

Appendix B**Precipitation Type**

The type of precipitation that falls in your forecast area is often a critical component of current weather. Will the precipitation be solid, liquid, or freezing? Where will the rain-snow line be located? While rain can get you wet and create some driving challenges, it is snow and freezing precipitation that can have a significant impact on the community. It is your job to forecast this precipitation type correctly. In some situations it is mainly a rain versus snow event; on other days freezing rain and ice pellets add a tricky element to the mix. Let's examine these forecast components.

Rain versus Snow

For determination of rain versus snow you need to know more than just the surface temperature. An early study based on surface observations showed the frequency of rain and snow as a function of temperature as follows:

Probability	Temperature
95 percent probability of snow	34°F / 1.1°C
equal probability of rain and snow	36.5°F / 2.5°C
95 percent probability of rain	42°F / 5.6°C
no snow observed	43°F / 6.1°C or more

Although the freezing point of water is 32°C/0°C, snow is observed at the Earth's surface for temperatures in the 30sF, and in rare events, even into the low 40sF. Please note, however, that with the current observing system (ASOS), snow is not reported for temperatures above 39°F.

Low Level Thermal Structure: Whether rain or snow occurs at the Earth's surface depends upon the low level thermal structure. That is, the temperature profile in the lowest 8 to 10 thousand feet above ground level (AGL) determines what happens to precipitation as it falls toward the ground (which we assume forms above the freezing level as snow). To form rain, you need an above-freezing layer deep enough to melt snow to rain. Studies have found that the melting depth, that is, the depth of the above freezing layer, varies from 750 feet to 1500 feet AGL, depending upon snowflake type, melted drop size, and lapse rate.

Operationally you have no way to determine snowflake type or melted drop size. You may have some feeling for the lapse rate. In general, the depth necessary for melting snow to rain is less when the temperature increases more rapidly toward to surface, i.e., steeper lapse rate. On average, assume that the freezing level must be at least 1200 feet AGL to ensure that snow will melt to rain. Another study summarized the chance of snow as a function of the height of the freezing level (or depth of the layer in terms of pressure difference across the layer):

Freezing Level Height (AGL)	Probability
35 mb / 920 feet	50 percent
25 mb / 660 feet	70 percent
12 mb / 315 feet	90 percent

Anticipating Low Level Temperature Change: The key to determining precipitation type is anticipating changes in the low level temperature structure. At 0000 and 1200 UTC soundings provide a picture of the low level thermal structure, but as time progresses, this structure can change due to a variety of factors. You need to forecast this change, particularly in the short term. Computer forecast models can provide this type of data, but you can also look at current data and anticipate changes.

The temperature change equation is one way to assess physical factors that create these changes. In the temperature change equation, the local change in temperature is a function of three terms:

- horizontal temperature advection
- vertical displacement of air
- non-adiabatic (diabatic) heating

Horizontal temperature advection is usually the *dominant factor influencing the local temperature change*. If there is warm air advection, temperatures increase. If there is cold air advection, temperatures decrease. The best example of cold air advection impacting a location is the very strong cold air advection and temperature drop that follows a cold front passage during the winter.

The vertical displacement term is usually opposite in sign and about half the magnitude of the horizontal advection term. The omega equation tells us that warm air advection (WAA) is associated with upward vertical movement while cold air advection (CAA) is associated with downward vertical movement.

Rising air cools at the adiabatic rate while sinking air warms at the dry adiabatic rate. Thus, as a general rule, the combination of WAA (warming) and rising air (cooling) results in a net warming but at about half the magnitude expected from WAA alone.

Consider the special case of a cold core upper low where there is no thermal advection but there is upward vertical motion. In this case the main thermal effect is from the vertical displacement term. This is a case where snow will tend to stay as snow or where rain may change to snow as cooling occurs.

Non-Adiabatic Effects: The non-adiabatic term can impact the vertical temperature profile in a number of ways. Two specific examples are discussed below.

Evaporational Cooling: Consider what happens when precipitation falls through an unsaturated layer, particularly a very dry layer. As rain falls through the unsaturated layer, it evaporates, eventually saturating the layer and cooling it to its wet-bulb temperature.

