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REVIEW OF TECHNIQUES TO AID THE FORECASTER IN DIFFERENTIATING AREAS OF FREEZING RAIN AND ICE PELLETS

Jeff Johnson - NWSFO Great Falls, MT

Introduction

Freezing rain can produce a variety of extremely hazardous conditions. Safety in the aviation community can be seriously compromised by even the smallest amount of freezing precipitation, not to mention the increased cost incurred by the airlines due to aircraft deicing and delayed or canceled flights. To the general public, ice on roadways can be a serious problem. Fallen trees and branches, as well as downed power and communications lines can be both dangerous and costly. Since frozen precipitation (ice pellets and snow) does not coat surfaces with a glaze of ice in most cases, it is not considered quite as dangerous. Therefore, accurately forecasting freezing precipitation can help to minimize many safety hazards, and the costs they can incur.

Freezing rain or ice pellet formation requires an elevated layer of above freezing temperatures situated above a layer of subfreezing temperatures adjacent to the surface. The extent to which ice particles melt in this warmer layer of air determines whether the precipitation falls as ice pellets, or reaches the ground as supercooled rain that freezes on contact with the colder surface. If an ice particle only partially melts in the warm layer, then the presence of an ice nuclei would promote refreezing in the cold layer, allowing the particle to reach the surface as an ice pellet. However, if the ice particle completely melts before re-entering the subfreezing air, it will usually reach the ground as a supercooled liquid and freeze on contact. Therefore, the critical factor in distinguishing between freezing rain and ice pellets is whether the ice particle will completely melt in the elevated warm layer.

This Technical Attachment (TA) presents methods that have been researched and tested, in an effort to aid the forecaster in determining whether precipitation will fall as freezing rain or ice pellets. Also presented is information on the Model Output Statistics (MOS) guidance developed from the Nested Grid Model (NGM) output, and some observations made by the Techniques Development Laboratory (TDL) to help the forecaster interpret the predictions produced by MOS.

Techniques

A. Use of a non-dimensional parameter - Czys et al.

A non-dimensional parameter, τ, was developed to aid the forecaster in distinguishing between areas of freezing rain and ice pellets (Czys et al. 1996). It is defined as the ratio of the time available for melting to the time required for complete melting.

$$\tau \equiv \frac{\text{time available for melting}}{\text{time required for complete melting}}$$

The ratio assumes the particle radius to be the largest of all particles present. An isonomogram (see Fig. 1) was developed to allow this parameter to be easily used by the forecaster. If $\tau \geq 1$, then the conditions are favorable for complete melting of the largest and all smaller particles, which would infer freezing rain. If $\tau < 1$, then the largest particle would not completely melt in the warm layer, suggesting ice pellets. For $\tau < 1$, the extent to which ice pellets reach the surface is dependent on the concentration of particles smaller than the largest particle used in the ratio, and the assumption the smaller particles will not coalesce or evaporate before reaching the surface.

In order to determine the critical radius of the particle for use in the ratio, a procedure was followed that used reflectivity data from the radar summary produced by the National Weather Service (NWS), along with previously established relationships between characteristics of particle size distribution and reflectivity. A critical radius value of 400 µm proved to apply well in a sample of 17 cases of freezing rain and ice pellet episodes examined. However, one can see from Fig. 1 that other critical radius sizes may be used if the forecaster determines them to be more representative.

Once the forecaster has determined the melting layer depth and its corresponding mean layer temperature, he or she may then refer to the isonomogram. A value falling above the critical radius curve would indicate freezing rain, while a value below the critical radius curve would indicate ice pellets. One word of caution in using this parameter is that it will fail to identify freezing drizzle in instances where the entire sounding is below freezing.

In an effort to validate this method in a forecasting environment, it was tested using data from the Valentine's Day ice storm of 1990 which affected much of the Midwest, and on data from several other freezing rain and ice pellet episodes during the winter of 1995-96 throughout the Midwest. Results from the Valentine's Day ice storm showed remarkable spatial agreement between both diagnosed and observed areas of freezing rain and ice pellets (see Figs. 2 and 3).

