Winter weather forecasting

Wes Junker

Another inch with the vort!

e-mail:norman.junker@noaa.gov

A longer version of the slides for this talk is available at:

www.hpc. ncep.gov/html/hpcframes.html

Hydro-meteorological Prediction Center

Snow Forecasting

- Things to think about when forecasting snow and snowfall amounts
- How to forecast precipitation type
- snowfall accumulations
- Synoptic and mesoscale aspects of heavy snow
  - The heaviest snow usually falls within a mesoscale band.

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.
- <u>an assessment of whether the model is handling the mesoscale structure correctly.</u>
- <u>knowledge of the model low-level temperature biases.</u>
  - 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, if you are predicting all snow, you need to estimate the 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)
  - how much evaporation will take place
  - how fast will crystals grow?
- 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)

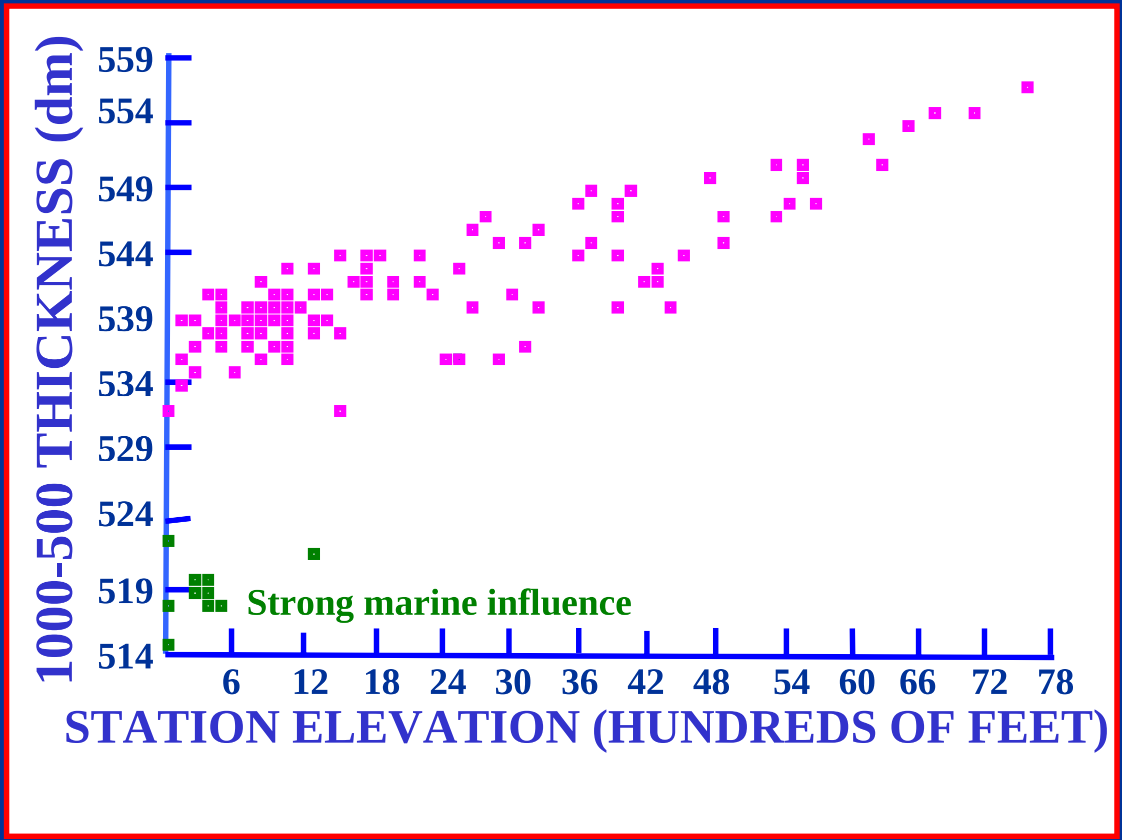
Traditional ways to forecast precipitation type

- 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

Partial Thickness

Adapted from Cantin et al. 1990

Used for southeastern Canada

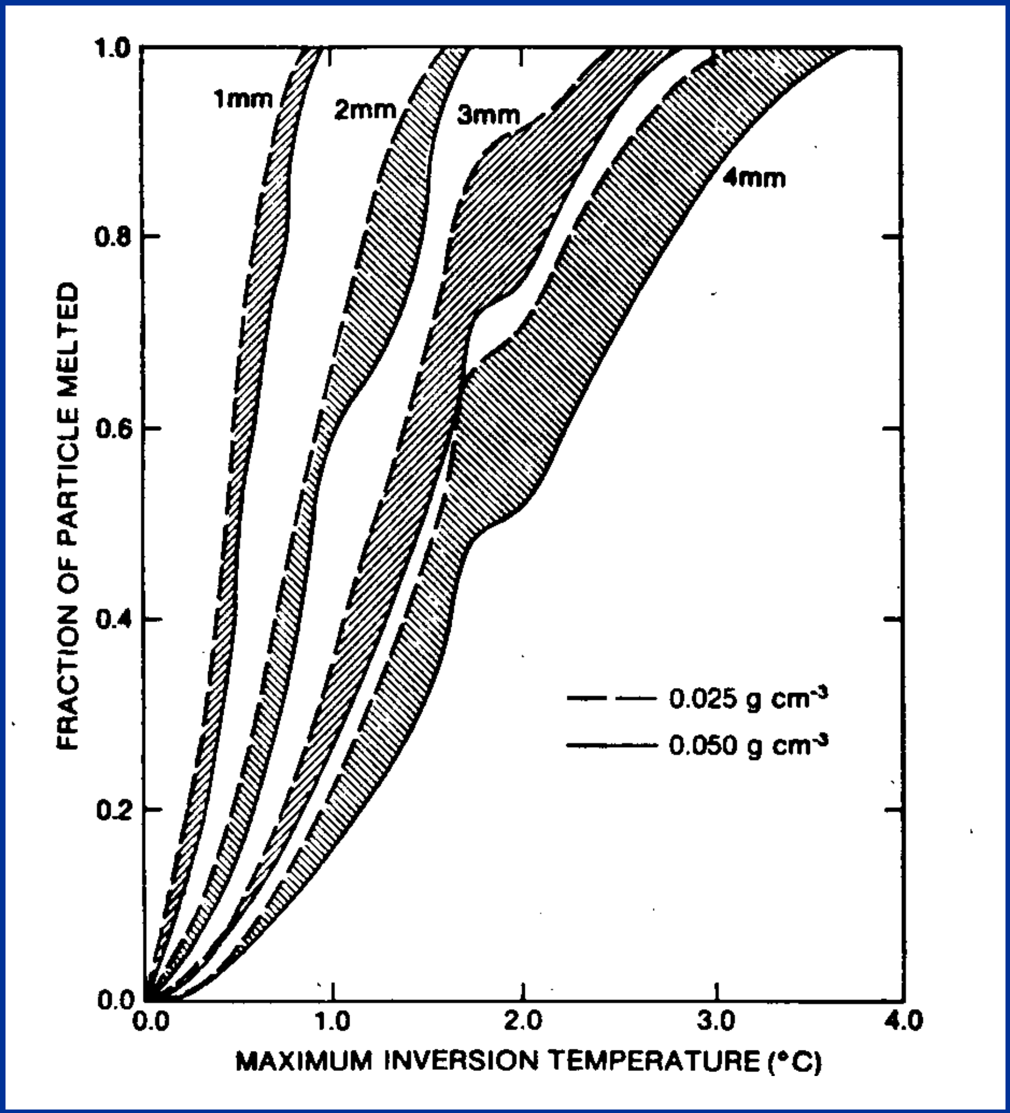
Thickness (dm)		Precipitation Types	
850-700	1000-850	Significant UVV or low-level cold advection	Weak UVV and near zero low-level cold advection
<154	<129	Snow	Snow, except sleet and/or freezing rain is possible near 154
<154	129-131	Snow or sleet except may be freezing rain near 154, usually rain with 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 (not as important as other factors)

If there is a cold layer below the inversion, the question of precipitation type is determined by how much of the snowflake melted



The degree of snowflake melting as a function of maximum inversion temperature. The curves correspond to particle size expressed in terms of diameter of raindrop having an equivalent mass. Two initial snowflake densities were used in the calculations

From Stewart and King, 1987

Precipitation type?