What happens if the temperature of a layer is initially above freezing, but the wet-bulb temperature of the layer is below freezing? In this case, rain changes to snow as the layer cools. The non-adiabatic term becomes the dominant factor as long as evaporation is occurring. Once the layer becomes saturated and evaporation stops, thermal advection or vertical displacement will again become the dominant factor in determining changes in the local temperature profile.

Using the physical processes just described, you can imagine a situation where rain turns to snow due to evaporational cooling, then as the layer saturates and WAA reasserts itself, the snow turns back to rain. This situation is neither simple to analyze nor easy to forecast.

Melting of Snow to Rain: Melting snow to rain requires latent heat. This heat is taken from the surrounding air. In order to obtain substantial temperature change due to melting, it is necessary to have rather heavy amounts of precipitation falling with little or no warm advection. If this occurs, you can have heavy rain turn to heavy snow as the freezing level sinks downward due to cooling by latent heat absorption.

Although this situation can occur, cases of substantial lowering of the freezing level due to melting are relatively rare because the combination of heavy precipitation without warm air advection is uncommon.

Other Non-Adiabatic Effects: Radiation and surface sensible heat exchange are non-adiabatic effects that are often important in temperature forecasting. Experience has shown that both of these factors usually have a minor impact on the rain-snow forecast problem. Their effect is typically close to the surface and does not influence the vertical temperature profile above the boundary layer. There are a couple of exceptions, however.

The type of surface, i.e., snow versus water, may be important in some situations. This factor is a combination of sensible heat transfer, advection and vertical mixing in the boundary layer. For example, low level on-shore flow over Norfolk, Virginia, tends to keep the lower levels of the atmosphere warm enough for liquid precipitation. The flow of low level air over the warm off-shore water keeps temperatures above freezing. As a result, snow is not a frequent occurrence on the Norfolk peninsula. As another example, warm air flowing over a snow field can be cooled and moistened as it helps sublimate the surface snow. If there is turbulence mixing in the boundary layer, clouds may form.

A situation where radiational effects can influence precipitation type occurs when temperatures are around the freezing point and the precipitation is liquid. If the temperature is above freezing, no freezing precipitation will occur. If the temperature is below freezing, freezing rain is likely. Even on a cloudy day, there will be some diurnal temperature change due to radiation heating during the day and radiational cooling at night. Assuming other effects such as advection are minor, the diurnal temperature change may be sufficient to move temperature across the freezing point and modify the precipitation type from freezing rain to rain, or vice versa.

The impact of non-adiabatic factors can often be difficult to judge. Use your basic knowledge of phase changes for water in combination with advection and radiation effects when evaluating these situations. A good analysis of current weather is important in these situations.

Operational Considerations

Many of the factors discussed above are difficult to evaluate operationally. If your forecast area contains an upper air station, twice a day you will have a picture of the low level temperature structure. You can use this observation in combination with the three modifying effects described above (horizontal advection, vertical displacement, and non-adiabatic effects) to anticipate short-term changes in the low level thermal structure.

If you do not have a local upper air station, you will likely depend upon model soundings. *Nota bene*, be sure that the model sounding implications correlate with what your analysis of current data implies. For example, if the model sounding implies rain, but the surface observation shows snow, use the model sounding with caution.

Freezing Rain and Ice Pellets

One of the most dangerous types of winter weather is freezing rain. The coating of ice it produces makes travel hazardous and causes power lines to collapse. The *Glossary of Meteorology* defines freezing rain and ice pellets (more commonly known as sleet) as follows:

Freezing Rain: rain that falls in liquid form but freezes upon impact to form a coating of glaze upon the ground and on exposed objects; this implies that the surface temperature is 32 degrees Fahrenheit or less

Ice Pellets: transparent or translucent pellets of ice, 5 mm or less in diameter

Vertical Temperature Structure: The vertical temperature structure in the lowest 10,000 feet of the atmosphere determines whether freezing rain or ice pellets occur. In both situations, the vertical structure is similar: an elevated above-freezing layer is located over a sub-freezing layer near the Earth's surface. This basic structure is shown in Figure B-1.

