5.2

# USING LOW-LEVEL PRECIPITABLE HYDROMETEOR MIXING RATIOS FROM THE MM5 TO DETERMINE PRECIPITATION TYPE: OHIO VALLEY CASES FROM THE 2002-2003 WINTER

CHRIS SMALLCOMB AND TONY STUREY
*National Weather Service, Weather Forecast Office*
*Louisville, Kentucky*

## 1. INTRODUCTION

Arguably, cold season precipitation type forecasting is one of the greatest challenges facing meteorologists in the Ohio River Valley region. Common winter storm tracks along or west of the Mississippi River often produce a variety of winter elements further east, depending on the initial extent of southward cold air penetration and subsequent amount of overrunning warm air return. Cyclones tracking farther east through the Ohio Valley have a tendency for secondary redevelopment along the eastern seaboard. This secondary redevelopment can lead to the disruption of both cold and warm air mechanics and a resultant precipitation type change. Societal impacts from significant winter weather can range from public inconvenience to loss of property and life, affecting a wider area than warm season severe local storms.

In order to provide customers with accurate winter weather forecasts, techniques have been employed for predicting cold season precipitation type, including layered thickness evaluations and examination of hourly model soundings via BUFKIT. Recently, algorithms have been developed to take advantage of real-time 3-D numerical model output. Bourgouin (2000) determines precipitation type by computing the magnitude of the melting and freezing energies in the environment, while Baldwin et al. (1994) diagnoses surface precipitation type employing a decision tree type methodology based on the analysis of the thermodynamic vertical profile. Both of these techniques have achieved wide acceptance and usage within the operational community.

In this study, we explore a locally and independently developed methodology for precipitation type determination using real-time 3-D NWP output. This approach centers around examining low-level precipitable hydrometeor mixing ratios derived directly from an operational version of the NCAR/PSU MM5 (Grell et al. 1994) run at NWS Louisville, KY (herein referred to as the LMK-MM5). The methodology is similar to that used in the RUC-2 precipitation type derivations (Brown et. al. 1998 and FSL RUC/MAPS diagnosed variables website http://ruc.fsl.noaa.gov), a fact that was discovered late in this papers preparation, however the emphasis here is on the operational application of directly viewing the low level mixing ratio distributions. Several cases from the 2002-2003 boreal winter season are used to show the viability of this technique for operational precipitation type forecasting.

*Contact Information:*
National Weather Service
6201 Theiler Lane, Louisville, KY 40229
502.969.8842 (http://www.crh.noaa.gov/lmk)
chris.smallcomb@noaa.gov

## 2. SCHEME DESCRIPTION

With certain moisture schemes, the LMK-MM5 outputs mixing ratios of the precipitable hydrometeors rain and snow. These are direct output from the microphysical parameterization, which takes into account all model thermo-dynamic processes, as the parameterizations interact directly and indirectly with the larger scale computations and other parameterizations. Examining the mixing ratios of snow and rain at a near-surface level, along with ground or surface temperatures, allows our forecasters to assess the surface precipitation type within the model forecast by viewing a single chart for a specified forecast time. This experimental chart is the focus of the paper.

The near-surface level used in the operational charts is the 0.995 sigma surface, basically about 40 meters above the ground. The amount of variability of the hydrometeor distribution between that level and the actual surface is assumed to be negligible.

Surface precipitation types determinable by this method are (and the associated requirements at a given grid-point):

- Rain: $q_{ra} > 0$, $q_{sn} = 0$, and $T_{grnd} \geq 0°C$
- Freezing rain: $q_{ra} > 0$, $q_{sn} = 0$, and $T_{grnd} < 0°C$
- Rain/snow mix: $q_{ra} > 0$, $q_{sn} > 0$, and $T_{grnd} \geq 0°C$
- Snow: $q_{ra} = 0$, $q_{sn} > 0$, and $T_{grnd} < 0°C$ ($T_{grnd}$ could be > 0°C but ground accumulations would likely be limited or non-existent)

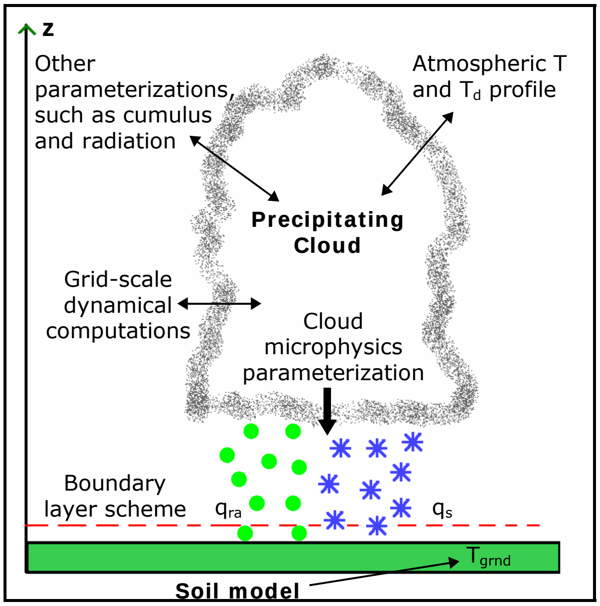


**Figure 1.** *Schematic diagram as described in text.*

where $q_{ra}$ is the mixing ratio of rain (g kg$^{-1}$), $q_{sn}$ the mixing ratio of snow (g kg$^{-1}$), and $T_{grnd}$ the temperature (°C) within the top layer of soil.

