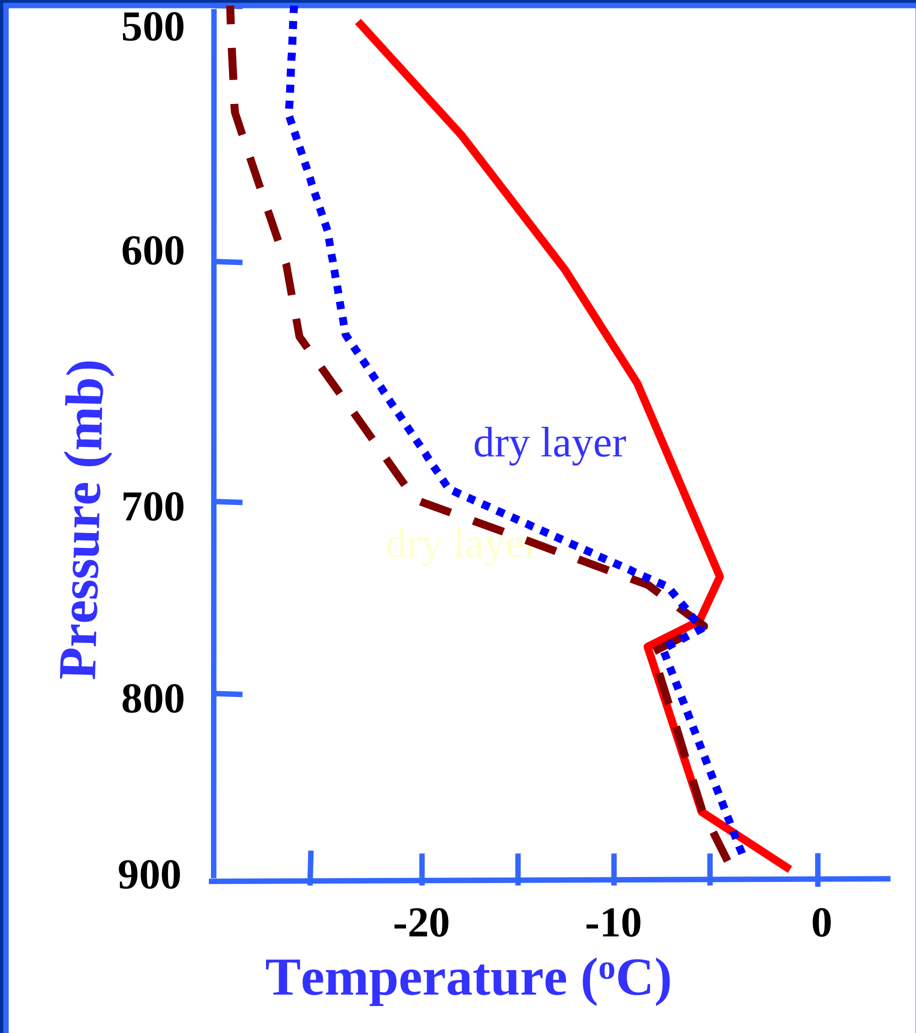
FROM SOUNDING

1. IDENTIFY DEPTH OF WARM LAYER (ABOVE 0^{O}C)

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

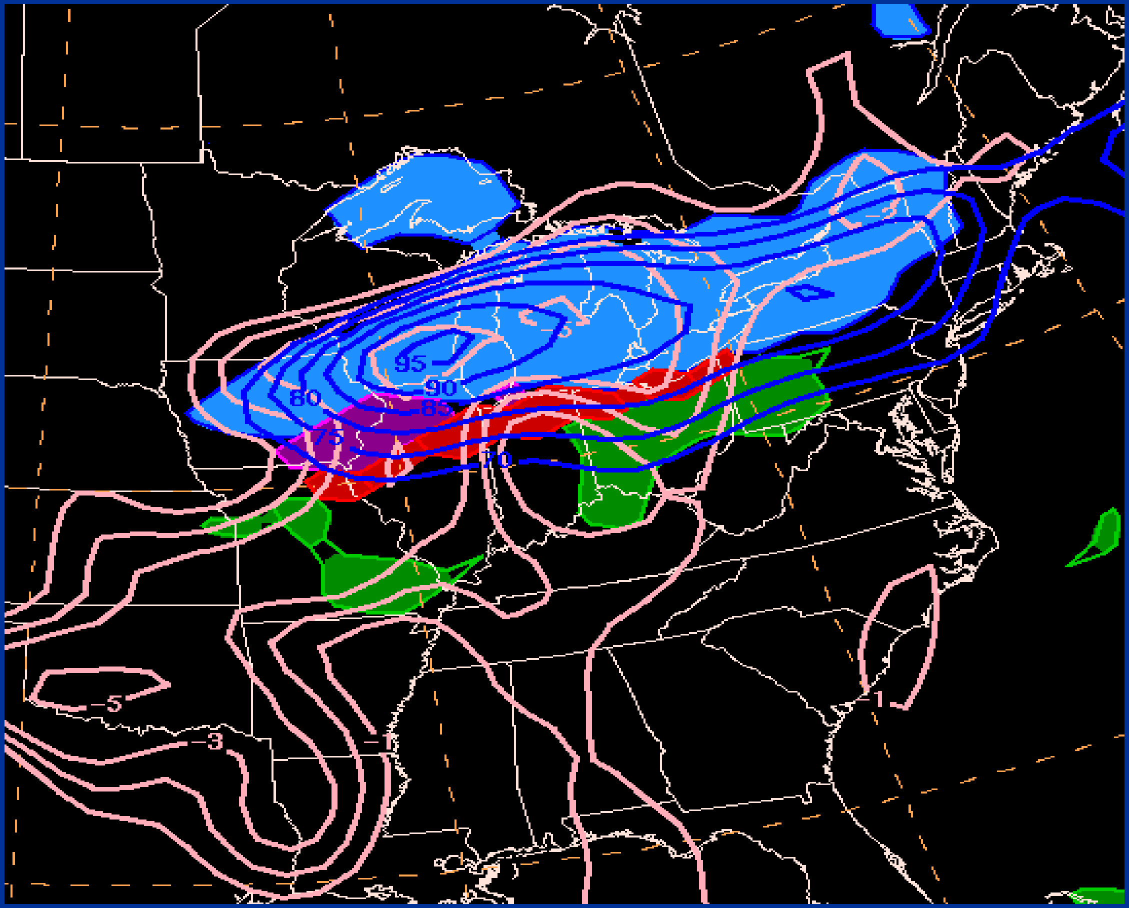
Freezing drizzle



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^{o} to -10^{o}C range and that there should be a pronounced dry layer just above the cloud top. A typical sounding for freezing drizzle is shown.

NCEP ETA PRECIPITATION TYPE ALGORITHM



BLUE SHADED AREA IS WHERE MODEL SOUNDING SUGGESTS SNOW, VIOLET WHERE IT INDICATES SLEET AND RED FREEZING RAIN, DARKER BLUE LINES INDICATE Rh, WHITE LINES INDICATE VERTICAL MOTION.

Snowfall intensity

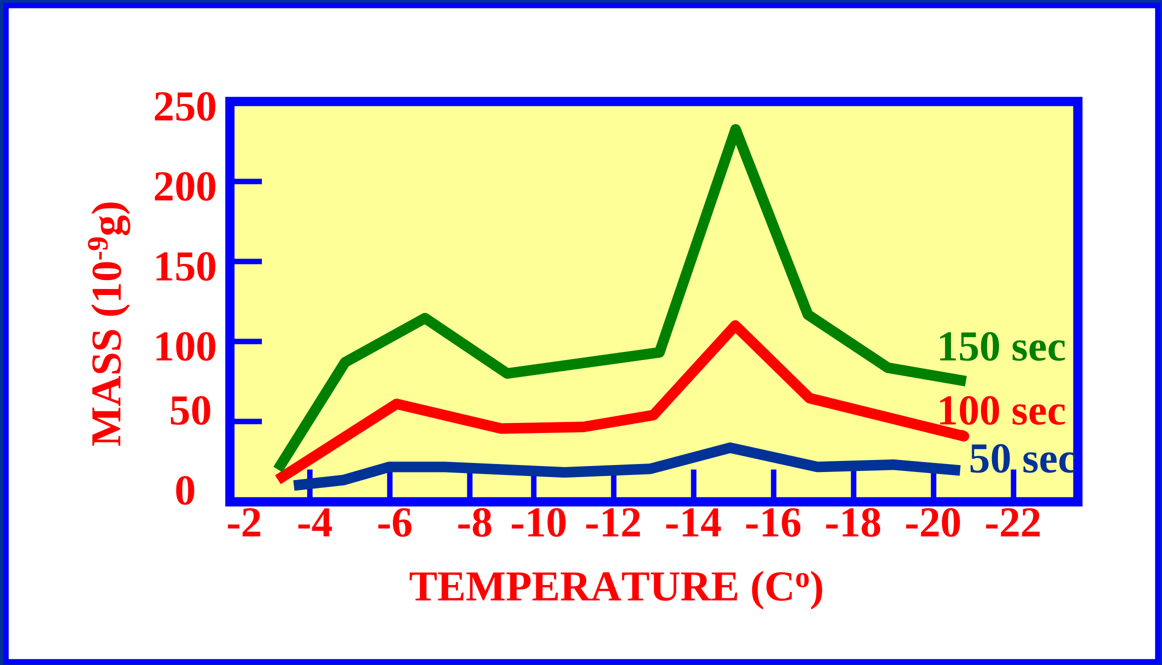
- The rate that snow falls is a function of
  - rate of growth of a single crystal
    - which peaks around -15^{o}C
  - and the number of crystals per unit volume,
    - the number can be increased
      - by fragile crystals (dendrites and needles) fracturing
      - by ice splintering during riming
      - fragmentation of large super-cooled drops during freezing