Freezing Rain Physics: For freezing rain, assume that the precipitation forms as snow and then falls into warm (above-freezing) layer. By the time the precipitation reaches the base

of the warm layer, it is *completely melted* and falls into the cold (below-freezing) layer as a liquid droplet.

In order for liquid droplets to freeze, you need freezing nuclei and temperatures generally below -10 degrees Celsius, something called *heterogeneous nucleation*. Typically, at temperatures warmer than -10 degrees Celsius, the number of freezing nuclei is not sufficient to initiate the freezing process. As a result the droplets stay liquid and become *supercooled*. When these supercooled droplets hit something at ground level, or an aircraft above the ground, the droplets freeze and a glaze forms.

The key here is that the snow completely melts and forms the supercooled droplet.

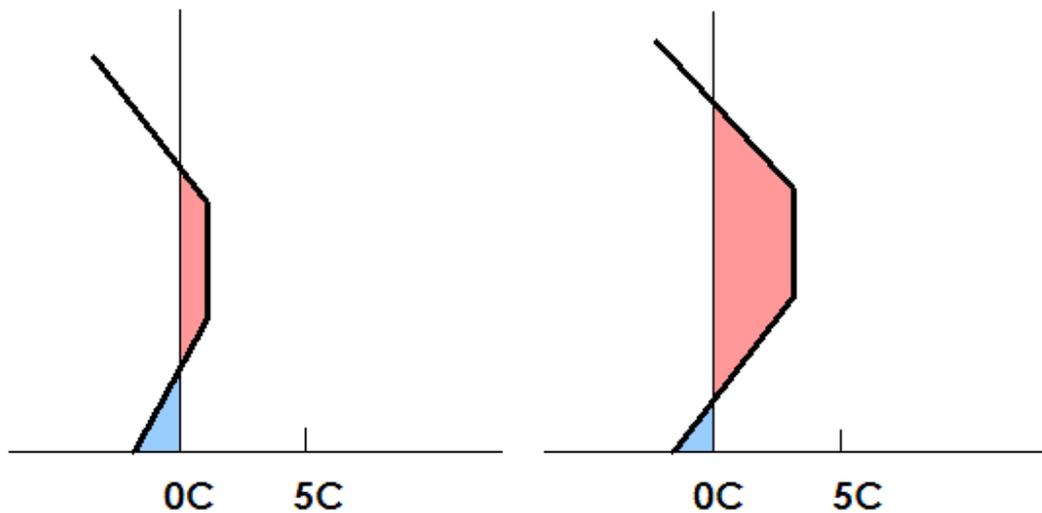


Figure B-1: Vertical Temperature Structure for Ice Pellets (left) and Freezing Rain (right)

Ice Pellet Physics: For ice pellets or sleet, again assume that the precipitation forms as snow. When this snow falls into the warm (above-freezing) layer, the snow *partially melts*. By the time the precipitation reaches the base of the warm layer, it is a mixture of ice crystals surrounded by liquid water.

As the ice crystal/water mixture falls into the cold (below-freezing) layer, the ice crystals act as freezing nuclei and the refreezing process occurs. The result is an ice pellet or sleet.

The key here is that the snow partially melts and refreezing occurs.

Differences: Studies of freezing rain and ice pellet situations examined the differences between the two situations in terms of four parameters:

- strength of the cold layer
- depth of the cold layer
- degree of melting in the elevated warm layer
- depth of the elevated warm layer

Strength of the Cold Layer: The strength of the cold (below-freezing) layer is measured in terms of the coldest temperature in the layer. If the temperature is less than -10 degrees Celsius and there are sufficient freezing nuclei, and given enough time for freezing to occur, either snow or sleet can form.

Depth of the Cold Layer: One study indicated that if the depth of the cold layer is greater than 2,500 feet, there is a tendency for snow or ice pellets to form. If the depth of the cold layer is less than 2,500 feet, there is a tendency for freezing rain to form. This study did not take into consideration the amount of melting that takes place in the warm layer (as described above). As a result, use the depth of the cold layer as a secondary evaluation factor.