B. The 'energy method' - Bourgouin

A method developed by Pierre Bourgouin (1992, 1999), known as the 'energy method', is based on the negative energy (NE) and positive energy (PE) areas calculated from the sounding. In this regard, NE is defined as that area of the sounding where the temperature is less than 0°C, and the PE is defined as that area of the sounding where the temperature exceeds 0°C, with the units of joules per kilogram (J/kg) (see Fig. 4).

Data from 56 cases were used to distinguish between freezing rain and ice pellet episodes. This data was taken mainly from the 1989-1990 and 1990-1991 cold seasons over North America. The parameters measured were positive energy, negative energy, ratio of positive energy to negative energy, mean 1000-850mb and 1000-700mb temperatures, surface temperature, and surface dew point.

Figure 5 shows the negative energy as a function of positive energy. In order to come up with a relationship that can distinguish between precipitation types, an equation was developed using the least-squares method that plots a straight line through the transition zone. A result that falls above the line would infer ice pellets, while a result below the line would infer freezing rain.

The equation developed was:

$$NE = 56 + (0.66 \times PE)$$

A transition zone, where either type of precipitation is equally probable, was defined by adding ± 10 J/kg as follows:

$$NE > 66 + (0.66 \times PE) \quad \Rightarrow \quad \text{ice pellets}$$

$$NE < 46 + (0.66 \times PE) \quad \Rightarrow \quad \text{freezing rain}$$

In order for these equations to be used, both the negative energy and positive energy areas must be determined. Each area can easily be obtained by using the following equation (Iribarne and Godson, 1981):

$$|\mathrm{Area}| = c_p \overline{T} \oint d \ln \theta = c_p \overline{T} \ln\left(\frac{\theta_t}{\theta_b}\right)$$

where,

c_p	Specific heat capacity at constant pressure.
T	Absolute temperature.
θ	Potential temperature.
θ_t	Potential temperature at the top of the layer.
θ_b	Potential temperature at the bottom of the layer.
$\overline{T}$	Average temperature in the layer extending from θ_t to θ_b.

Bourgouin's energy method showed very little bias in verification. Using the developmental data, it was able to accurately predict precipitation type 81% of the time. Using an independent sample of 27 cases from the 1991-1992 cold season, Bourgouin's method accurately predicted precipitation type 83% of the time. Bourgouin's method has been used operationally at the Canadian Meteorological Centre (CMC) since 1994.

C. Additional observations - Zerr

The relationship of characteristics of the melting layer to the refreezing layer led to some important observations pertaining to precipitation type (see Zerr 1997). Zerr developed two theoretical models, one to simulate the melting characteristics of a dendritic snowflake, and the other to simulate the refreezing characteristics. After studying the findings from 34 freezing rain and ice pellet events using mostly NWS soundings, Zerr concluded that the reported precipitation type at the surface was more dependent on the melting characteristics in the temperature profile than to the refreezing characteristics. Through his findings, Zerr supported using the methods described by Czys et al. in determining precipitation type.

Use of NGM-based MOS guidance

In 1992, TDL included precipitation type prediction equations in the MOS (see Fig. 6), utilizing data from the NGM output. These equations were designed to predict the type of precipitation that reaches the surface, as well as probability forecasts of precipitation type which are conditional on precipitation actually occurring. These precipitation type forecasts are available from September 16 to May 15.

The precipitation type is divided into three categories. The 'freezing' category includes pure and mixed freezing rain, freezing drizzle, and ice pellets episodes, and is denoted with a 'Z' under 'PTYPE' on the MOS product. The 'snow' category includes only pure snow, and is denoted with an 'S'. The liquid category includes only pure rain or drizzle, or a mixture of rain or drizzle with snow, and is denoted with an 'R'. Unfortunately, there is no category that differentiates between freezing rain or freezing drizzle and ice pellets. However, TDL has established some guidelines based on other forecast categories from the MOS to assist the forecaster in this regard. This will be discussed later in this section.