The ultimate strength of this method is that it takes into account all processes that are occurring in the model to determine a surface precipitation type (Fig. 1). Microphysical processes occurring within a given cloud interact directly and indirectly with other model parameterizations, the grid-scale dynamical computations, and the thermodynamic environment in the vicinity. Precipitable hydrometeors, namely rain ($q_{ra}$) and snow ($q_{sn}$), are produced then from the microphysics scheme and fall towards the ground. Hydrometeor distributions may be altered by the sub-cloud thermal profile and any interactions with the model's boundary layer parameterization. The precipitable hydrometeors then collide with the surface of the model, where the top-layer soil temperatures ($T_{grnd}$) are driven by a soil model. Therefore, an examination of simply the hydrometeor distributions at a near-surface level along with the ground temperature, would allow a forecaster to assess the surface precipitation type in a physically sound fashion.

In its present form, due to the absence of sleet (graupel) particle mixing ratio output, this technique lacks the ability to assist forecasters directly in predicting sleet or ice pellets. However, it should be noted that from observations during significant events, sleet tends to be located where the rain/snow mixing ratios are overlapped.

The precipitation intensity is logically correlated to the hydrometeor mixing ratio values; heavy snow bursts likely would be associated with snow crystal mixing ratio bull's eyes.

The real-time operational version of the LMK-MM5 integrates a twice daily 36 hour forecast covering the Ohio and Tennessee River Valley region of the eastern U.S. (Fig. 2). Inputs include a 3-D initial condition from the RUC with boundary conditions supplied every 3 hours from the Eta (resolution of approximately 40 km). The horizontal resolution is 10km with 23 half-sigma vertical levels. The Grell cumulus scheme (Grell et al. 1994), MRF/Hong-Pan PBL (Hong and Pan 1996), Shultz microphysics (Schultz 1995), "simple cooling" radiation, and the "five layer"

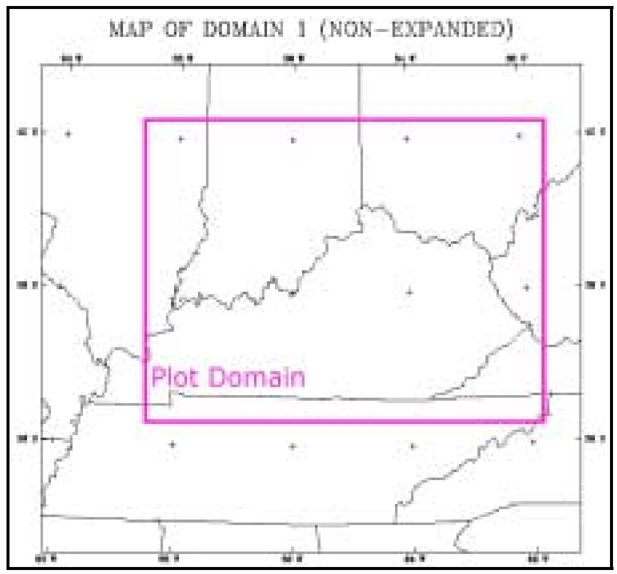


**Figure 2.** *The LMK-MM5 grid domain (outer rectangle) and precipitation type plot boundary (inner rectangle).*

soil model are the options used that are most relevant to this paper. Experiments showed that this specific combination of options, particularly the moisture (microphysics) scheme, exhibited the best boundary layer precipitable hydrometeor output consistent with the vertical thermal profile. As the model integrates, forecasters access the experimental precipitation type charts via an internal office webpage.