Degree of Melting in the Elevated Warm Layer: Modeling studies evaluated the amount of melting that occurs based upon the strength or maximum temperature in the elevated warm layer. The results of this study were as follows:

- If the maximum temperature in the warm layer exceeds 3 or 4 degrees Celsius, snowflakes tend to melt completely to liquid. This results in rain or freezing rain, depending upon the surface temperature.
- If the maximum temperature in the warm layer is less than 1 degree Celsius, only partial melting occurs, followed by complete refreezing in the cold layer. The result is snow.
- If the warm layer maximum temperature is between 1 and 3 degrees Celsius, a mixture of partially melted and completely melted snowflakes occurs. This results in ice pellets, or more commonly a mixture of snow, rain, (or

freezing rain) and ice pellets.

The diagrams in Figure B-1 illustrate the difference in the strength of the elevated warm layer.

Depth of the Elevated Warm Layer: The amount of melting in the warm layer is also a function of the depth of the warm layer. In a qualitative sense, the deeper the warm layer, the more time available to melt snow to rain. Similarly, the thinner the warm layer, the less time available to melt snow to rain. Specific numbers are not available to quantify this factor.

Cross-Sections: Freezing rain and ice pellet events usually occur when warm humid air overrides cold surface air. This situation is common with a stationary front. North winds pump cold air into the low levels while warm south wind lift along the frontal surface and produce the elevated warm layer. The cross-section in Figure B-2 is taken perpendicular to such a front with the cold air on the left and the warm air on the right.

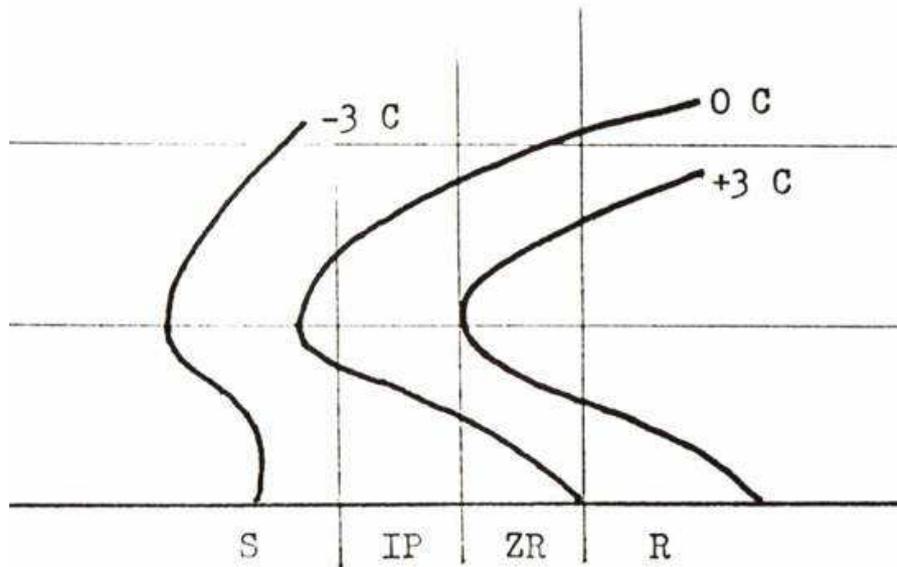


Figure B-2: Cross-Section for a Freezing Rain and Ice Pellet Event

Highlighted on the figure above are the +3, 0 and -3 degree Celsius isotherms. The tongue of elevated warm air is obvious.

- Above the area where the temperature is colder than +1 degree Celsius, snow is the likely precipitation type.

- Above the area where the temperature is warmer than 0 degrees Celsius, rain is the likely precipitation type.
- Above the area where the surface temperature is below 0 degrees Celsius and the elevated warm layer is +3 degree Celsius or warmer, freezing rain is the likely precipitation type.
- Above the area where the surface temperature is below 0 degree Celsius and the elevated warm layer is between +1 and +3 degree Celsius, ice pellets or sleet is the likely precipitation type.