Several parameters are used in the equation process, including NGM forecasts, station geographic or climatic variables, and surface observations.

Not all stations are included in the operational forecasts of precipitation type, since there are areas of the country that experience freezing rain, sleet, and snow only on rare occasions. This applies to stations in the southern half of Florida, as well as much of California. In addition, the freezing precipitation equations and probabilities are not generated for several stations in Alaska.

As with any model guidance, the MOS does contain some deficiencies, and since the MOS is based on the NGM, any deficiencies from the NGM output will likely be carried over to the MOS product. In their evaluations of the MOS precipitation type forecasts, TDL noticed that the guidance does a poor job in the presence of a very shallow cold air mass and/or a surface below freezing. When these conditions are present, the NGM vertical temperature profiles should be checked. Another thing to keep in mind is that due to the spatial resolution of the NGM, the MOS output is of synoptic scale, and likely unable to resolve mesoscale features well.

As previously stated, there are no equations designed to differentiate between freezing rain or freezing drizzle and ice pellets. Since ice pellets are considered a rare event, TDL did not have enough data to treat ice pellets as a separate category. However, TDL was able to make several observations about precipitation type based on other forecasted parameters in the MOS, using verification statistics of the operational forecasts for a portion of the 1992-1993 cold season, and the entire 1993-1994 cold season. One observation made was that if the MOS predicted temperatures were above the mid to upper 30s, a precipitation type 'Z' probably indicated freezing rain. If temperatures were predicted to be near freezing, precipitation type 'Z' probably indicated ice pellets or a mixed precipitation event. When the temperatures, dew points, amount of snow, and precipitation types are consistent, a forecaster can have more confidence in the guidance.

Applications in the Forecasting Environment

Two techniques, along with observations about the NGM-based MOS guidance (discussed in the previous section), have been explained in this TA in an effort to aid the forecaster in determining between episodes of freezing rain and ice pellets. One technique involves using an isonomogram developed by Czys et al. Once the forecaster has determined the melting layer depth and mean layer temperature, he or she can easily refer to this diagram to determine whether freezing rain or ice pellets are likely.

The second technique involves calculating the negative energy and positive energy areas from the sounding, where in this regard NE is defined as that area of the sounding where the temperature is less than 0°C, and the PE is defined as that area of the sounding where the temperature exceeds 0°C. Once these areas have been computed, the equations developed by Bourgouin can aid the forecaster in determining precipitation type. Currently, Bourgouin's method is used in the precipitation type forecast maps available on the Canadian Meteorological Centre website. In addition, BUFKIT, which was developed at the NWS Forecast Office in Buffalo, fully implements Bourgouin's precipitation type analysis. Information about BUFKIT, including how to download the software, is available from NWS Forecast Office Buffalo website.

With the addition of AWIPS to the forecasting environment, the Bourgouin method could be implemented using existing and forecast model soundings. Also, the parameters necessary to use the isonomogram developed by Czys et al. could be automated. Because these techniques have shown accuracy in differentiating between areas of freezing rain and ice pellets, it is the author's suggestion that these data be made available on AWIPS.

Conclusion

Freezing rain poses a variety of safety and economic concerns. It has been established that for freezing rain or ice pellets to occur, a layer of above freezing air must overlay a layer of subfreezing air that lies adjacent to the surface. If a hydrometeor completely melts in the above freezing air, it will usually fall to the surface as liquid in the absence of an ice nuclei. However, if the particle does not completely melt in the warm layer, the presence of an ice nuclei will promote refreezing.

Being able to differentiate between areas of freezing rain and ice pellets can be a difficult task for the forecaster. Using the proven techniques discussed in this TA, in addition to other established methods, can greatly aid in producing the best possible forecast.