When cloud top temperatures are -25^{o}C or colder the concentration of ice particles is usually sufficient to use up all the condensate in stratiform and orographic clouds

ICE CRYSTALS GROW BY

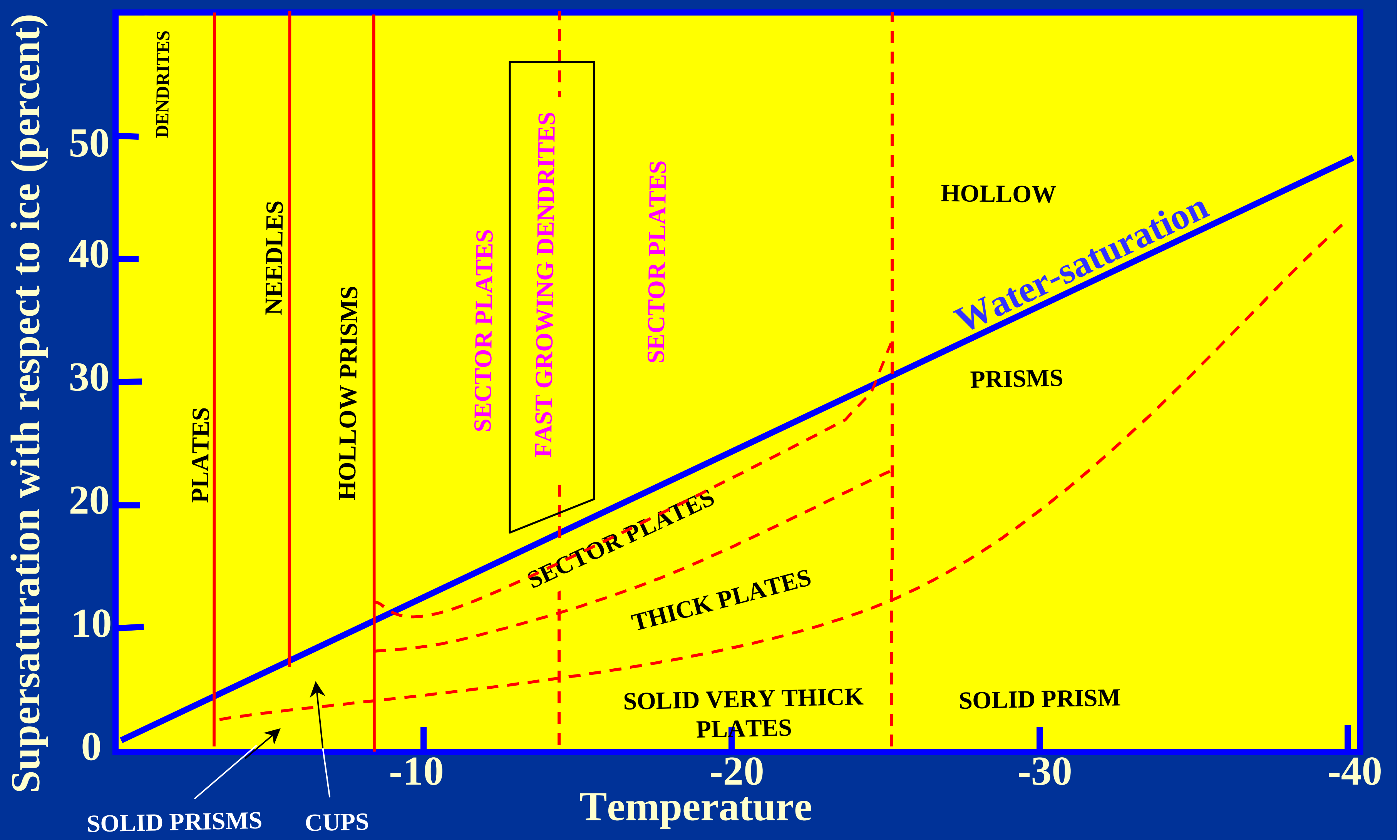
--Deposition, because $e_{sw} > e_{si}$, vapor is transported from droplets to ice crystals

--By collisions between super-cooled cloud drops and ice crystals



Experimentally determined variation of the mass of ice crystals growing by diffusion of vapor in a water saturated environment, as a function of growth time and temperature. (From Ryan et al., 1976; by courtesy of the American Meteorological Society, and the authors.)

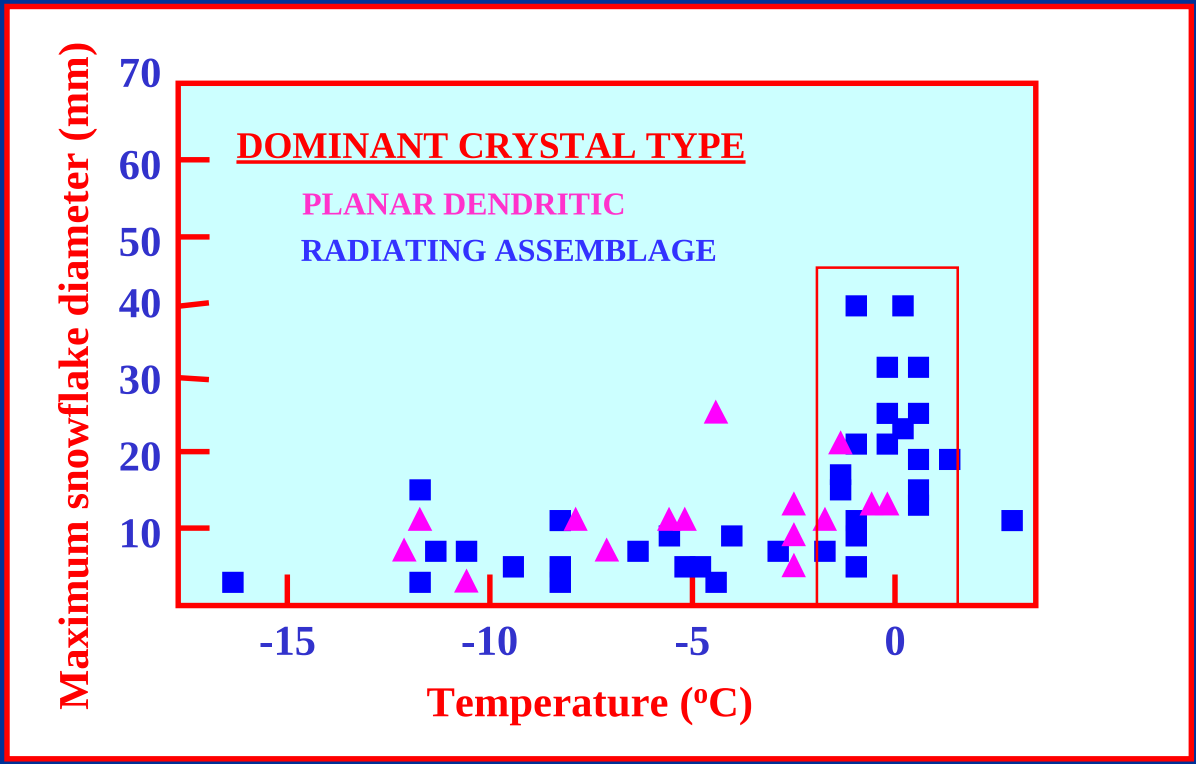
The variation of crystal habit with temperature and supersaturation according to the experiments of Mason et al.



