WESTERN REGION TECHNICAL ATTACHMENT
NO. 99-12
JUNE 22, 1999

THE IMPORTANCE OF MICROPHYSICS IN SNOWFALL: A PRACTICAL EXAMPLE

Michael Staudenmaier, Jr. - NWSO Flagstaff, AZ

[Editor's Note: The following Technical Attachment (TA) is NWSO Flagstaff's Training Module No. 2 from May 1999.]

Overview

This module is designed to improve snowfall amount forecasting by evaluating the impact of certain microphysical processes which are involved in the production of snow. Examination of three easily diagnosed parameters will be discussed, along with an example to show the potential use of microphysics in the operational environment.

1. Objectives

Upon successful completion of this module, the reader will be able to:

a. Discuss the three types of snow crystal growth which occurs in clouds.

b. Discuss the temperatures which are important to these types of snow crystal growth.

c. Understand the importance of the melting layer in forecasting snow vs. rain.

d. Easily apply some basic principles of microphysics in the day-to-day forecast process during the winter season.

2. Introduction

Snow amount forecasting is by far the forecast problem that receives the most attention across northern Arizona, along with much of the United States during the winter months. Needless to say, it is also one of the most difficult tasks faced by forecasters during this period. All forecasters know that snow amount forecasting is accomplished by solving the equation:

Snow intensity X Snowfall duration = Snow amount

When both terms on the left-hand side of the equation are fully understood, the process of determining potential snowfall amounts becomes trivial. However, even though models give us good hints regarding both terms, they do not give us the complete answer, and therein lies the job of the operational forecaster; to go beyond model guidance and further define these terms.

This goal of this module is to aid the forecaster in further defining the first term: Snow intensity. By creating additional tools to aid in forecasting this term, forecasters will be able to more accurately forecast snow amounts, which in the end will help out a variety of our public who make their daily decisions based on snow amount forecasts. Snow forecasts are our 'severe weather' across much of the Western Region in the winter, and this is what the public uses to assess our performance.

Much of this module will discuss the role of microphysics in the intensity of snowfall, based on snow crystal growth. By understanding those processes which lead to maximized growth of snowflakes, we can better define the first term in the equation. The importance of melting layers will then be discussed, along with the role they play in determining snow versus rain forecasts. The remainder of the module will be used to verify a series of storms, which affected northern Arizona from 1-4 April 1999, using the microphysical parameters discussed.

3. Microphysics of Snow

The microphysics of snow plays an important role in the amount of snowfall which is possible under a particular synoptic environment. More emphasis needs to be placed on easily diagnosed microphysical processes, to differentiate those soundings where large growth of snowflakes is maximized. Classic winter precipitation events start with ice crystals forming by heterogeneous nucleation and growth through deposition. These ice crystals then may continue to grow into snowflakes by aggregation and riming. These processes will be discussed below.

a. Heterogeneous Nucleation:

Although most water that we see around us does not supercool appreciably, cloud droplets commonly exist in the supercooled liquid state down to temperatures as low as -20^{0}C and on occasion, down to -35^{0}C, while droplets of very pure water, only a few microns in diameter, may be supercooled down to -40^{0}C in the laboratory (Mason, 1962). Spontaneous freezing occurs at -40^{0}C, but at higher temperatures, they can freeze if they are infected with foreign particles. Outside the laboratory, the freezing of liquid droplets is strongly dependent on a process known as heterogeneous nucleation. Heterogeneous nucleation of ice occurs in a supersaturated atmosphere when water molecules collect and freeze onto the surface of a foreign particle, such as dust and clay particles, or even a pre-existing ice crystal. For certain types of particles, heterogeneous nucleation of ice can occur at temperatures as warm as -5^{0}C, however it is more likely at temperatures less than -10^{0}C. Larger droplets tend to freeze fastest as they are more likely than smaller drops to have a freezing nuclei or ice embryo.

b. Growth by Deposition:

Snow crystal growth through deposition is the first process by which ice nuclei grow in size. The basic premise is that because of a gradient of saturation vapor pressures between ice nuclei and super-cooled water droplets, growth will occur as water from the water droplets is evaporated and then deposited on the ice nuclei. This process causes growth of ice nuclei at the expense of water droplets. This growth is maximized at -15^{0}C, where the saturation vapor pressure gradient between water and ice is greatest. Although this process plays an important role in allowing ice nuclei to grow in size, the second process, aggregation, is more important in creating large snowflakes.

c. Growth by Aggregation:

Snow crystal growth through aggregation is the second process which allows the larger crystals produced by deposition to continue to grow in size. The basic premise of this process is that different types of snow crystals are produced depending on the temperature of the atmosphere. Laboratory tests and observational studies have shown that the basic shape of ice crystals is highly dependent on the temperature in which it grows. Ice needles and columns tend to form at temperatures colder than -22^{0}C, where dendrites and plates form at warmer temperatures of -10^{0}C to -22^{0}C. Both types of snow crystals have significantly different terminal fall speeds, with columns and needles falling faster than dendrites and plates. This allows the columns and needles to fall into the area where dendrites and plates are residing, and through collision, aggregation of snow crystals occurs. This leads to larger and larger flakes as they continue to fall to the ground.

d. Growth by Riming:

Growth by riming occurs when ice crystals collide and collect liquid water drops which then freeze to the ice crystal. This process is most efficient when ice crystals fall into a saturated layer of supercooled water droplets, typically in clouds with temperatures of 0 to -10^{0}C. Minor riming may not result in much modification to the shape of ice crystals, but excessive riming can produce snow graupel and sleet. The riming process may play a role in orographic regions where warmer upslope cloud are seeded from above by ice crystals falling from higher clouds, including wave clouds, leading to higher precipitation rates than would commonly be expected from only upslope clouds (Staudenmaier, 1999).

The "stickiness" of snow crystals increases as temperatures warm above -10^{0}C in the sounding. Deep low-level isothermal layers near -3^{0}C to 0^{0}C leads to the largest flakes, due to the fact that "stickiness" is maximized at these temperatures.

e. Melting Layers:

Sometimes the sounding consists of a melting layer somewhere in the lower portion of the sounding. At this point, the question may be: Will the snow melt before it reaches the ground becoming rain, and/or will it refreeze close the ground and become sleet? The ultimate answer lies in the depth of the melting layer(s) and the surface conditions. Typically, the depth of warm air needed to melt snow as it falls is from about 750 feet to 1500 feet depending on the mass of flakes falling through this layer and the lapse rate (a measure of the strength of the melting layer). When lapse rates are small, the melting layer tends to be weak, and a deeper melting layer will be required to melt the snow. When lapse rates are large, the melting layer is strong, and snow will melt within a shallower melting layer. On average, the 50% probability where flakes will reach the ground is with a melting depth of around 920 feet AGL. If the depth is greater than this, the probability is less than 50% that snow will continue to exist as it reaches the surface, and if the depth is less than 920 feet, the chances are greater that snow will reach the surface. Remember to take into consideration any wet bulb effects that may occur, especially if that melting layer is also a dry layer.

Another aspect to the melting layer is the maximum temperature found in this layer. According to research done by Stewart and King (1986), if the maximum temperature in the melting layer is only around +1^{0}C, then snow is much more likely to reach the ground, no matter what the depth. If the maximum temperature lies between +1^{0}C and +4^{0}C, then sleet is most likely (depending on the size of the snowflakes), especially if temperatures cool below freezing at/very near the surface. For smaller size particles (melted drop size of less than 2 mm), freezing drizzle is more likely if the surface conditions are below freezing. If the maximum temperature in the melting layer is greater than +4^{0}C, then flakes with a melted drop size of 4 mm and less will melt completely as they pass though this layer, with the result of rain or freezing rain, depending on the surface conditions. If flakes are greater than 4 mm in size (melted), then a mix of precipitation can be expected. Both the depth of the melting layer and the maximum temperature should be used to try to decide if snow will become sleet or rain before reaching the ground.

4. The Storms of 1-4 April 1999: A Real Example

During the period of 1-4 April 1999, a series of storms moved across Arizona. These storms were significant, since not only did they produce over 32 inches of snowfall during that period, but also doubled the snowfall total for the season in only 4 days. Model guidance was adequate for this event, as all the snowfalls except the first one were well advertised and correlated well to the strongest periods of dynamics. However a strong relationship also existed between the heavy snowfall and when the microphysical contributions were strongest.

How can we incorporate the microphysical processes discussed above, in an easy to apply method in the operational office? The easiest method found was to examine the soundings, both current and forecasted, and examine whether the relative humidity was greater than 85% at -15^{0}C and at -22^{0}C. If the sounding was nearly saturated at -15^{0}C, then growth by deposition would be maximized, and if the sounding was also nearly saturated at -22^{0}C, then growth by aggregation was maximized due to many different types of ice crystals being formed. Examination of the depth of the melting layer and maximum temperature in this layer was also easily done by looking at the sounding information both current and forecasted. By examining only these few parameters, some of the microphysical mechanisms discussed above were easily accounted for.

Below is a table showing a few parameters used for the verification along with the amount of snowfall recorded during the period. -15C SAT and -22C SAT refer to near saturated conditions at those temperature levels in the Flagstaff sounding. If a column has a YES in it, then near saturated conditions existed at that temperature level. 700-500 LR refers to the lapse rate from 700-500 mb with higher numbers being more unstable. Snowfall was accumulated six hours either side of the sounding time, thus for 1APR/12Z, the snowfall from 06-18Z was accumulated for the snowfall total. Thus, it is assumed that the sounding was representative for the six hours either side of the time it was measured. There were no significant melting layers, so this information will not be included.