- 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.
- The cold layer
  - If temperature is less than --8^oC, 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^oC, 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.

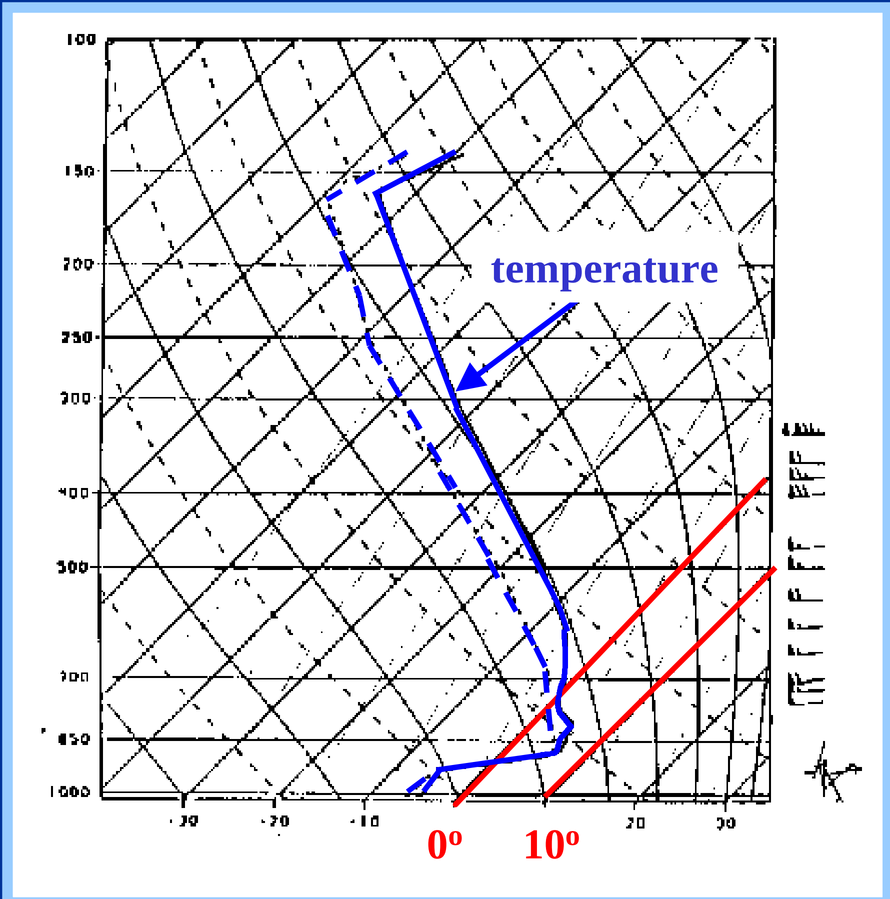
From Stewart and King, 1987

PRECIPITATION TYPE?

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.

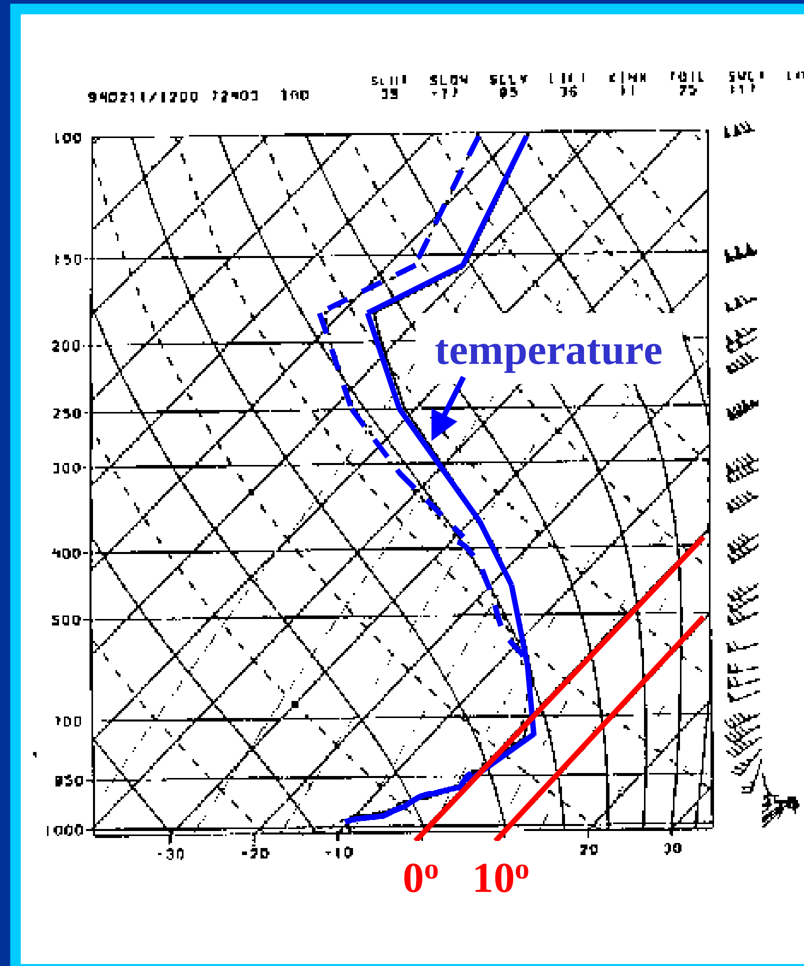
A freezing rain sounding (left)