SNOWFLAKE SIZE IS ALSO DEPENDENT ON AGGREGATION

***MULTIPLE ICE PARTICLES FORM MAIN SNOWFLAKE**

***AGGRAGATION PROCESS IS MAXIMIZED AS TEMPERATURE APPROACHES 0ºC**



Maximum observed snowflake diameters as a function of air temperature for two types of snowflake compositions. (From Rogers, 1974, 1974b)

WHY SHOULD I CARE ABOUT THE PHYSICAL CHARACTERISTICS OF THE SNOWFLAKES

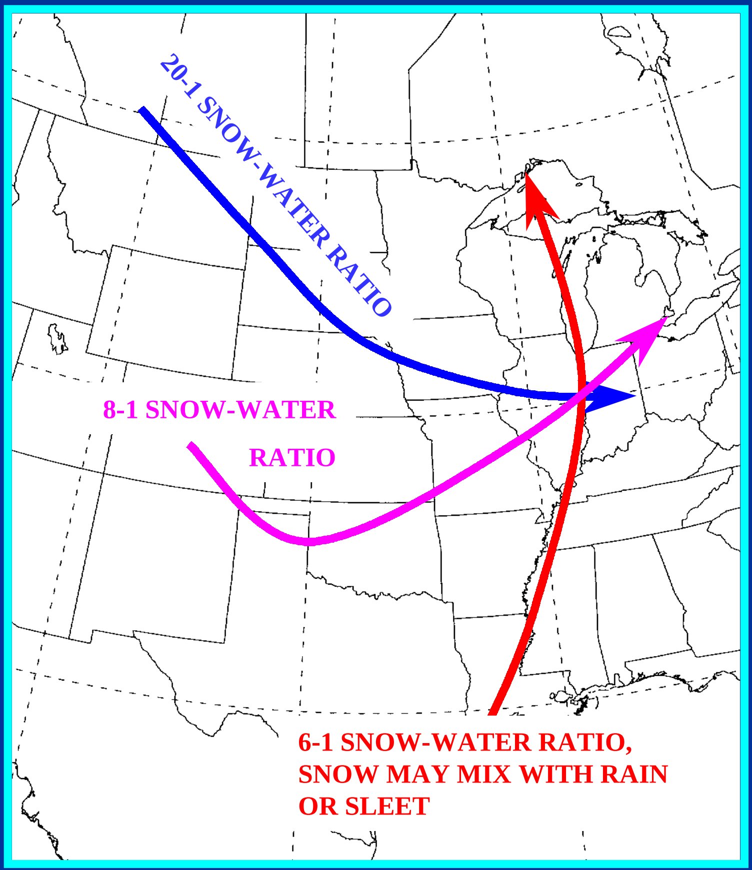
- The dominant crystal type may affect the snow to liquid equivalent ratio (how fluffy the snow is).
  - Unrimed Dendritic and plate crystals have a lacy structures that usually produce the highest snow to liquid ratios (best accumulators)
  - The make-up of the cloud may affect the snow to liquid ratio. When there is abundant liquid water in cloud causing crystals to grow by riming, snow to liquid ratios are lower (may be 10 to 1 or lower)
- Cloud physics effect how efficient the system is at producing snowflakes. Dendrites crystals grow fastest.
- The size and composition of the snowflake may help determine how quickly it sticks on the ground when temperatures are marginal for snowfall accumulations.
  - Large aggragates may take longer to melt than smaller single crystals.

Forecasting snow to liquid ratio Summary

- Warm ground and boundary layer temperatures can keep snow-water ratios down
- a warm layer that approaches zero ^{o}C also will usually keep the ratios low.
- Storms having clouds with a large amounts of supercooled droplets will not have as high a ratio as storms in which most crystal growth is by deposition.
- Soundings that are almost isothermal with a large portion of the sounding near zero ^{o}C will usually have a ratio of 8 or 10 to 1.
- Deep cold air promotes higher ratios but if the temperatures are too cold the crystal type may not be conducive to high ratios. .
- Storm tracks often provide keys to forecasting the snow to water ratio
  - tracks near oceans have more liquid water in clouds which usually produces lower snow-liquid ratios

For example

Southern storm tracks typically are associated lower snow to liquid ratios than clipper type systems



AVERAGE SNOW-WATER RATIOS FOR FOR SOUTHEASTERN WISCONSIN WITH VARIOUS STORM TRACKS

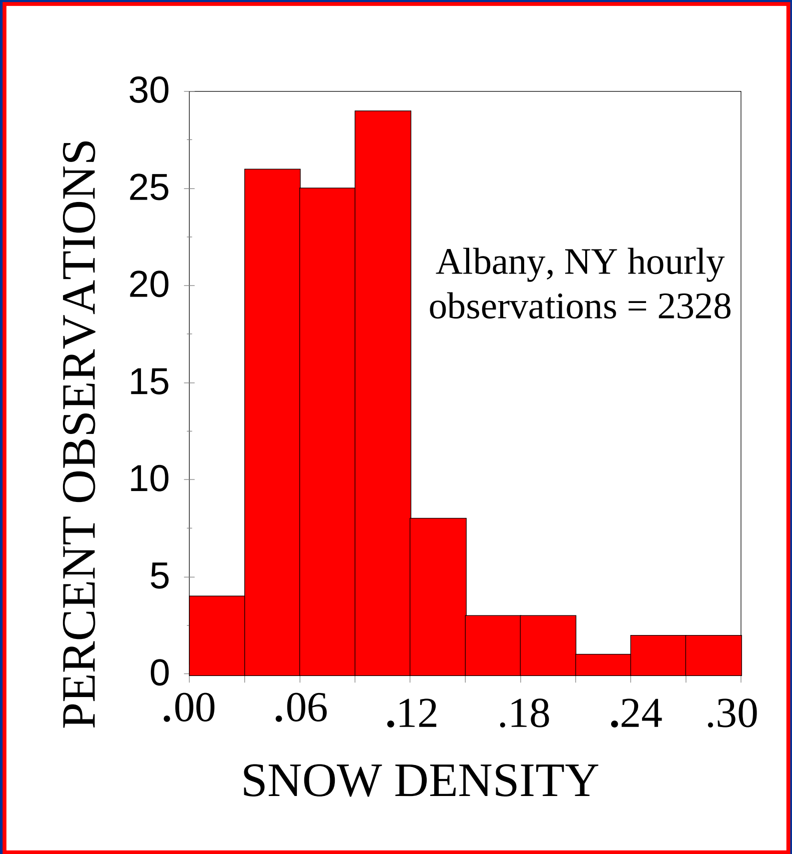
1) Northern storm tracks that favor snow crystal growth by deposition favor high snow-water ratios.

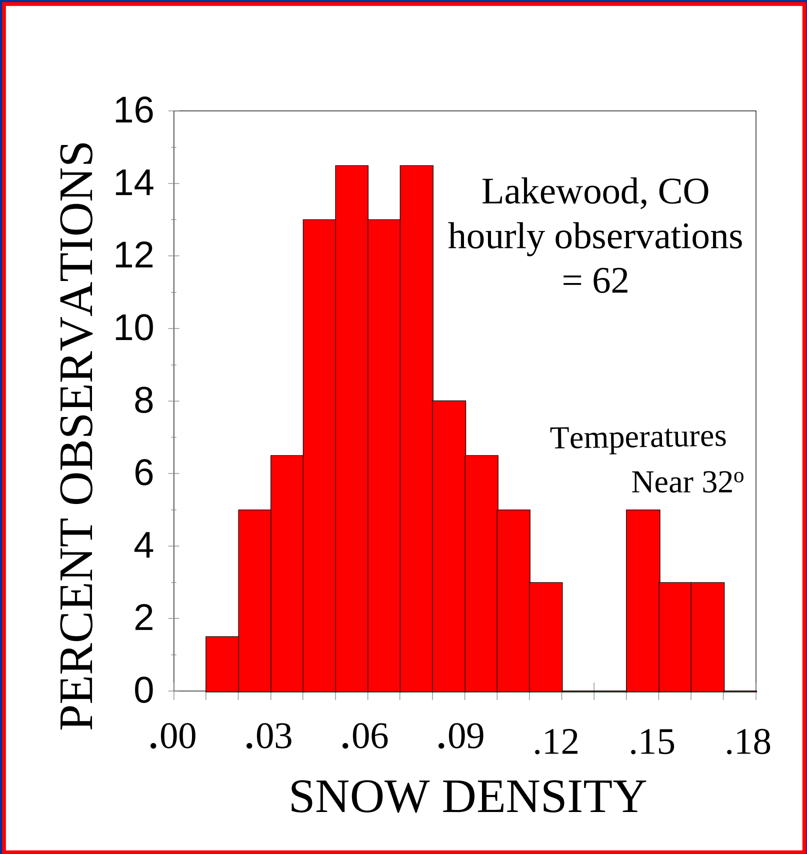
2) When ice crystals grow by riming or crystals colliding with supercooled droplets, the snow-water ratios are lower.

3) Southern storm tracks and tracks that tap moisture and warm air from oceans rarely have snow to water ratios that are greater than 10-1 except well west of the storm track. Look for low ratios where precipitation becomes mixed with sleet.