Acknowledgments

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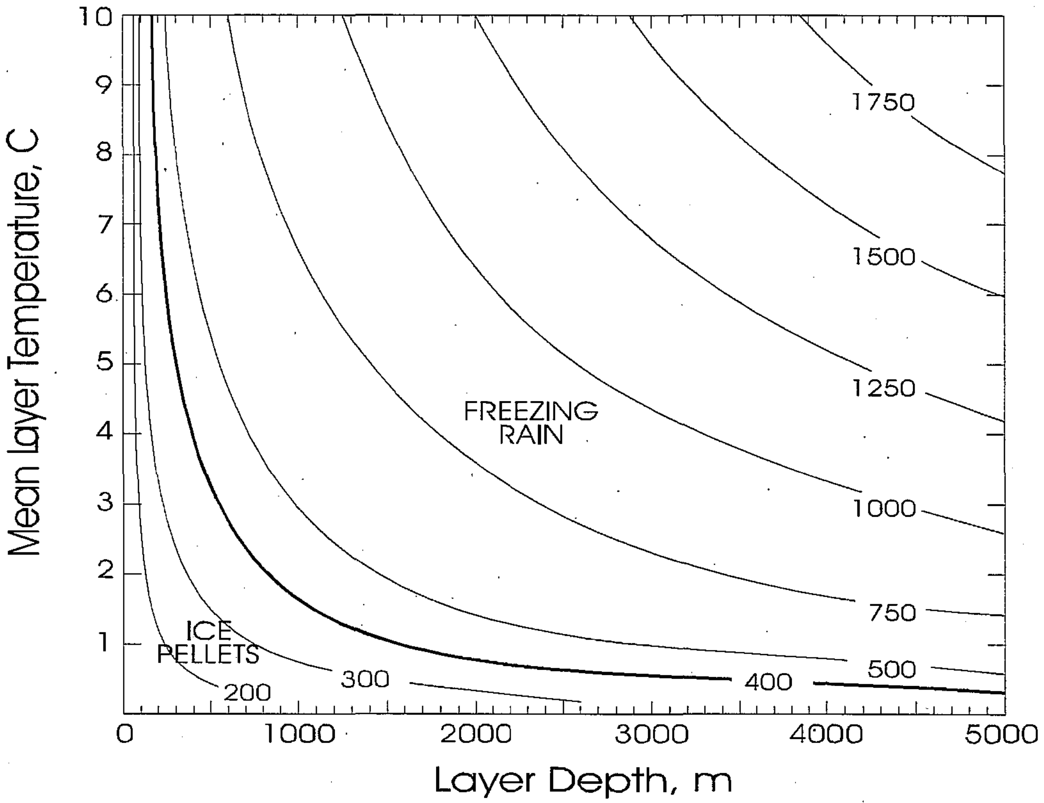

Figure 1. Isonomogram of $\tau=1$ for different critical radii of ice particles, calculated over a range of warm layer depths and mean warm layer temperatures.

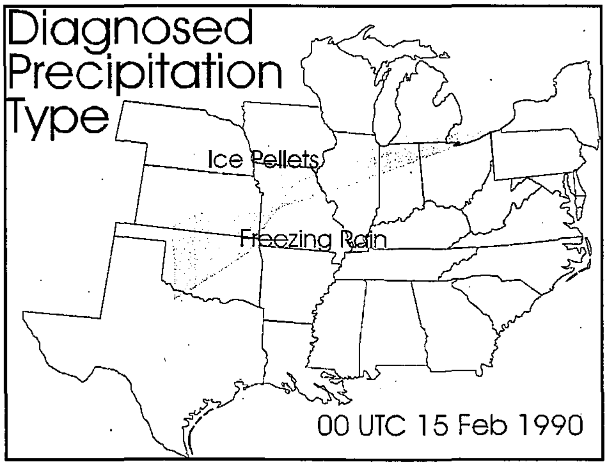

Figure 2. Areas of ice pellets and freezing rain as diagnosed using the distribution of τ shown in Fig. 1.