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



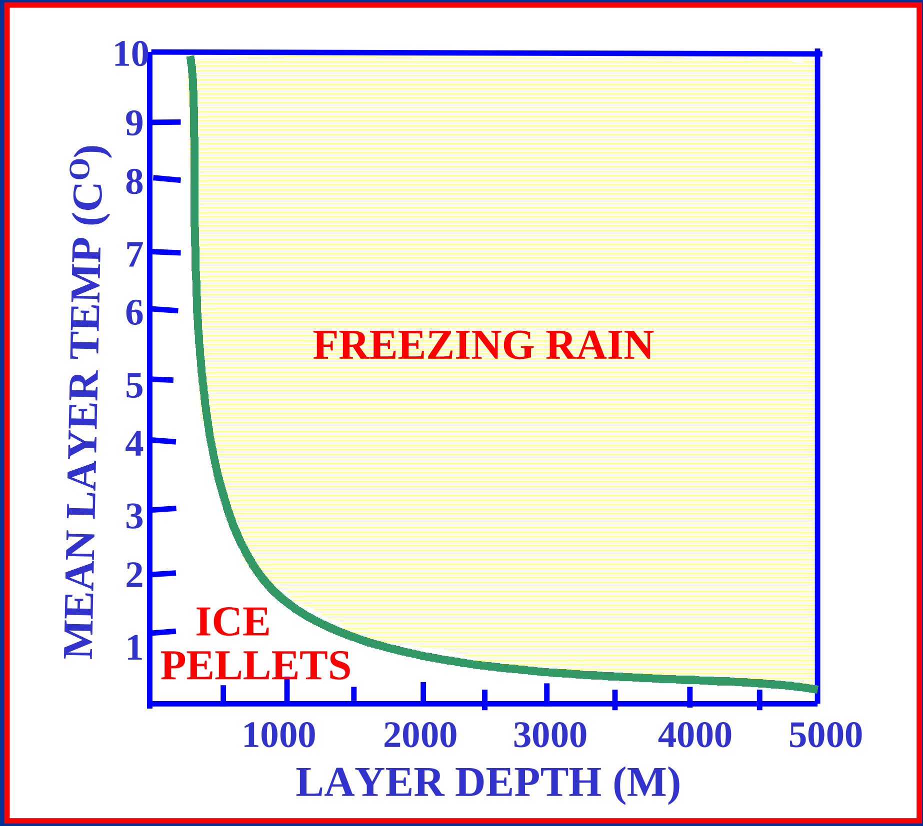
An ice pellet sounding

Note temperature of warm layer is 1-3^{o}C



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

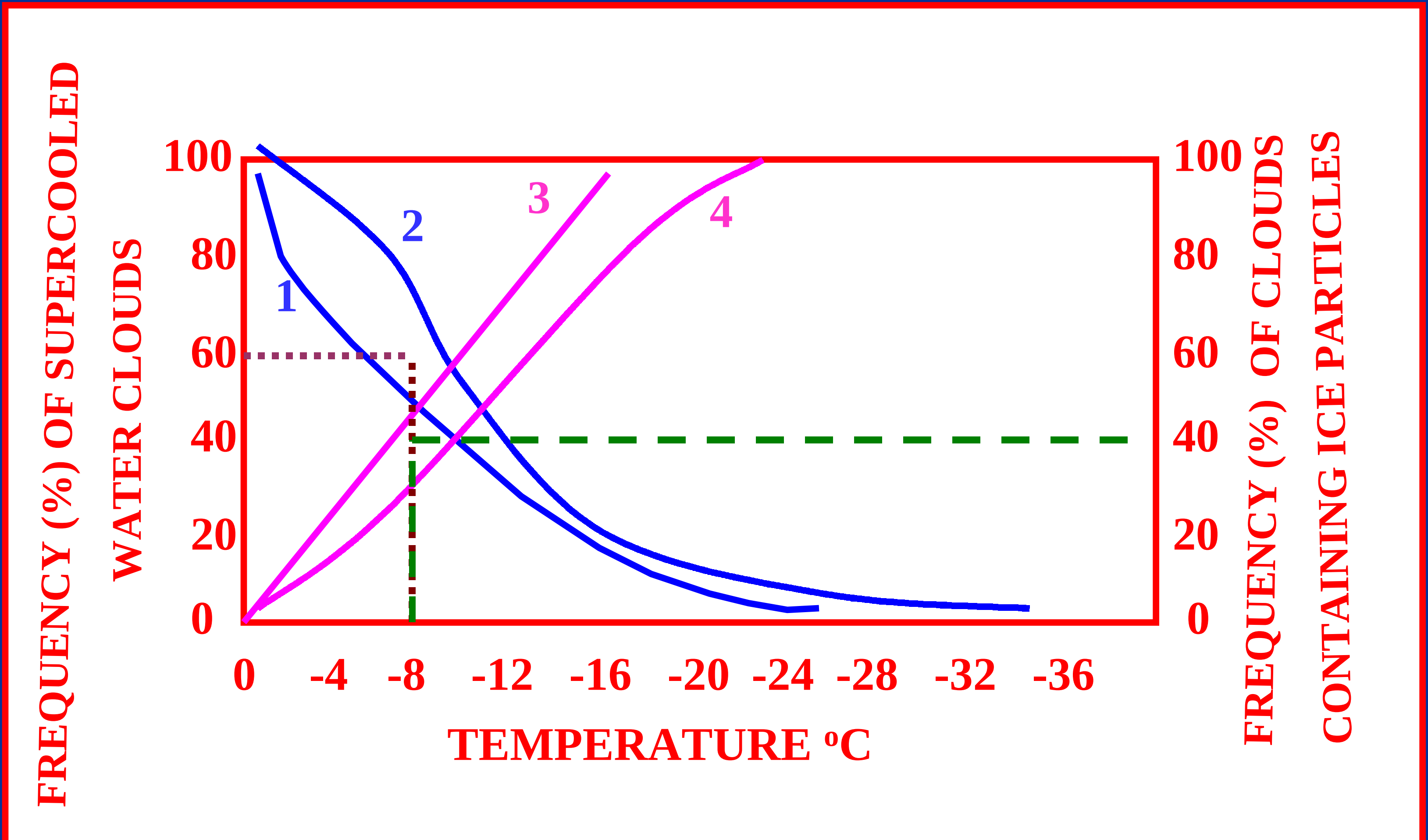
CLOUD PHYSICS PLAYS AN IMPORTANT ROLE IN DETERMINING PRECIPITATION TYPE

Ice forms on various nuclei at various temperatures

Substance	Symmetry	Threshold temperature (^oC)
Silver Iodide	Hex	-4
Covellite	Hex	-5
Kaolinite (a clay)	Triclinic	-9
Illite	Monoclinic	-9
Vermiculite (clay)	Monoclinic	-15

Note that very few (some organic compounds) have activation temperatures that are below -4oC

From Mason, 1971



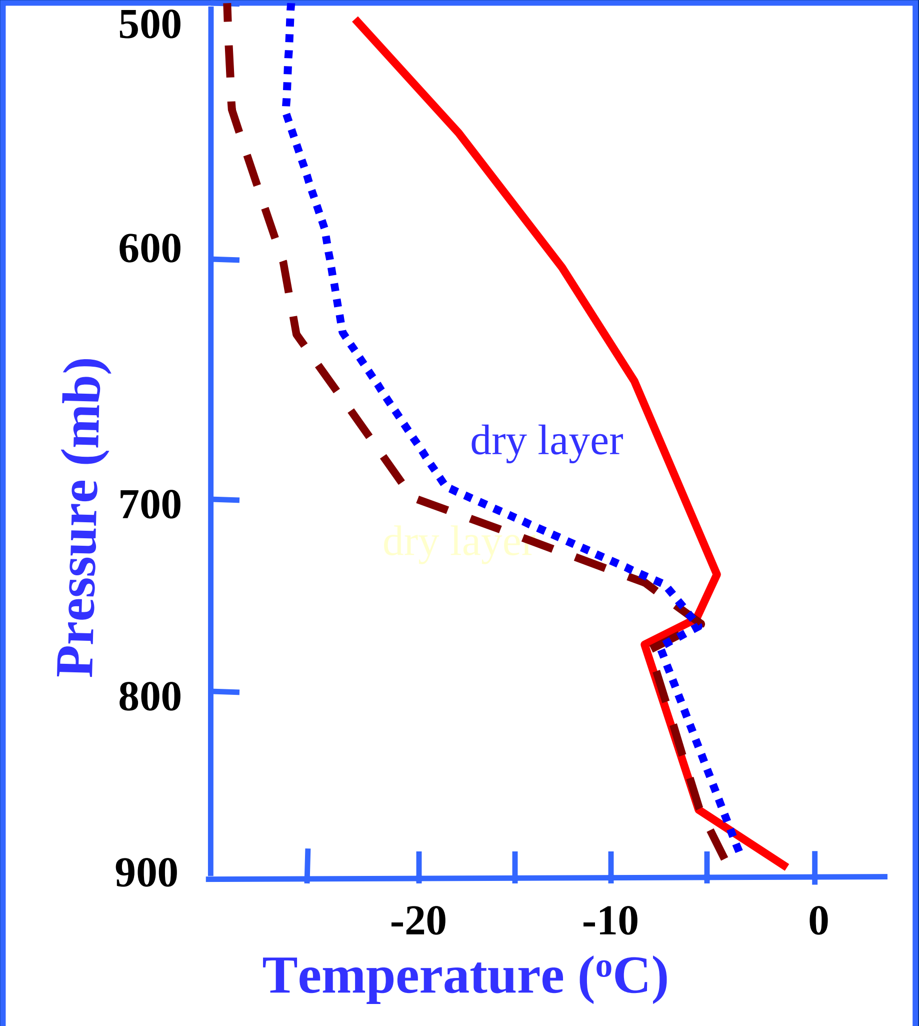
Variation of frequency of supercooled clouds containing ice crystals. **Curves 1 and 2 (all water clouds) pertain to ordinate at left. Curves 3 and 4 (mixed cloud studies) pertain to the ordinate at right.**

From Pruppacher and Klett, 1978

At what minimum cloud temperatures do crystals usually form?