Date	-15C SAT	-22C SAT	700-500 LR	PRECIP H20	SNOWFALL
1APR/12Z	YES	YES	4.7C/KM	0.27"	9.6"
2APR/00Z	YES	NO	5.0C/KM	0.18"	1.0"
2APR/12Z	YES	YES	5.6C/KM	0.22"	6.2"
3APR/00Z	YES	YES	7.9C/KM	0.19"	1.1"*
3APR/12Z	YES	NO	7.4C/KM	0.17"	1.6"
4APR/00Z	YES	NO	5.0C/KM	0.23"	0.8"
4APR/12Z	YES	YES	7.4C/KM	0.20"	11.7"
5APR/00Z	YES	NO	6.4C/KM	0.17"	0.7"
5APR/12Z	NO	NO	3.5C/KM	0.22"	TRACE

As can be seen, on the days where we had saturated conditions through -22^{0}C, precipitation was heaviest. *The only exception to this is 3APR/00Z when the atmosphere stabilized rapidly after 00Z, so that the conditions were rapidly drying out at -22^{0}C soon after 00Z. Thus, this sounding wasn't representative of the conditions from 00Z-06Z. Additionally, it appears that when saturated conditions exist below -22^{0}C, along with high instability, snowfall was really maximized as seen during the 4APR/12Z period. However, the instability isn't the key parameter, as other time periods had just as high of instability, with little snowfall. The role of instability in these periods was mainly to continue light precipitation through the night and into the morning.

Precipitable water values showed little correlation with snowfall amounts, with little day-to-day changes. Moisture generally is NOT the limiting factor for snowfall across northern

Arizona. Dynamics and microphysics appear to be the key. If the dynamics are there, the moisture will come through lifting. Add the proper conditions for maximized microphysical processes and the potential for heavy snowfall is even greater.

5. Conclusions

The effects of microphysical processes on snowfall production have typically not had a place in the operational forecast office. However, these processes are important in understanding not only how snow actually occurs, but also, how much of it may occur. Numerical models tend to do a decent job with forecasting the snowfall duration portion of the equation, but still do not do a good job with the snowfall amount portion. Part of this reason may be due to the oversimplification of the operational numerical models which do not take into consideration most microphysical processes. As forecasters, we need to understand these physical processes more and then apply them in our forecasts. By understanding how ice crystals form from heterogeneous nucleation, then grow through deposition, aggregation, and riming to become large enough to fall to the ground, we then can determine those days where conditions are optimal for heavier snow. Then by examining melting layers more in depth, a more accurate forecast of precipitation type can be made.

The bottom line is to look for soundings which are nearly saturated through a deep portion of the atmosphere, consisting of saturated conditions from near 0^0C at the surface to colder than -22^0C, which typically is near or above 500 mb. The deeper the saturated near-freezing conditions near the surface, the larger the snowflakes will be due to "stickiness", and if the saturated conditions continue above the -22^0 degree isotherm, then different types of crystals will be produced allowing aggregation to occur throughout the lower atmosphere. Finally, examine the character of the melting layer (if any) to determine if rain, sleet, or freezing rain is more likely than snow.

Acknowledgments

Much of the information detailed in this training module was gathered from An Introduction to Winter Precipitation Nowcasting, a CD-ROM developed by the NWSTC.

References

Mason, B.J., 1962: *Clouds, rain and rainmaking.* Cambridge University Press. 145 pp.

Staudenmaier, M.J., 1999: Winter precipitation enhancements due to organized gravity wave action over northern Arizona. In-house.

Stewert, R.E., and P. King, 1986: Freezing precipitation in winter storms. *Mon. Wea. Rev.*, **115**, 1270-1279.

EVALUATION

1. Without reference to this training module, list the three different growth processes for snowflakes and describe what each of these mean, and what temperatures are important for each.

2. You come in to work for the morning shift in January, and examine the sounding from that morning. You notice that the sounding is nearly saturated from the surface to -20^{0}C. Moderate vertical motion is expected to last through the day from the surface to about 400 mb. Based on this information, would you expect the microphysics contribution to snowfall to be low, moderate, or high for the morning period? Does your answer change for the upcoming afternoon and evening? If so, why?

3. The sounding for 1200 UTC 12 March shows saturated conditions through much of the sounding up to -24^{0}C. However, near the surface the sounding warms to +3^{0}C in a layer 800 feet thick before cooling off to -2^{0}C near the surface. What form of precipitation would you expect during the morning and why?

4. The same sounding is forecast to warm through the day in the lower levels so that the melting layer warms to +4^{0}C in a layer 940 feet thick by afternoon with the surface temperatures expected to be near +2^{0}C. What form of precipitation would you expect during the afternoon and why?