This cross-section shows the typical sequence of precipitation type as you move from the warm to cold side of the system. Precipitation starts as rain on the warm side. The rain becomes freezing rain as the surface temperature drops below 32 degrees Fahrenheit. As you move farther into the cold air, the precipitation turns to sleet and finally to snow.

From an operational forecast perspective, the thermal structure above a location will likely change over time. As a result your best forecast may be something like: "a mixture of freezing rain and sleet." What is important is that you recognize that freezing precipitation will occur and include it in your forecast. Timing of individual precipitation types may be difficult, particularly if you forecast covers a broad area.

Freezing Drizzle

Approximately 30 percent of all freezing precipitation events do not have an elevated warm layer. The majority of these cases are freezing drizzle situations. A review of ice particle formation shows that a cloudy parcel of air with a temperature between -10 and 0 degrees Celsius, with no ice crystals present, and no large droplets, is *unlikely* to form ice. Instead, small supercooled liquid droplets tend to form, that is, drizzle.

One study found that soundings associated with freezing drizzle were characterized by:

- The sounding's temperature curve is entirely below 0 degrees Celsius.
- The temperature in the saturated surface-based layer is between -10 and 0 degrees Celsius.
- There are no clouds above low level cloud layer.

It is important that there are no higher cloud layers above the surface layer. If there is a higher cloud layer, ice crystals can drop into the lower layer. These crystals act as freezing nuclei and produce snow instead of freezing drizzle. An example of this type of sounding is shown in Figure B-3.

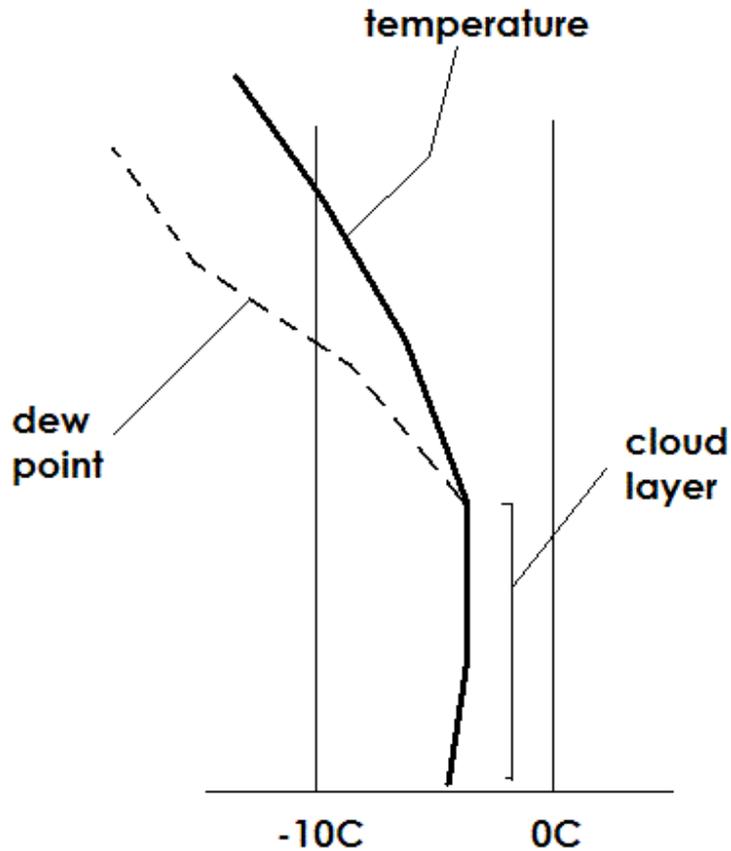


Figure B-3: A Typical Freezing Drizzle Sounding
(adapted from Huffman and Norman, 1988)

Thickness and Precipitation Type

The hypsometric equation tells us that the thickness of a layer bounded by two pressure surfaces is proportional to the mean temperature of that layer. This theoretical result has been used over the years to derive an empirical relationship between the thickness of various pressure layers and the occurrence of rain, snow, and freezing precipitation.

The sections that follow summarize four specific studies that relate precipitation type to thickness. Although not a perfect discriminator between rain-snow, thickness is a very useful method for locating the rain-snow line. These empirical relationships are based on statistical correlations among observed data and can be applied to model output to determine future locations of the rain-snow line.