- At -4oC or warmer
  - Ice formation is almost impossible without seeding from above.
- At -9^{o}C
  - The majority of clouds (over 50%) will be all supercooled water providing there is no cloud seeding from above
- At -14^{o}C
  - about 75% off all clouds will contain some ice
- At -18^{o}C or colder
  - almost all clouds have ice nuceii

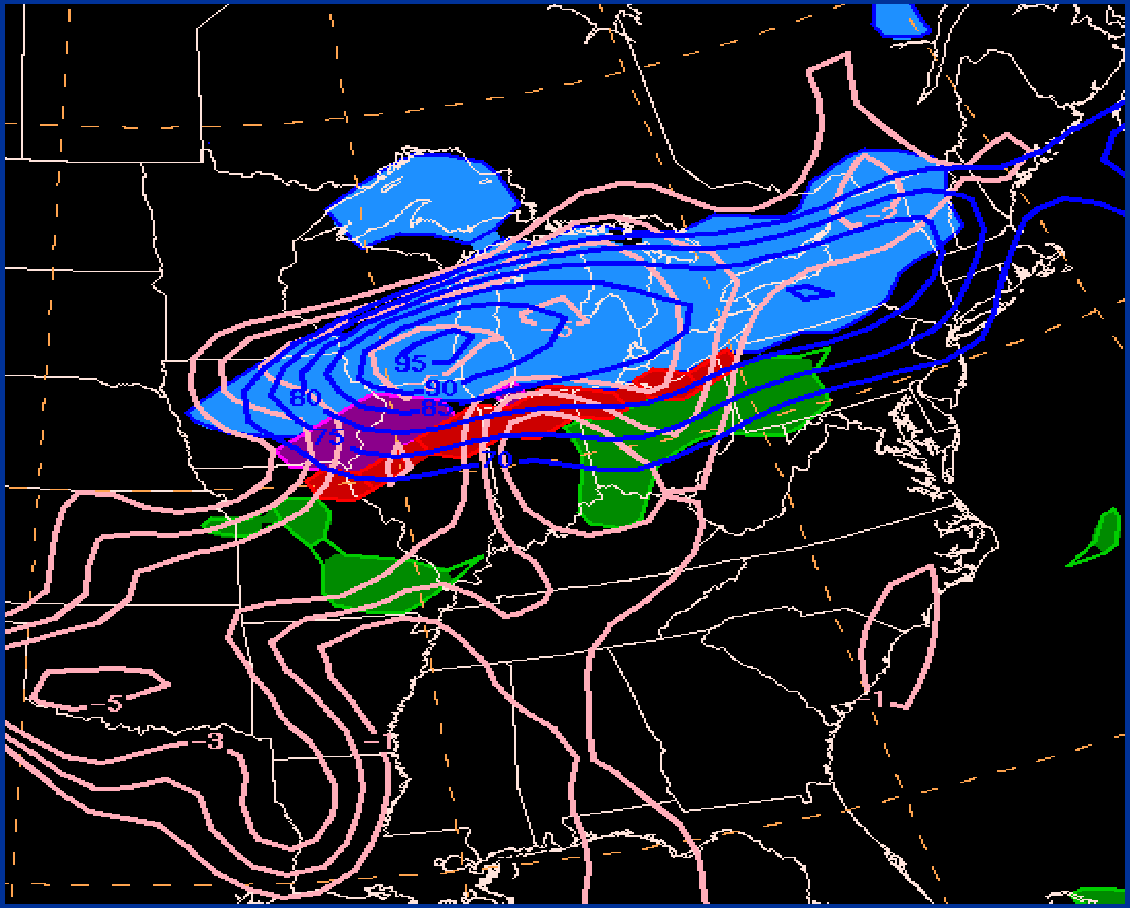
Freezing drizzle



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^oC 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, AT HPC WE NOW ALSO USE ALGORITHMS DEVELOPED BY RAMER AND CYS



If model has problems handling mass, wind or temperature fields, then its forecast of precipitation type will be wrong

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

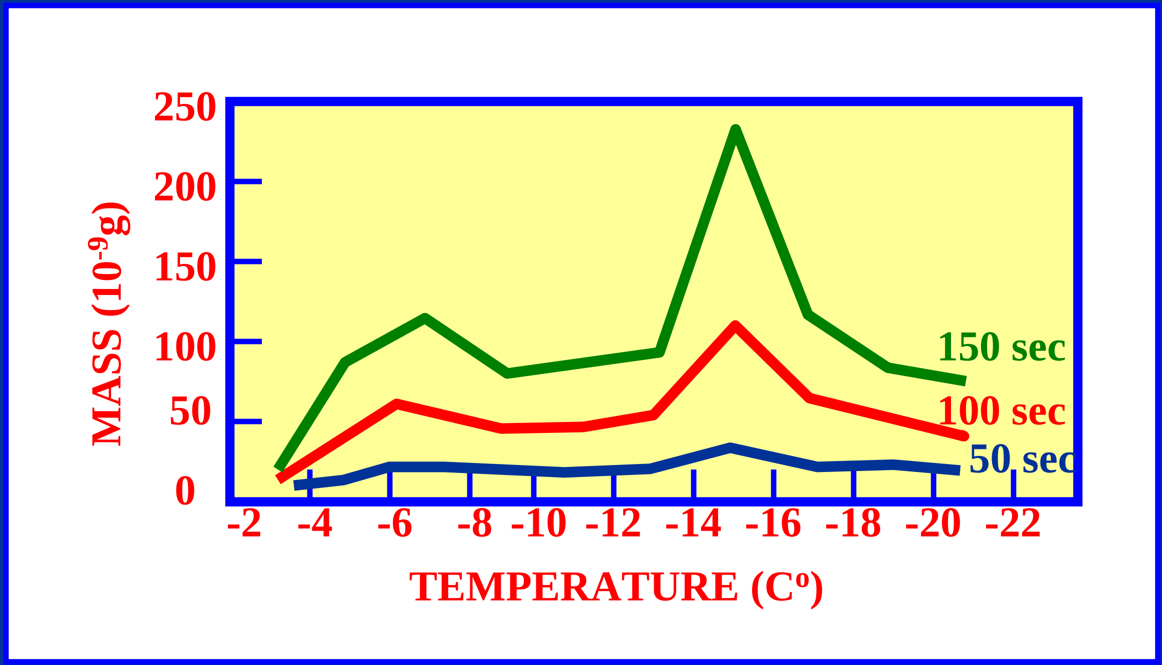
- The rate that snow falls is a function of
  - rate of growth of a single crystal
    - which peaks around -15°C
  - and the number of crystals per unit volume,
    - the number can be increased
      - by fragile crystals (dendrites and needles) fracturing
      - by ice splintering during riming
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

When cloud top temperatures are -25°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

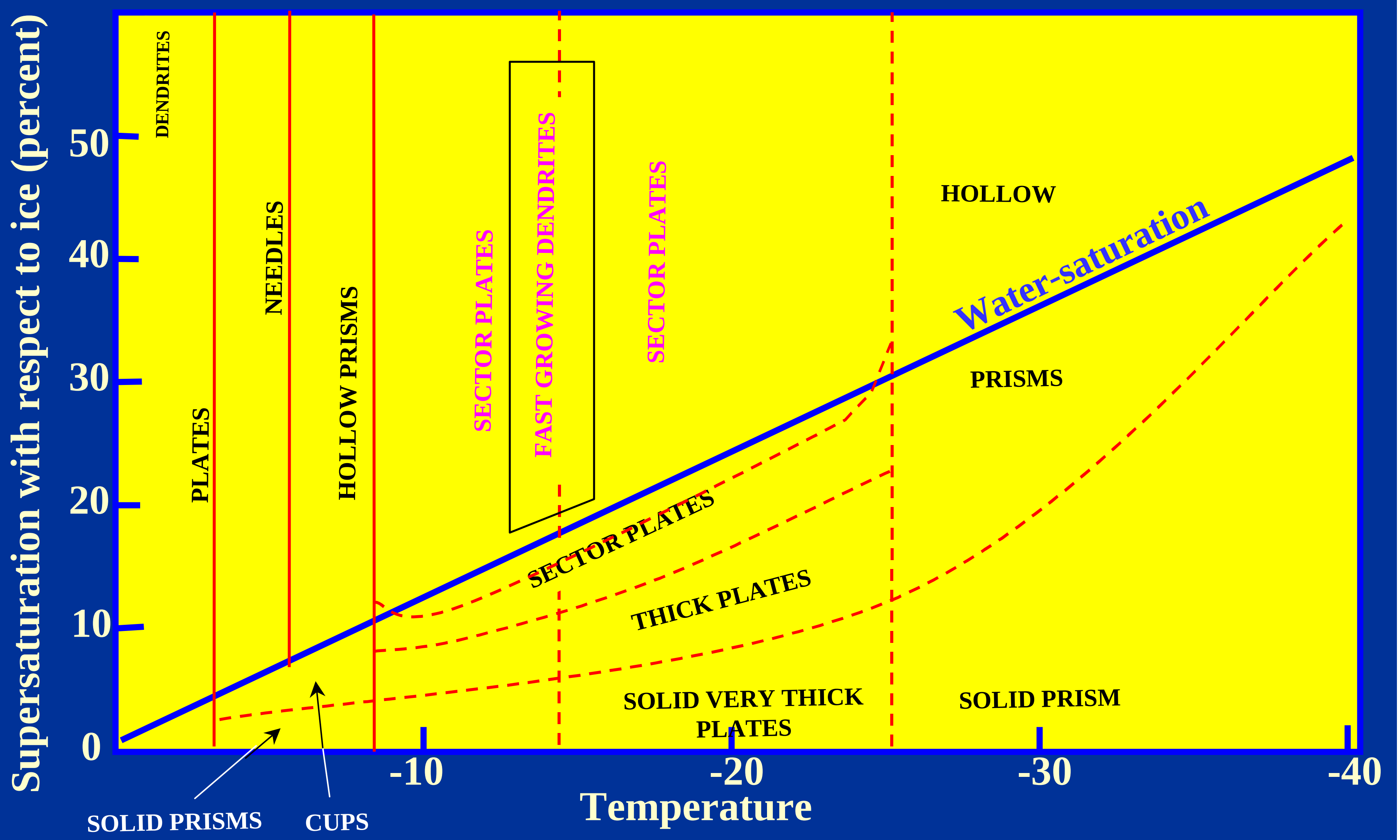
--Deposition, because $e_{sw}>e_{si}$, vapor is transported from droplets to ice crystals