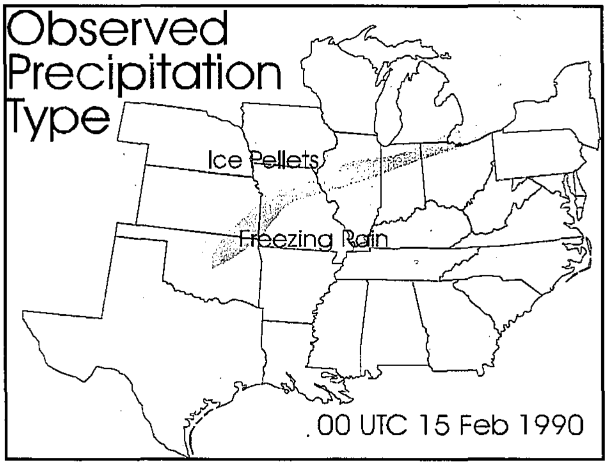

Figure 3. Observed areas of ice pellets and freezing rain.

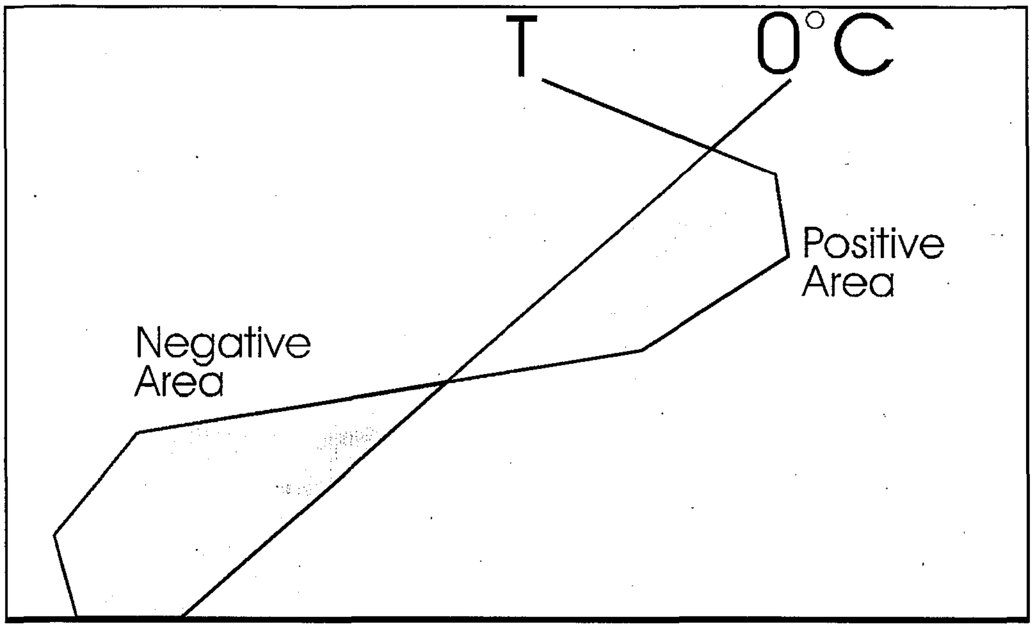

Figure 4. Typical vertical temperature profile for freezing rain and/or ice pellet events.