First Approximation to the Rain-Snow Line: A first approximation to the location of the rain-snow line can be made using temperature data at the 850 mb and 700 mb levels. The table below lists this approximation:

Pressure Level	Discriminator	Precipitation Type
850 mb	<0°C	Snow
	>0°C	Rain
700 mb	<-6°C	Snow
	>-6°C	Rain

This method does not involve thickness but gives a good first guess to the location the rain-snow line. Its major shortcoming is that it looks only a data from one level and does not consider the vertical temperature distribution which is important to determining precipitation type. Experience with the 850 mb discriminator has been very good.

Hanks' Rain-Snow Relationship: During the 1960s Howard Hanks developed a rain-snow relationship based upon the 1000-700 mb thickness. He found that the 2840 m thickness line effectively separated liquid precipitation from snow associated with a surface air temperature of 32°F or below 85 percent of the time.

He also found that these discriminator values varied with elevation. Specifically:

Elevation	Discriminator
<1000 ft	2840 m
2000 ft	2850 m
3000 ft	2860 m

Essentially, as the elevation increase, the critical thickness value for rain versus snow also increases.

General Relationships: The table below lists the rain-snow relationships for several layers, including those determined by Hanks. In applying these values to your forecast, remember that

if thickness values are less than the number in the "mainly snow" column, snow is the likely precipitation type. If thickness values are greater than the number in the "mainly rain" column, rain is the likely precipitation type. For the most likely location of the rain-snow line, use the values in the "50 percent" column.

Pressure Layer	Mainly Snow	50 percent	Mainly Rain
850-500 mb		4050 m	
850-700 mb	1520 m	1540 m	1555 m
1000-500 mb	5360 m	5400 m	5490 m
1000-700 mb	2800 m	2840 m	2870 m
1000-850 mb		1300 m	1325 m

As mentioned in the Hanks discussion above, there is some variation of these values with elevation. For example, across Kansas, the 1000-500 mb 5400 m thickness value works well over eastern Kansas while a thickness value of 5460 m is better over northwest Kansas (3000-4000 ft elevation). If you are forecasting for a specific area, there are likely local forecasting rules that tell you what works best in your area.

Freezing Rain-Sleet-Snow Relationships: Freezing rain and sleet (ice pellets) require the presence of a warmer than freezing layer above the colder than freezing layer near the earth's surface. Thickness can be used to approximate this warm-over-cold requirement. Specifically, you can represent the warm layer with the 850-700 mb thickness and the cold layer with the 1000-850 mb thickness. The table below shows the relative values that can be used to forecast freezing precipitation.

Layer	Thickness Values			
850-700 mb	< 1540 m	1540-1555 m	> 1555 m	> 1555 m
1000-850 mb	< 1300 m	< 1300 m	< 1300 m	> 1300 m
Sfc Temp		< 32°F	< 32°F	
Precip Type	snow	frzg precip	frzg precip	rain

This method does not distinguish between freezing rain and sleet, but combines them into a generic term, freezing precipitation. When using this table, combine the values of the 850-700 mb thickness, the 1000-850 mb thickness, and the surface temperature to determine the type of precipitation.

An Example: The plot in Figure B-4 shows several thickness values for each radiosonde station. The upper left value is for the 850-700 mb layer; the lower left values is for the 1000-850

mb layer; and the upper right value is for the 1000-700 mb layer. Thickness contours for the 1520 m, 1540 m and 1555 m for the 850-700 mb layer (solid lines) and 1300 m for the 1000-850 mb layer (dashed line) are drawn on the chart. This chart can be used to apply the technique outlined in the last section.