--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.)

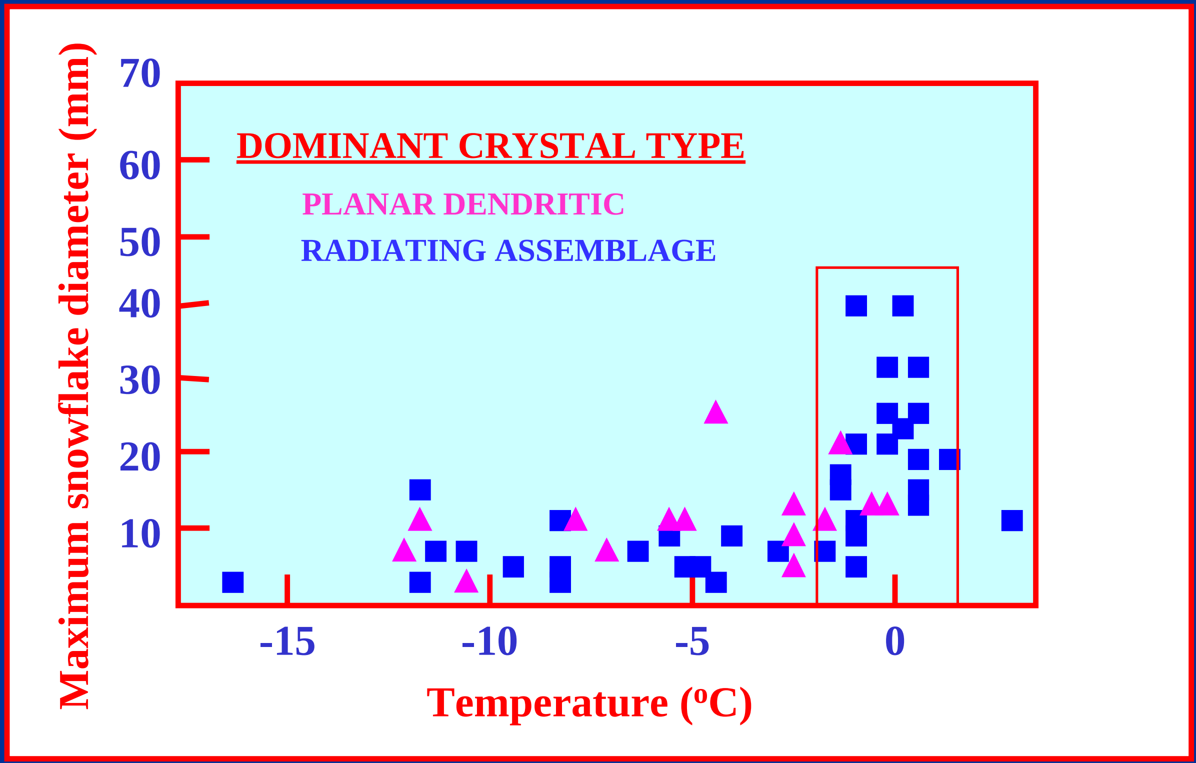
The variation of crystal habit with temperature and supersaturation according to the experiments of Mason et al.



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)

SNOWFLAKE DENSITY

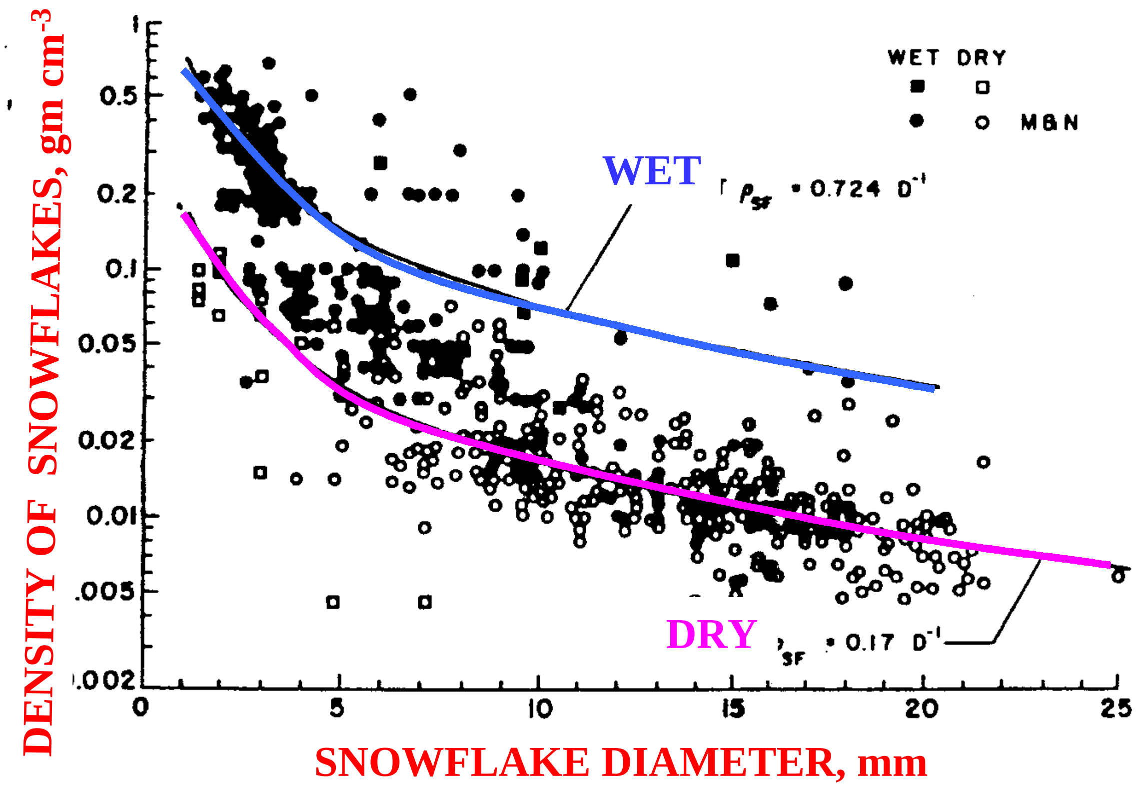


FIG. 1. Average snowflake density versus snowflake diameter from Magono and Nakamura (1965), represented as open and solid-filled circles, and from Rogers (1974), represented as open and solid-filled squares. The curve for the dry snowflakes represents the least squares equation from Holroyd (1971) and the curve for wet snowflakes represents the least squares curve from Rogers (1974). [From Rogers (1974).]