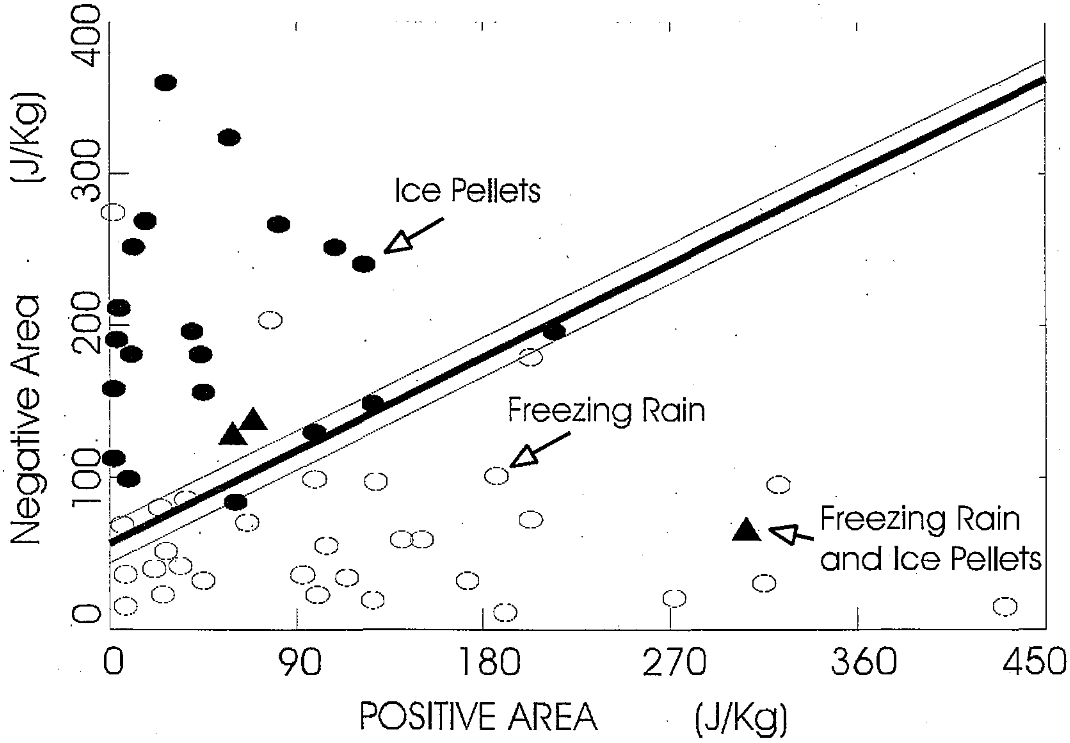

Figure 5. Negative energy as a function of positive energy. Plotted are the data points used from the dependent sample.

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GTF   CW   NGM MOS GUIDANCE  12/16/98  0000 UTC
DAY /DEC 16              /DEC 17                 /DEC 18
HOUR   06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12
MX/MN                    47          33          44          32
TEMP   36 34 31 35 41 46 43 40 37 35 34 38 42 42 37 35 34 35 35
DEWPT  34 31 29 31 32 33 33 32 30 29 28 29 29 29 29 28 28 28 29
CLDS   CL CL CL SC SC OV BK OV OV BK OV BK SC SC SC SC SC BK OV
WDIR   22 22 21 21 22 22 24 25 28 29 29 30 29 24 20 21 21 21 00
WSPD   09 09 06 08 10 11 08 08 07 07 05 06 06 05 01 02 02 03 00
POP06         0     1     5     5     6     4     0     8    14
POP12                     5          11           3          16
QPF         0/    0/    0/0   0/    0/0   0/    0/0   0/    0/0
TSV06      0/ 3  0/ 2  4/ 6  2/ 2  0/ 4  0/ 0  0/ 7  0/ 5  0/ 2
TSV12            0/ 4        5/ 7        0/ 3        0/ 9   / 2
PTYPE   R  Z  Z  R  R  R  R  R  R  S  S     R     R     S     S
POZP   15 22 31  6  0  0  0  0  7  6 14     5     4     6     8
SNOW        0/    0/    0/0   0/    0/0   0/    0/0   0/    0/0
CIG     7  7  7  7  7  7  6  7  4  6  7     7     7     7     7
VIS     5  5  5  5  5  5  5  5  5  5  5     5     5     5     5
OBVIS   N  N  N  N  N  N  N  N  N  N  N     N     N     N     N
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Figure 6. Sample NGM-based MOS guidance. Shaded are the precipitation type forecasts.