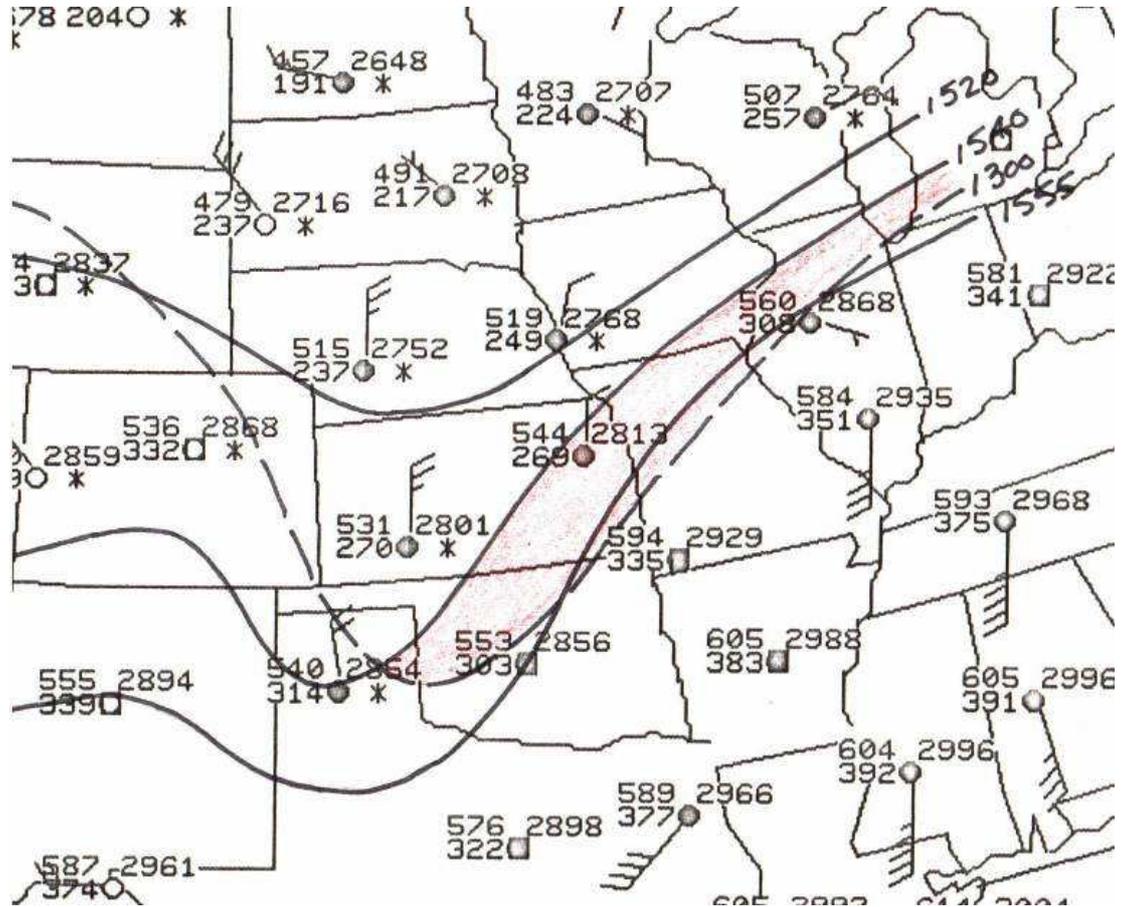


Figure B-4: Thickness Values

Looking at the chart, you can see an area from western Oklahoma, through southeastern Kansas, across northern Missouri, into northern Illinois where the 1000-850 mb thickness is less than 1300 m and the 850-700 mb thickness is greater than 1540 m. This is a prime area for freezing precipitation according to the above technique.

The corresponding surface observations are shown in Figure B-5. You can see a relatively narrow band of freezing rain and sleet (ice pellets) along the same line as the area outlined in the thickness chart.

forecast process. The basics for freezing rain and ice pellets have been presented here. Use this information wisely and you should have a good handle on the short-term changes in these types of situations.

Thickness values have been used for decades for determining precipitation type and are a very effective approach to this winter forecast challenge. The 1000-500 mb thickness was readily available in the past and has been a main focus of thickness application. With the availability of gridded data sets in today's operational environment, you now have the ability to look at any or all of the layer thicknesses listed above.

One last thing to remember: you need moisture and lift to produce precipitation. Thickness values just provide a clue to the precipitation type, not the occurrence of the precipitation.

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