WHY SHOULD I CARE ABOUT THE PHYSICAL CHARACTERISTICS OF THE SNOWFLAKES

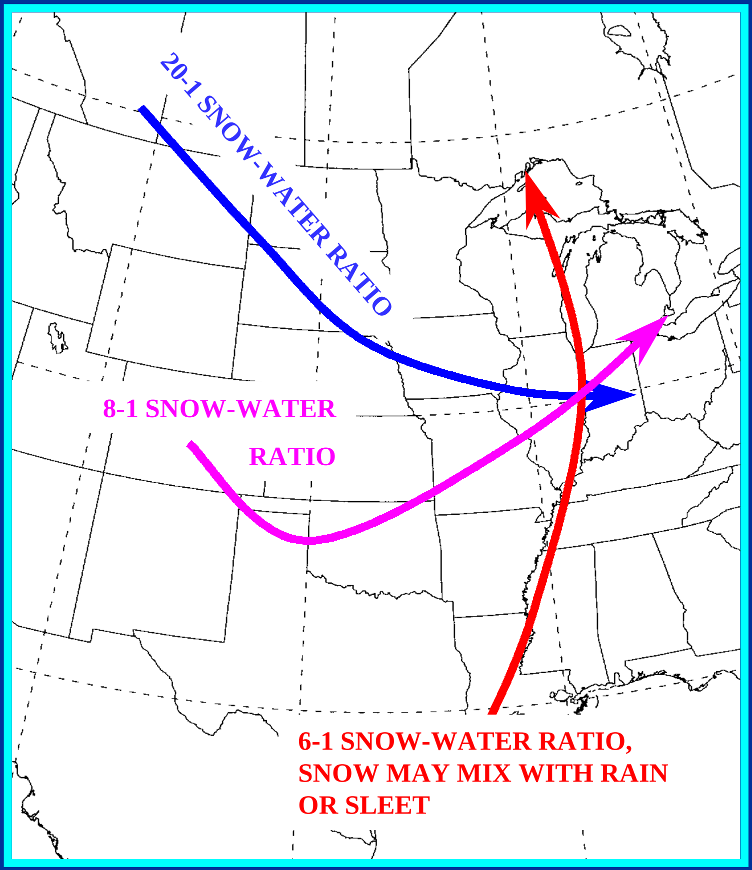
- The dominant crystal type may affect the snow to liquid equivalent ratio (how fluffy the snow is).
  - Unrimed Dendritic and plate crystals have a lacy structures that usually produce the highest snow to liquid ratios (best accumulators)
  - The make-up of the cloud may affect the snow to liquid ratio. 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.
- High winds will keep snow ratios down because snowflakes will fracture and lose their lacy structure
- 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

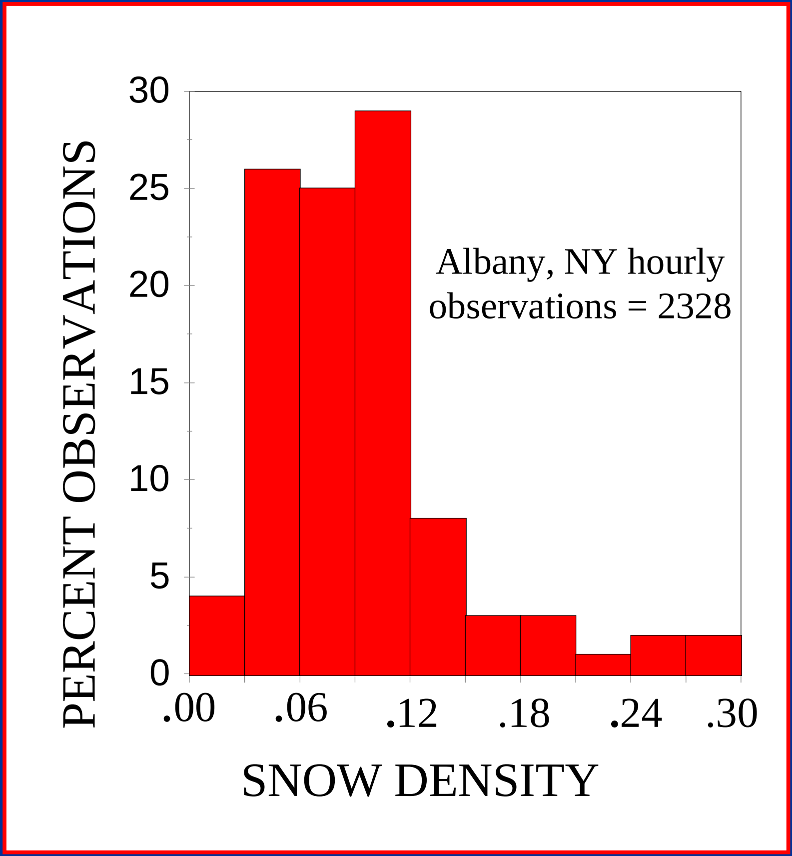
1) Northern storm tracks that favor snow crystal growth by deposition favor high snow-water ratios.

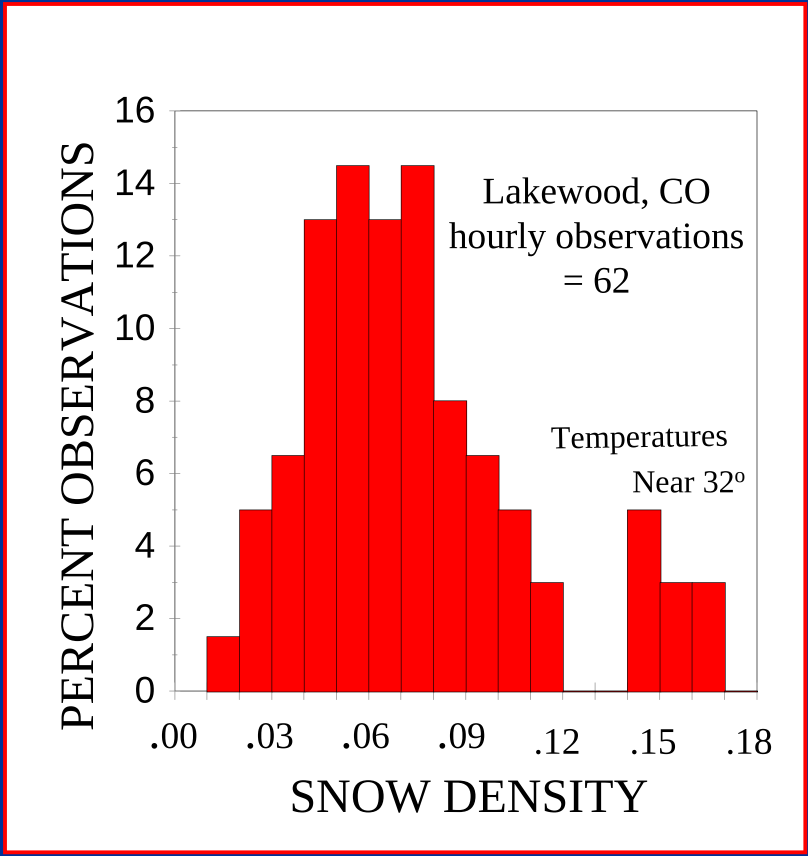
2) When ice crystals grow by riming or crystals colliding with supercooled droplets, the snow-water ratios are lower.

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).