Adapted from Harms, 1970

Snow to liquid ratios vary significantly by geographic region. In Colorado the snow to liquid ratio is usually much higher than 10 to 1 (or snow density less than .10).



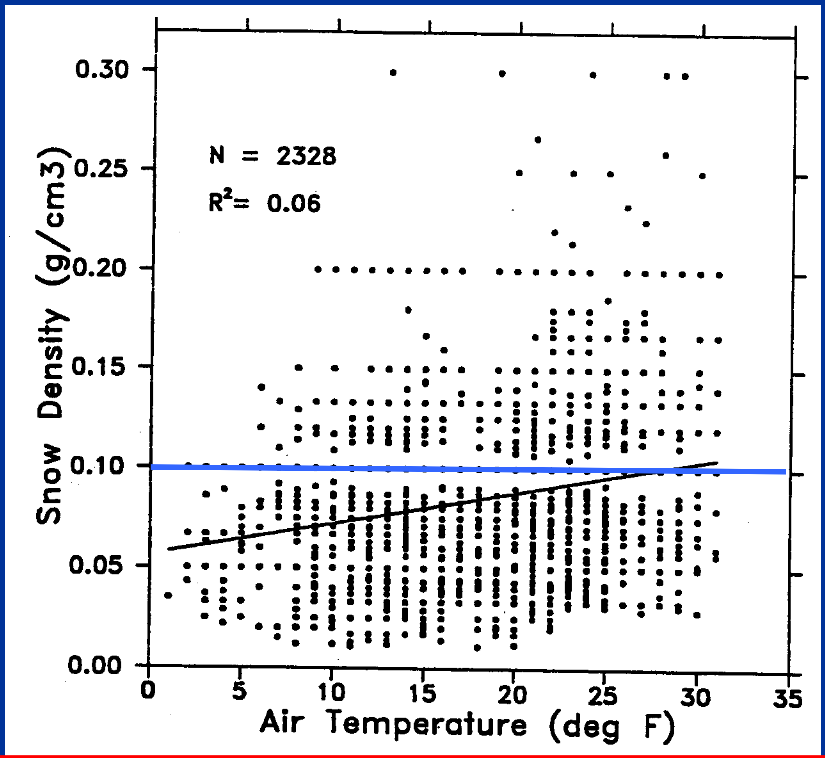


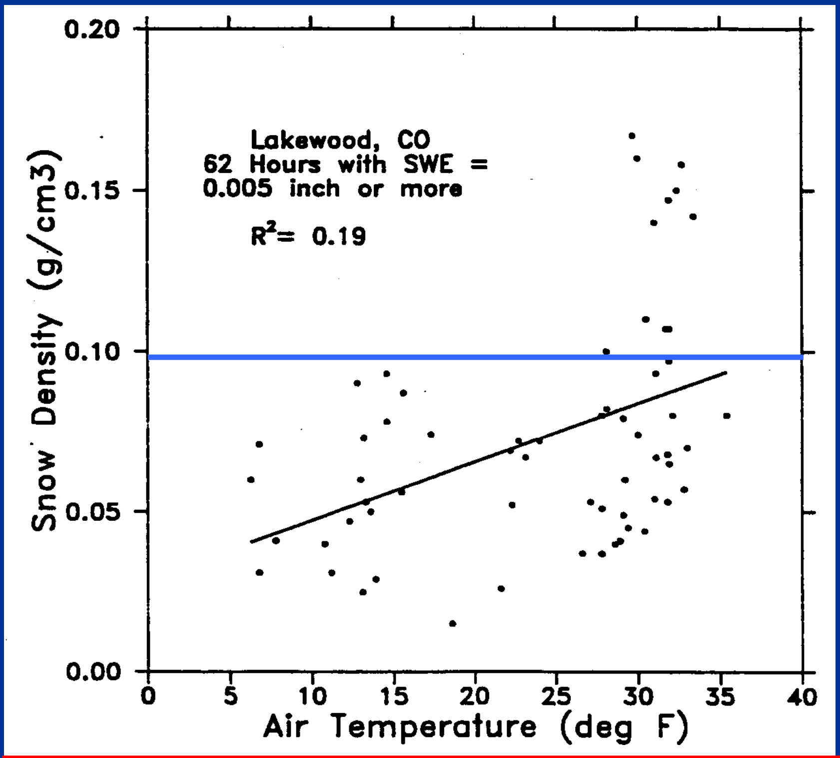
Percent distribution of snow density based on 2328 hourly observations from 73 sites near Albany

Percent distribution of snow density based on 62 hourly observations from 73 sites near Lakewood, CO

Adapted from Super and Holroyd, 1997

SNOW DENSITY AS A FUNCTION OF TEMPERATURE. NOTE THE LOW CORRELATION SHOWN IN THE GRAPHS



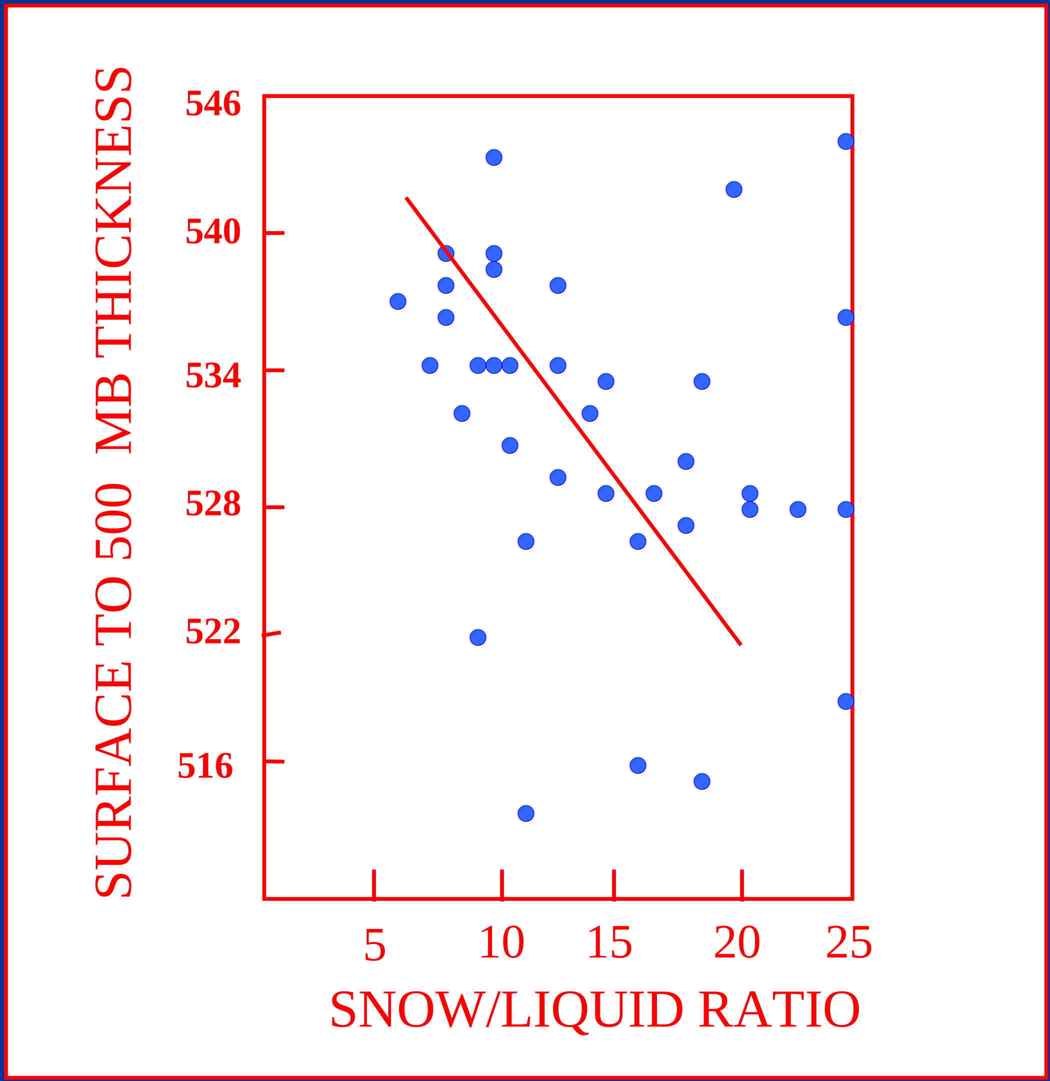


ALB, NY AREA SNOW DENSITIES PLOTTED AGAINST AIR TEMPERATURE. A LINEAR REGRESSION LINE THAT BEST FITS THE DATA IS SHOWN IN BLACK. THE BLUE LINE IS A 10 TO 1 SNOW TO LIQUID RATIO

SNOW DENSITIES AGAINST AIR TEMPERATURE FOR LAKEWOOD, CO. A LINEAR REGRESSION THAT BEST FITS THE DATA IS SHOWN IN BLACK. THE BLUE LINE IS A 10 TO 1 SNOW TO LIQUID RATIO

From Super and Holroyd, 1997

SNOW RATIO TABLE FOR THE EASTERN HALF OF COUNTRY (not mountain locations)



At around 540 thickness the ratio was 10-1 or lower. At 528 the ratio was around 17-1. However there was considerable spread..