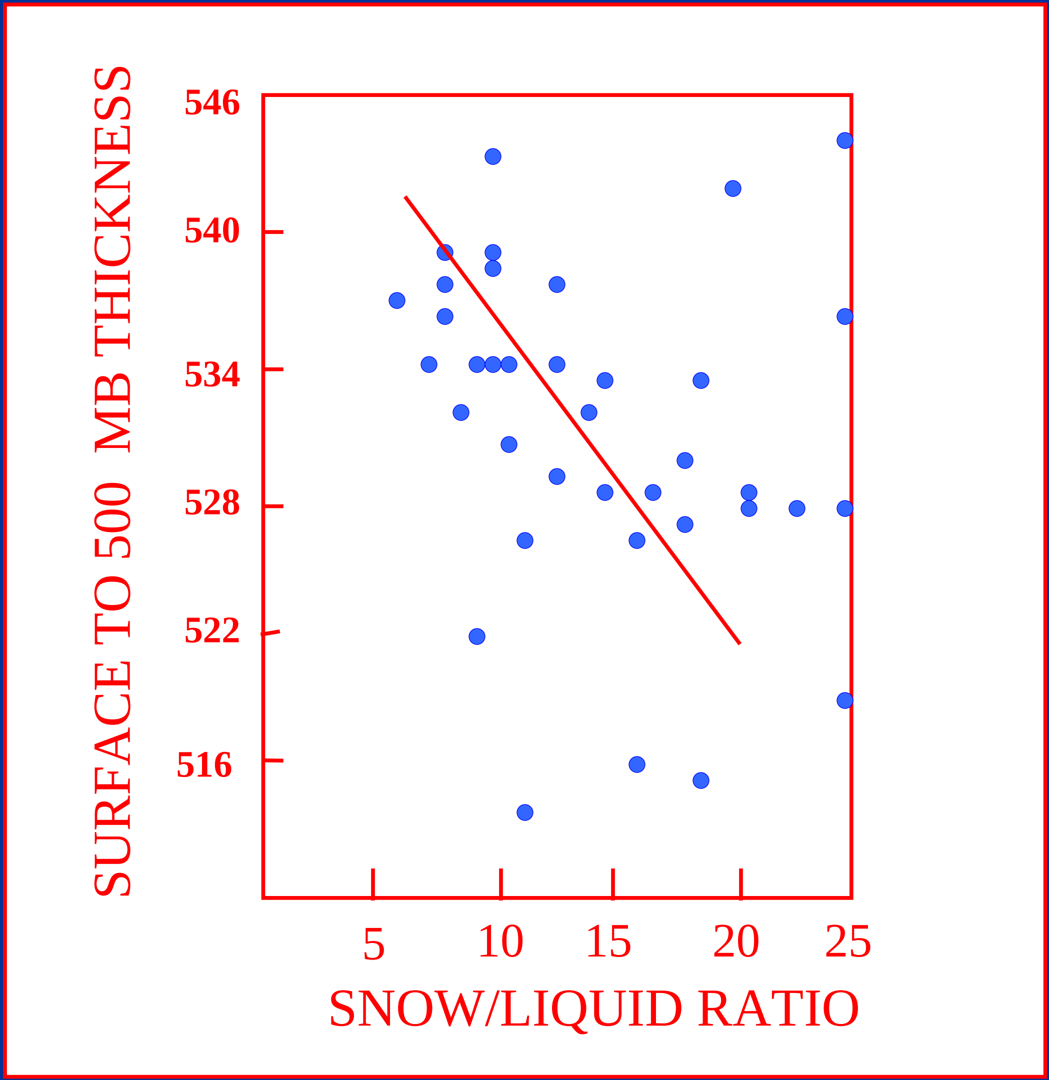


Percent distribution of snow density based on 2328 hourly observations from 73 sites near Albany

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

Adapted from Super and Holroyd, 1997

SNOW 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 surface 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.

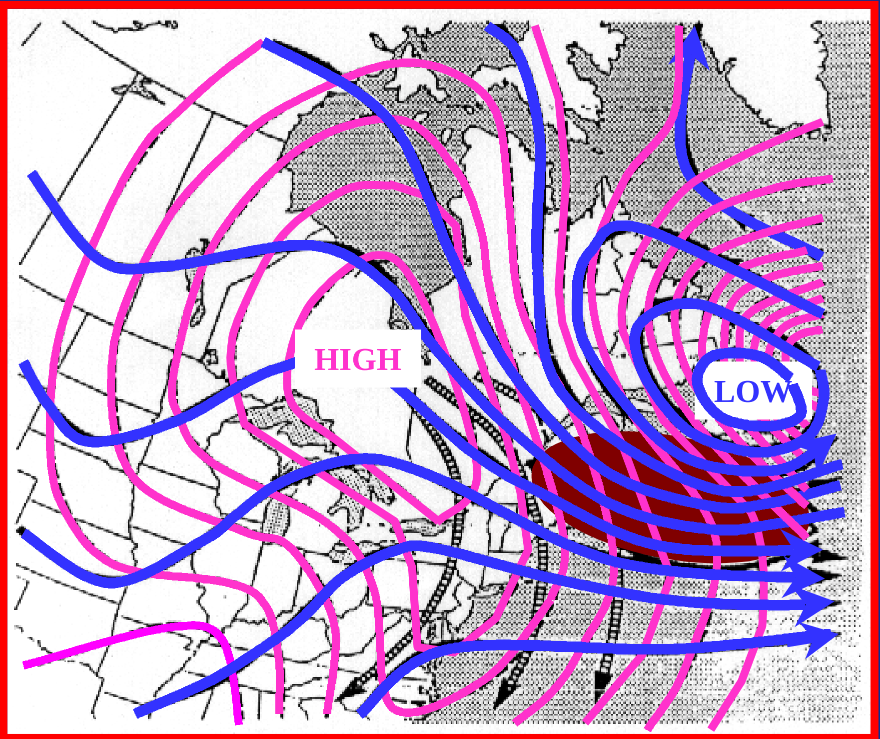
Upper level aspects of snowstorms that can change the strength of the vertical motion or moisture transport into a system

- large changes in amplitudes between trough and downstream ridge accompanied cyclogenesis (this increases south to north moisture transport
- all marked decrease in half-wavelength between the trough axis and downstream ridge indicative of self-development process (increases vorticity, upper level divergence and promotes cyclogenesis)
- a trough that becomes diffluence and takes on a negative tilt. (increases upper level divergence and promotes cyclogenesis)
- phasing of multiple vorticity maxima observed in about half the cases
- a vorticity max that is moving east-northeast. (such movements suggests that the system will have more moisture available than a vort that is moving to the east southeast (this is especially true in the Plains)

Adapted from Kocin and Uccellini, 1990

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

From Kocin and Uccellini, 1990



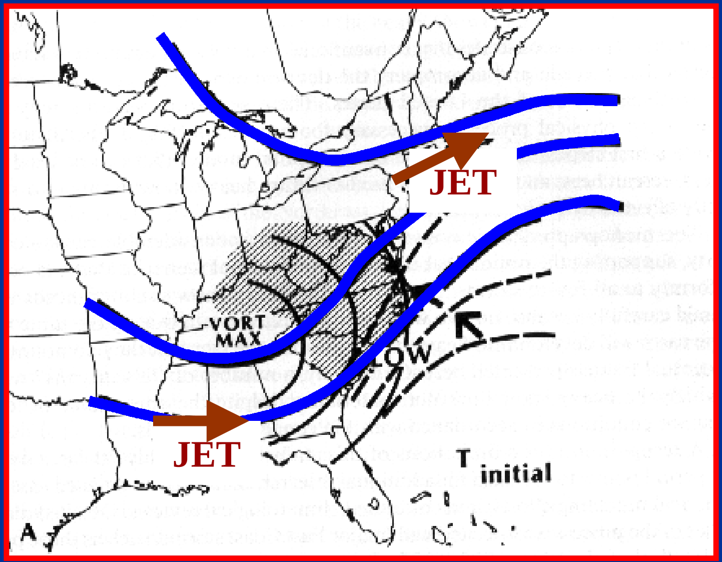
SURFACE ISOBARS 500 MB HEIGHTS
JET STREAK

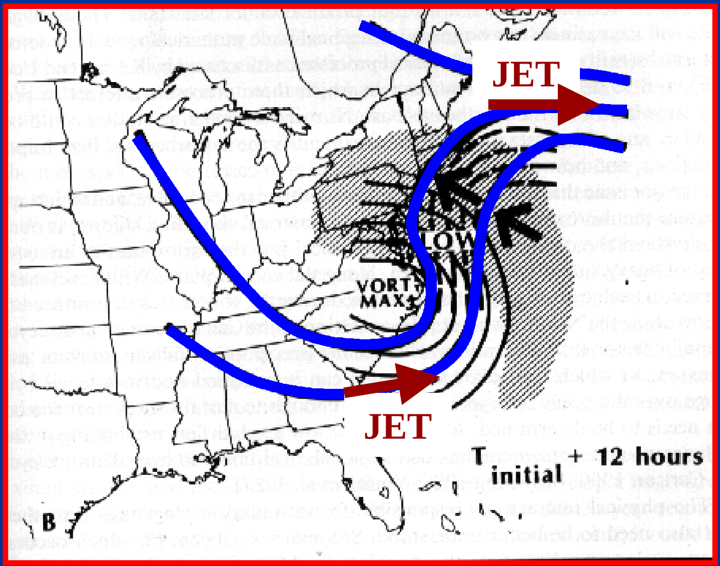
THE UPPER LOW NEAR THE MARITIMES HELPS TO HOLD THE UPPER LEVEL RIDGE AXIS NEAR THE GREAT LAKES REGION. THIS CONFIGURATION HOLDS CONFLUENT FLOW OVER THE NORTHEAST AND LOCKS THE SURFACE HIGH OVER THE NORTHEAST.