From Scofield and Spayd, 1984

Other Tidbits about snow to liquid ratios

- The fluffiest snows (high snow to liquid ratios) usually occur with light winds and temperatures near 15^{o}F(-9.5^{o}C).
- At colder temperatures crystal type and size change,
  - at very cold temperatures crystals tend to be smaller so they pack closer together as they accumulate producing snow that may have a ratio of 10 to 1 (sometimes even lower.)
- A study by Mote (1991) found that ratios for Omaha, Nebraska averaged around 14 to 15 to 1 during the period Dec-Feb. and found that the highest ratios occurred with lighter snow events and the lower ratios with the very heaviest snowfall. The heaviest storms had a 11-1 ratio.

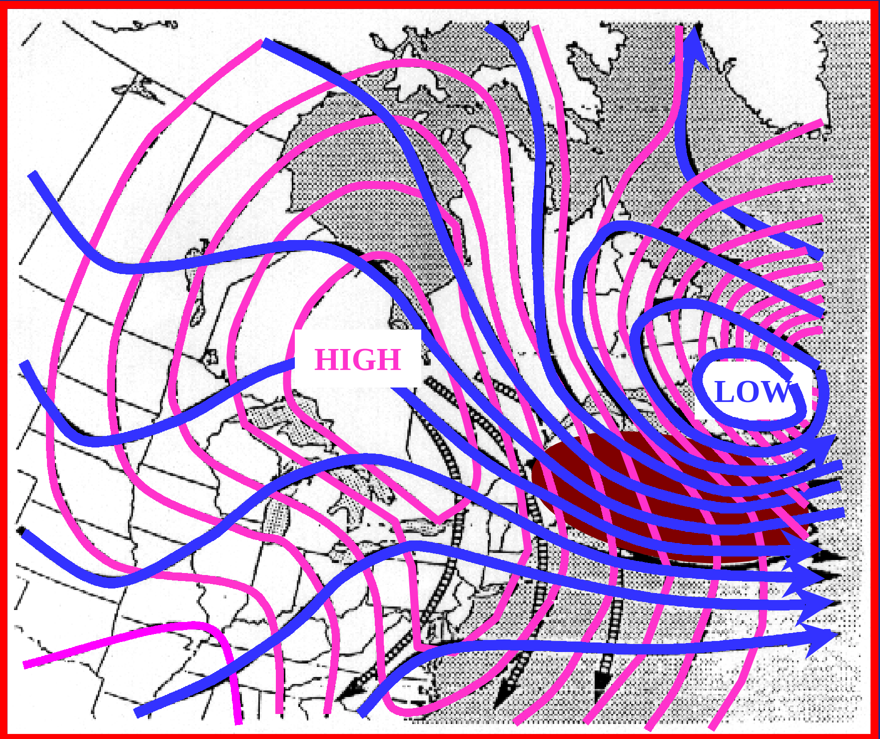
Upper level aspects of major east coast snowstorms (storms that produce a significant sized area of 10” or greater snowfall

- large increases in amplitudes between trough and downstream ridge accompanied cyclogenesis
- all cases exhibited decrease in half-wavelength indicative of self-development process (increasing vorticity)
- diffluence and negative tilt seen in nearly all cases
- phasing of multiple vorticity maxima observed in about half the cases
- heavy snow usually falls as a vorticity max moves east-northeast. heaviest snows fell north of the vorticity track
- trough or upper-level cyclone was usually located over eastern Canada
  - this provides confluence over Northeast allowing high pressure to build

From Kocin and Uccellini, 1990

THE IMPORTANCE OF THE EASTERN CANADA UPPER LOW AND CONFLUENCE FOR EAST COAST SNOWSTORMS

From Kocin and Uccellini, 1990



SURFACE ISOBARS **500 MB HEIGHTS**
JET STREAK

THE UPPER LOW NEAR THE MARITIMES HELPS TO HOLD THE UPPER LEVEL RIDGE AXIS NEAR THE GREAT LAKES REGION. THIS CONFIGURATION HOLDS CONFLUENT FLOW OVER THE NORTHEAST AND LOCKS THE SURFACE HIGH OVER THE NORTHEAST.

THE TRANSVERSE CIRCULATION ASSOCIATED WITH THE ENTRANCE REGION OF THE JET STREAK KEEPS LOW LEVEL NORTHERLY FLOW ALONG THE EAST COAST AND PROMOTES DAMMING

SHIFT THIS PATTERN TO THE WEST AND THE SAME PATTERN IS FAVORABLE FOR HEAVY SNOW OVER THE UPPER MIDWEST.

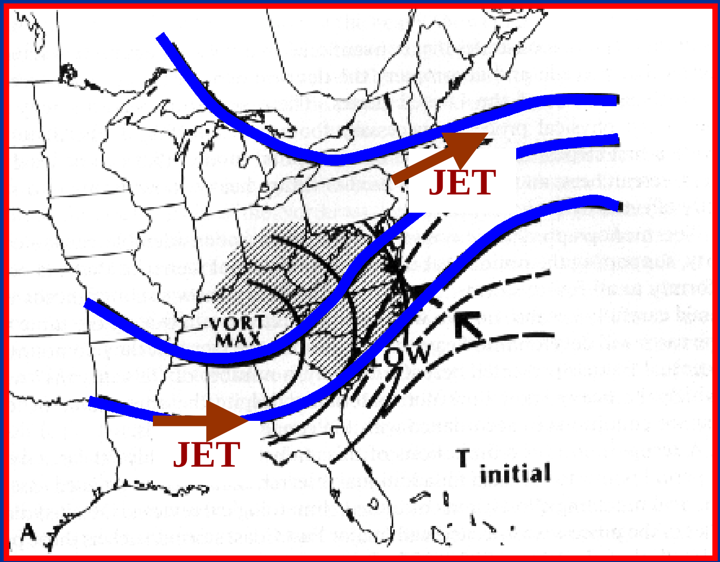
Cold air damming and coastal frontogenesis

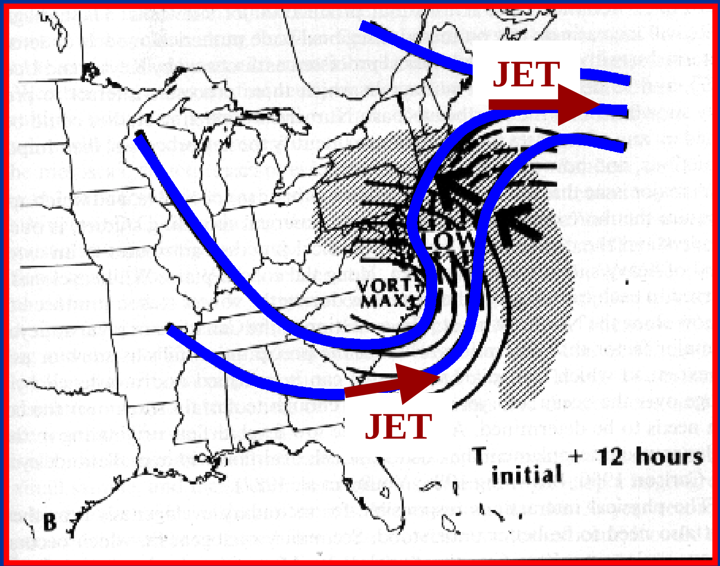
- Factors that favor cold air damming
  - a cold surface high passes north of the Mid Atlantic States and New England
  - cold air supplied by the surface high is channeled southward along the east slopes of the Appalachians.
  - A ridge of high pressure develops between the mountains and the ocean. This helps to keep a northerly component to the low level winds over the land.
  - Easterly or northeasterly low level winds over the ocean and the more northerly winds over the land tighten the thermal gradient near the coast.
  - When arctic air is present, the models often have a hard time holding onto cold enough low level temps when the surface high is still over New England or the Great Lakes regions.

Table from Kocin and Uccellini (1990)

	EASTERN CANADIAN TROUGH	"GREENLAND BLOCK"	CONFLUENCE
18-20 MAR 1956	YES	NO	YES
14-15 FEB 1958	YES	YES	YES
18-21 MAR 1958	YES	NO	YES
2-5 MAR 1960	YES	YES	YES
10-13 DEC 1960	YES	NO	YES
18-20 JAN 1961	YES	NO	YES
2-5 FEB 1961	YES	NO	YES
11-14 JAN 1964	YES	YES	YES
29-31 JAN 1966	YES	YES	YES
23-25 JAN 1966	YES	NO	YES
5-7 FEB 1967	YES	NO	YES
8-10 FEB 1969	YES	NO	NO
22-28 FEB 1969	YES	NO	YES
25-28 DEC 1969	YES	NO	YES
18-20 FEB 1972	YES	NO	YES
19-21 JAN 1978	YES	NO	YES
5-7 FEB 1978	YES	YES	YES
18-20 FEB 1979	YES	YES	YES
5-7 APR 1982	YES	YES	YES
10-12 FEB 1983	YES	YES	YES

THE SELF-DEVELOPMENT PROCESS

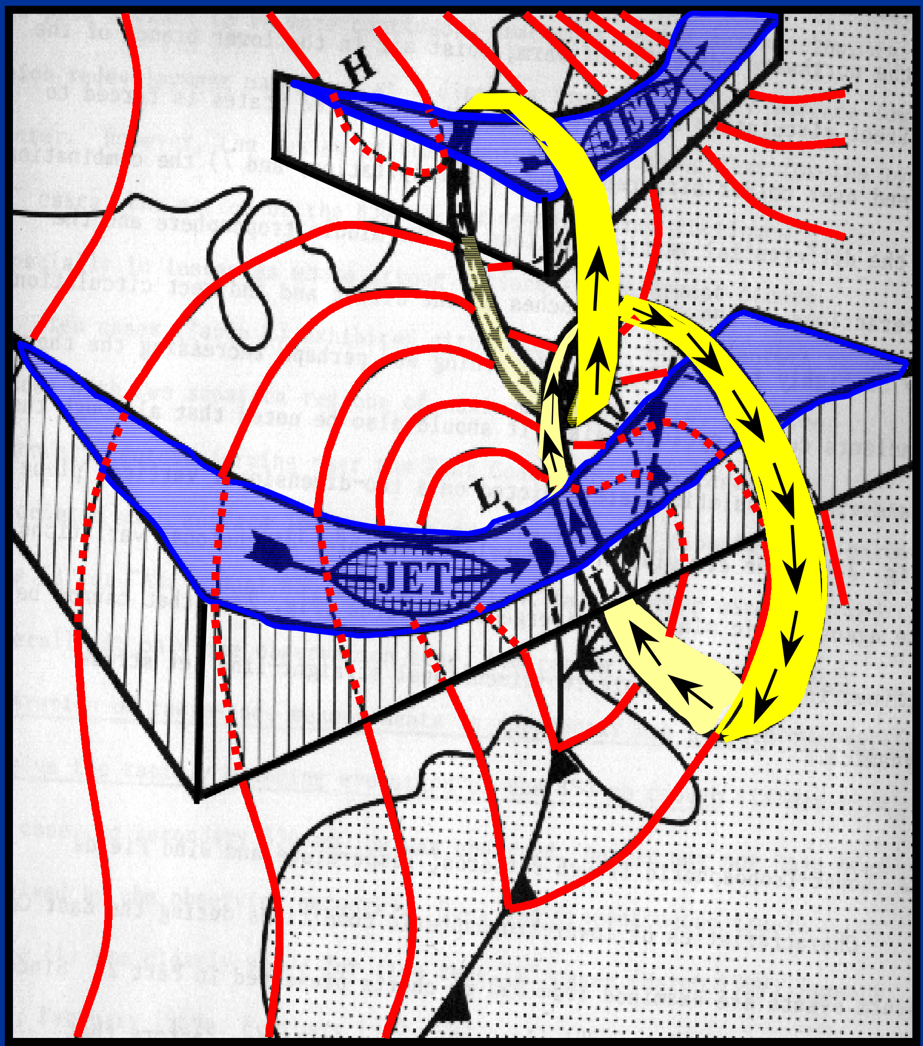




NOTE THE SHORTENING OF THE HALF-WAVELENGTH BETWEEN THE TROUGH AND DOWNSTREAM RIDGE AXIS. THIS HELPS TO STRENGTHEN THE VORTICITY, VORTICITY ADVECTION AND THE UPPER LEVEL DIVERGENCE. THE SURFACE LOW DEEPENS, PRODUCING INCREASED WARM ADVECTION WHICH BUILDS THE SHORTWAVE RIDGE AHEAD OF THE TROUGH. THIS INCREASES THE AMPLITUDE OF THE SYSTEM.

From Kocin and Uccellini, 1990

The most common upper level jet pattern with snowstorms that produce a large area of 10”+.



The lower branch of the direction circulation associated with the northern jet streak helps to provide an northerly component to the low level ageostrophic winds

The lower branch of the indirect circulation supplies a southerly component that helps enhance the low level jet.

The two branches act together to enhance low-level frontogenesis and upper level divergence

From Kocin and Uccellini, 1990

SNOW AND THE SURFACE LOW, THE HEAVIEST SNOW FALLS

(OVER THE CENTRAL AND EASTERN U.S.)

- AROUND 2.5 DEGREES LATITUDE (150 NM) TO THE LEFT OF THE LOW'S TRACK.
- ABOUT 5 DEGREES LATITUDE (300 NM) IN ADVANCE OF THE LOW.
- AS THE CYCLONE DEEPENS.
- HEAVY SNOW ENDS WHEN LOW BECOMES VERTICAL AND START TO FILL.
- HEAVY SNOW WAS USUALLY ASSOCIATED WITH LOWS THAT WERE TRACKING TO THE NORTHEAST

FROM GOREE AND YOUNKIN, 1966

850 LOWS AND HEAVY SNOW OVER CENTRAL AND EASTERN U.S.

- THE MEAN CIRCULATION INCREASED SIGNIFICANTLY DURING THE 12 HR PERIOD OF HEAVY SNOW
- THE HIGHEST PROBABILITY OF HEAVY SNOW LIES APPROXIMATELY 90 NM TO THE LEFT OF THE 850 LOW TRACK
- THE -5^{O}C ISOTHERM NEARLY BISECTS THE HEAVY SNOW
- IN THE FRONT QUADRANTS OF THE STORM LITTLE WARMING TAKES PLACE
  - STRONG VERTICAL MOTION IS TAKING PLACE.

FROM BROWNE AND YOUNKIN, 1970

500 MB HEIGHTS AND 1000-500 MB THICKNESS
THE HEAVIEST SNOW (CENTRAL AND EASTERN U.S.)
DURING THE NEXT 12 HRS USUALLY OCCURS

- ABOUT 2.5 DEGREES LATITUDE (150 nm) TO THE LEFT OF THE 500 MB VORT TRACK.
- ABOUT 6.5 TO 7 DEGREES DOWNSTREAM FROM THE VORT.
- ALONG THE PATH OF THE 500 LOW, SLIGHTLY DOWNSTREAM OF WHERE THE CONTOURS CHANGE FROM CYCLONIC TO ANTICYCLONIC
- WITHIN THE 531-537 1000-500 MB THICKNESS CHANNEL, NEAR THE THICKNESS RIDGE

FROM GOREE AND YOUNKIN, 1966

COOK METHOD

- AVERAGE SNOWFALL IN 24 HOURS WILL BE ABOUT HALF THE WARM ADVECTION IN C^{o} AT 200 MB
  - PROVIDING WARM ADVECTION IS PRESENT AT 700 MB
  - IF COLD ADVECTION IS TAKING PLACE AT 700 MB, THEN THE SNOWFALL WILL BE ABOUT A QUARTER OF THE OF THE WARM ADVECTION
  - 200 MB FLOW SHOULD NOT BE STRONGLY CONFLUENT

THE METHOD PROBABLY WORKS BECAUSE THE WARM ADVECTION IS A MEASURE OF THE STRENGTH OF THE TROPOSPHERIC FOLD AND THE POTENTIAL OF THE ASSOCIATED CYCLONE TO DEVELOP.