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.

THE SELF-DEVELOPMENT PROCESS

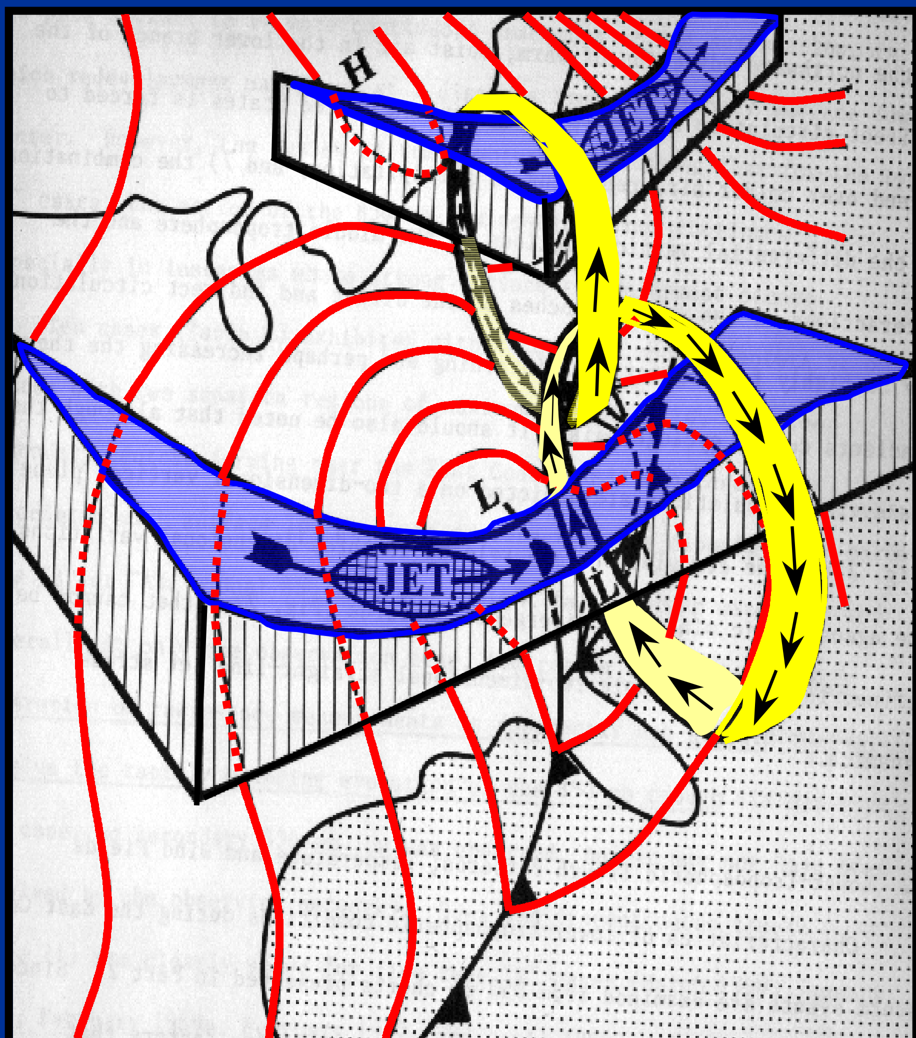




NOTE THE SHORTENING OF THE HALF-WAVELENGTH BETWEEN THE TROUGH AND DOWNSTREAM RIDGE AXIS. THIS HELPS TO STRENGTHEN THE VORTICITY, VORTICITY ADVECTION AND THE UPPER LEVEL DIVERGENCE. THE SURFACE LOW DEEPENS, PRODUCING INCREASED WARM ADVECTION WHICH BUILDS THE SHORTWAVE RIDGE AHEAD OF THE TROUGH. THIS INCREASES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

Remember, heavy 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

What about using empirical techniques or composites?

- The Garcia technique
  - Fairly subjective, does not take into account the slope of the isentrope or the movement of the system
- The Cook Method
  - Probably works because the warm advection at upper levels can be correlated with cyclogenesis.
  - Does not measure moisture available for the system or vertical motion.
- The Magic Chart
  - Uses net vertical displacement and 850 temperature (-3 to -5oC ribbon).
  - Does not take into account available moisture or whether there might be a warm layer.
- Composites (Goree and Younkin), Browne and Younkin, etc.
  - Some cases do not fit the mean patterns. If you rely strickly on composites you’ll miss the outliers.

References and related articles

- Bocchieri, J. R., 1980: The objective use of upper air soundings to specify precipitation type. *Mon. Wea. Rev.* **108**, 596-603.
- Browne, R. F. and R. J Younkin, 1970: Some relationships between 850-millibar lows and heavy snow over the Central and Eastern United States, *Mon. Wea. Rev.*, **98**
- Chaston, P.R., 1989: The Magic Chart for forecasting snow amounts. *National Weather Digest*, **14**, 20-22.
- Cook, B. J., 1966: The Lubbock Snowstorm of February 20, 1961. U.S. Dept. of Commerce, ESSA, Weather Bureau Southern Region, Tech. Memorandum No. 12. 10 pp.
- Czys, R. R., R. W. Scott, K.C. Tang, R. W. Przybylinski, and M. E. Sarbones, 1996: A Physically based, Nondimensional Parameter for Discriminating between locations of freezing rain and ice pellets. *Wea. Forecasting*, 11, 591-598.
- Doesken, N.J. and A. Judson, 1996: *The Snow Booklet, A guide to the Science. Climatology and Measurement of Snow in the United States.* Colorado Climate Center, Colorado State University. 84 pp.
- Garcia, C. Jr., 1994: Forecasting snowfall using mixing ratios on an isentropic surface. NOAA Tech. Memo., NWS CR-105, U.S. Dept. of Commerce/NOAA/NWS. 31 pp.
- Goree, P.A. and R. J. Younkin, 1966: Synoptic Climatology of Heavy Snowstorms over the Central and Eastern United States, *Mon. Wea. Rev.*, **94**, 663-668.
- Harms, R. H., 1970: Snow Forecasting for Southeastern Wisconsin. NOAA Technical Memorandum NWSTM CR-38, U. S. Dept. of Commerce, NOAA, NWS, 17 pp.

References Continued

- Huffman, G.J. and G. A. Norman, Jr., 1988: The Supercooled Warm Rain Process and the Specification of Freezing Precipitation. *Mon. Wea. Rev.*, **116**, 2172-2182.
- Kocin, P. J. and L. W. Uccellini, 1990: *Snowstorms along the Northeastern United States Coast, 1955 to 1985.* American Meteorological Society, Meteorological Monograph No. 44, 280 pp.
- Moore, J. T. and T. E. Lambert, 1993: the use of equivalent potential vorticity to diagnose regions of conditional symmetric instability. *Wea. and Forecasting*, **7** , 430-439.
- Mote, T.L., 1991: A statistical investigation of atmospheric thermodynamics and kinematics associated with intensity of snowfall at Omaha, Nebraska. Masters Thesis, University of Nebraska
- Ryan, B. F. , E. R. Wiehart and D. E. Shaw, 1976: The growth rates and densities of ice crystals between -3^{o}C and -21^{o}C. *J. Atmos. Sci.*, **33**, 842-850.
- Scofield, R. A. and L. E. Spayd, 1984: A technique that uses satellite, radar, and conventional data for analyzing and short-range forecasting of precipitation from extratropical cyclones. NOAA Technical Memorandum NESDIS 8, 51 pp.
- Stewart. R.E. and P. King, 1987: Rain/snow boundaries over southern Ontario. *Mon. Wea. Rev.*, **115**, 1270-1279.
- Super, A. B. and E. W. Holroyd III, 1997: Snow Accumululation Algorithm for the WSR-88D Radar: Second Annual Report. Bureau of Reclamation Report R-97-05, Denver, Co, June, 70 pp.
- Young, W. H., 1978: Freezing precipitation in the southeastern United States. M. S. thesis, Texas A7M University, 123 pp.