Garcia technique

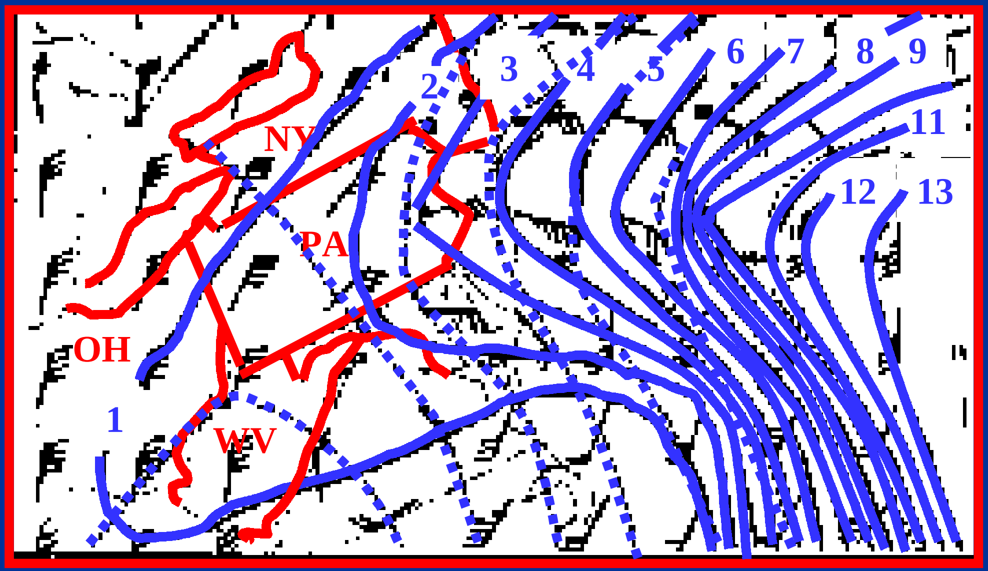
From Cope (1996)

Technique is very subjective and does not include an assessment of the vertical motion. Unfortunately, the amount of snow that falls is very dependent on the vertical motion!

- Developed to forecast maximum snowfall potential
- Use model forecasts of the isentropic surface located about midway between the 700 mb and 750 mb pressure surfaces.
- Average the mixing ratio directly over the area with the highest “effective” value upstream.
- Use 6 hourly forecasts and total the average mixing ratio (g/kg) for each period.

Garcia method (continued)

WHAT IS THE EFFECTIVE MIXING RATIO FOR CENTRAL PA?



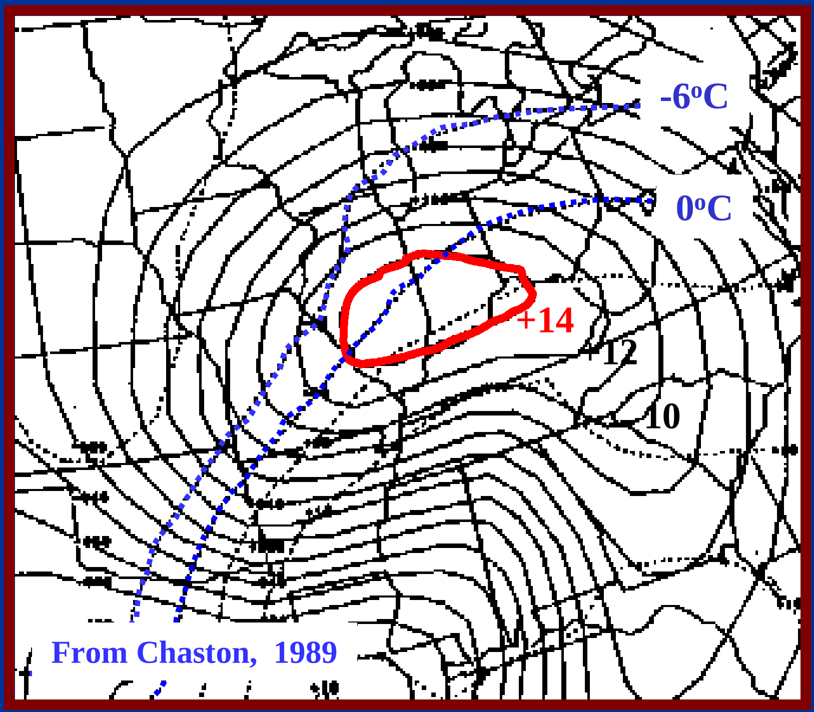
NGM 6-H FORECAST ON THE 292^{O}K ISENTROPIC SURFACE, VALID 0600 UTC 8 JAN 1996. HEAVY BLUE LINES ARE MIXING RATIO (g/kg), DASHED LINES ARE PRESSURE (TENS OF MB) AND WIND BARBS ARE IN KNOTS

THE METHOD GIVES YOU A FEEL FOR THE MAX SNOWFALL POTENTIAL OF THE STORM BUT DOES NOT TELL YOU WHERE THE MESOSCALE BAND OF HEAVIEST SNOW WILL FALL.

FIGURE ADAPTED FROM COPE 1996

Magic Chart

- THE MAXIMUM SNOWFALL IS EQUAL TO 2X(THE MAX VERTICAL DISPLACEMENT ON THE MAGIC CHART
- THE TECHNIQUE CALLS FOR THE MAX SNOWFALL ALONG THE -3º TO -5ºc
- NEED TO MAKE SURE THERE IS NO WARM LAYER



12 INCHES FELL IN CENTRAL ILLINOIS

NOT MY FAVORITE TECHNIQUE

Remember, snow usually occurs in mesoscale bands.

And can be focused by a variety of factors, for example:

- frontogenetic forcing along a boundary
- a convergence zone, i.e. the Puget Sound convergence zone.
- By convective plumes induced to the lee of large open expanses of water
- upper-level jet streaks
- terrain
- gravity waves
- conditional symmetric instability?

Synoptic, mesoscale and local effects need to be considered when forecasting snow

CONDITIONAL SYMMETRIC INSTABILITY

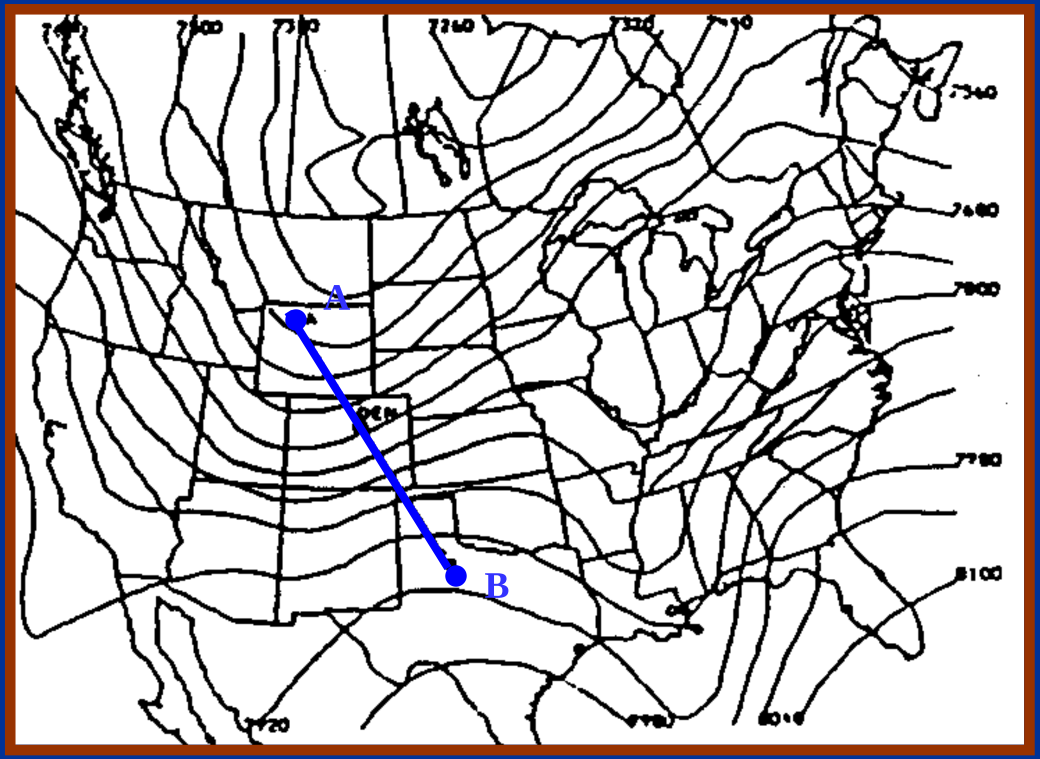
IS FAVORED UNDER THE FOLLOWING CONDITIONS

- UNDER LARGE VERTICAL WIND SHEAR
  - THIS WILL CAUSE $M_{.G}$ SURFACES TO BE RELATIVELY HORIZONTAL
- LARGE ANTICYCLONIC WIND SHEAR
  - ABSOLUTE VORTICITY WILL APPROACH ZERO AT THE LEVEL WHERE CSI IS OCCURRING
  - THIS PRODUCES WEAK INERTIAL STABILITY
- LOW STATIC STABILITY
  - ISENTROPIC SURFACE AND MORE IMPORTANTLY THE EQUIVALENT POTENTIAL TEMPERATURE (Θ_e) SURFACE BECOMES ALMOST VERTICAL

From Bluestein (1986)

When trying to forecast CSI, make sure the cross section is normal to the 850-300 mb thickness

FROM MOORE AND LAMBERT, 1993



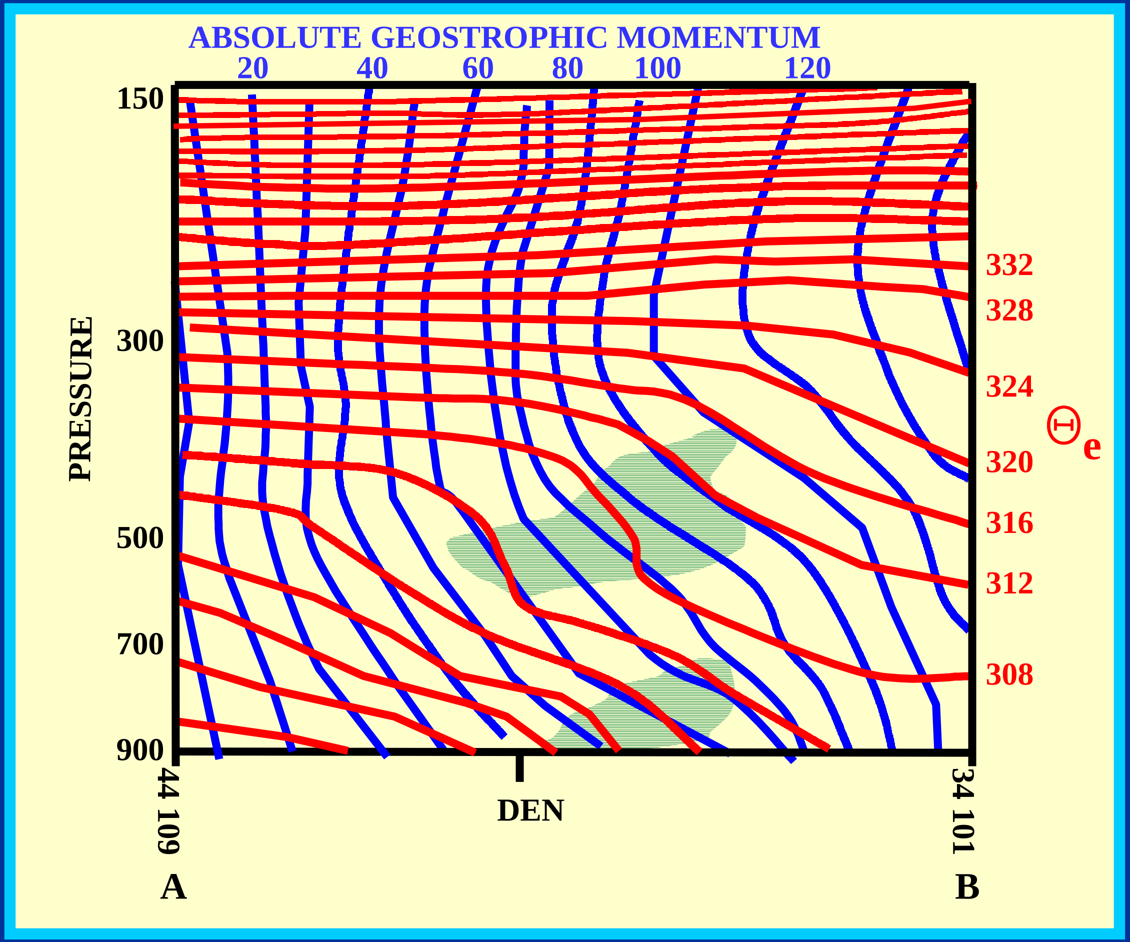
The 850-300 . mb thickness for 00 UCT Jan 1991. Line A-B depicts the position of the cross section shown on next 2 screens. Den=Denver

WHEN LOOKING FOR CSI ON A VERTICAL CROSS SECTION

1) THE AIRMASS NEEDS TO BE SATURATED (>80% RELATIVE HUMIDITY).

2) CSI IS PRESENT WHEN THE SLOPE OF THE Θ_e IS STEEPER THAN THE SLOPE OF THE MOMENTUM SURFACE.

3) THE LIGHT GREEN SHADING INDICATES AREAS OF CSI.

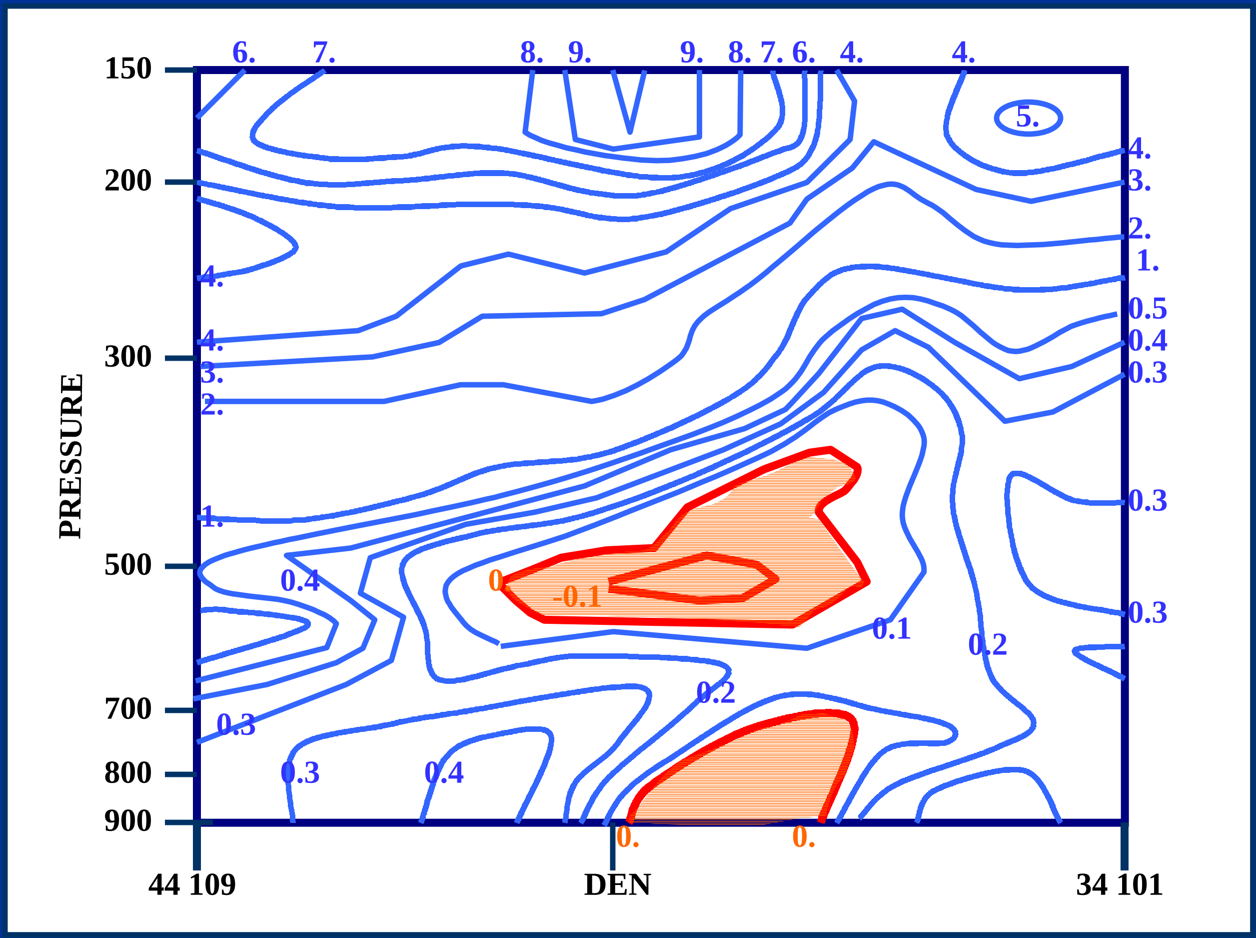


ADAPTED FROM MOORE AND LAMBERT, 1993

CAN ALSO USE EQUIVALENT POTENTIAL VORTICITY (EPV) TO FIND CSI

AIRMASS MUST BE SATURATED

NEGATIVE VALUES DENOTE CSI (SHADED AREA)



FROM MOORE AND LAMBERT, 1993

CSI and heavy snow

- Numerous researchers have noted heavy snow associated with CSI
  - have noted bands of heavy snow with CSI
    - unfortunately, there is no good way to predict exactly where the bands will set up.
- McCann (1996) studied 14 cases of 10 inches or more of snow east of the Rocky Mountains.
  - He noted that the tighter the horizontal temperature gradient the better the chances for slantwise convection.
  - CSI may be common in cases with a strong horizontal temperature gradient and CSI.

REMEMBER WHEN Θ_e DECREASES WITH HEIGHT, THE AIRMASS IS CONDITIONALLY UNSTABLE AND WILL PRODUCE UPRIGHT CONVECTION IF THE AIRMASS IS SATURATED AND THE PARCEL IS LIFTED

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