## 3. CASES FROM 2002-2003 WINTER SEASON

### 3.1 *04 December 2002*

The first significant winter storm of the 2002-2003 cold season impacted the Lower Ohio

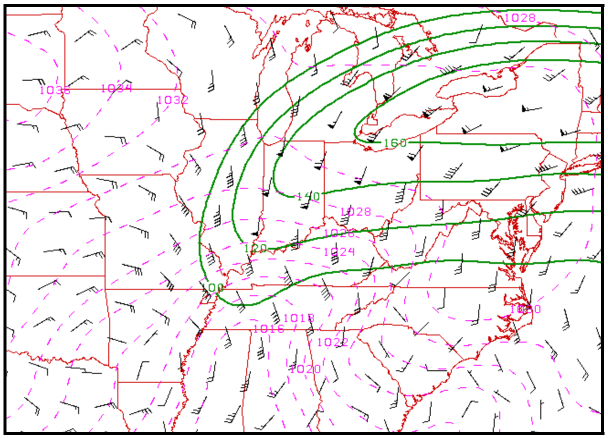


**Figure 3.** *00 UTC 05 December 2002. 250 hPa isotachs (kts) in green, 250 hPa ageostrophic wind component barbs (kts), and MSLP (hPa) in dashed pink.*

Valley on Wednesday, 04 December. Operational model guidance handled this weather system rather well, and the confidence level was high that a significant winter weather event would occur. Therefore, winter storm watches were issued more than 24 hours in advance. The favorable "lead time," coupled with an accurate precipitation type forecast, helped minimize serious societal impacts; transportation departments were well prepared and schools closed early ahead of the storm.

Upper tropospheric jet streak dynamics were critical for driving ascent within this heavy snow case. Ahead of an eastward moving 250 hPa trough, a robust anticyclonically-curved jet entrance region presided over the region, with the associated ageostrophic divergence collocated with broad deep-layer upward vertical motions (Fig. 3). Precipitation onset was limited by an antecedent dry mid and lower tropo-sphere. As saturation occurred, areas near the Ohio River within the cold air experienced moderate to heavy snows. The track of the surface low prompted boundary layer winds to turn more southeasterly, allowing low-level above freezing air to advect into southern Kentucky with rain being the dominant precipitation mode.

Snow accumulated 100-180 mm across north-central Kentucky and southern Indiana, with the maximum just south of Louisville. Freezing rain and sleet were noted in central parts of Kentucky, with 25-50 mm of rain across southern Kentucky.

The MM5 run used for this example was initialized at 00 UTC 04 December 2002 since it provided a reasonable solution of the event,

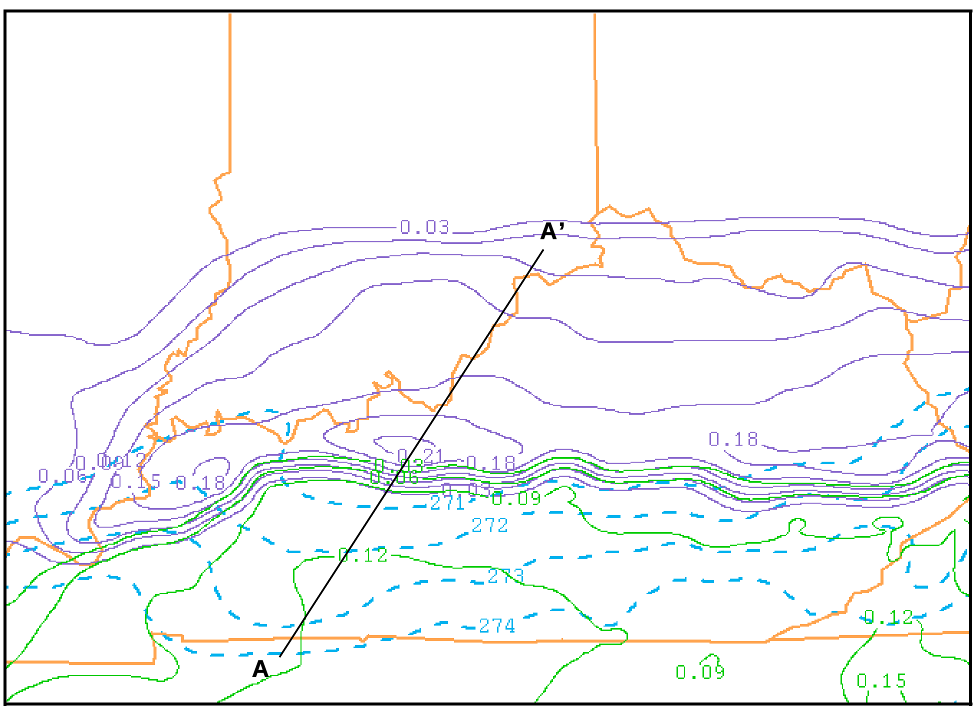


**Figure 4.** *Standard LMK-MM5 experimental precipitation type chart. Snow (purple) and rain (green) hydrometeor mixing ratios (g kg$^{-1}$) on the 0.995 sigma surface, and ground temperatures in the top few cm of the model soil in blue dashed lines (K). Only "critical" temperatures around 273 K are noted. This particular chart is valid at 00 UTC on 5 December 2002, a 24 hour forecast from the MM5 initialization at 00 UTC on 4 December. The black line (A-A') refers to the vertical cross-section in Fig. 5.*

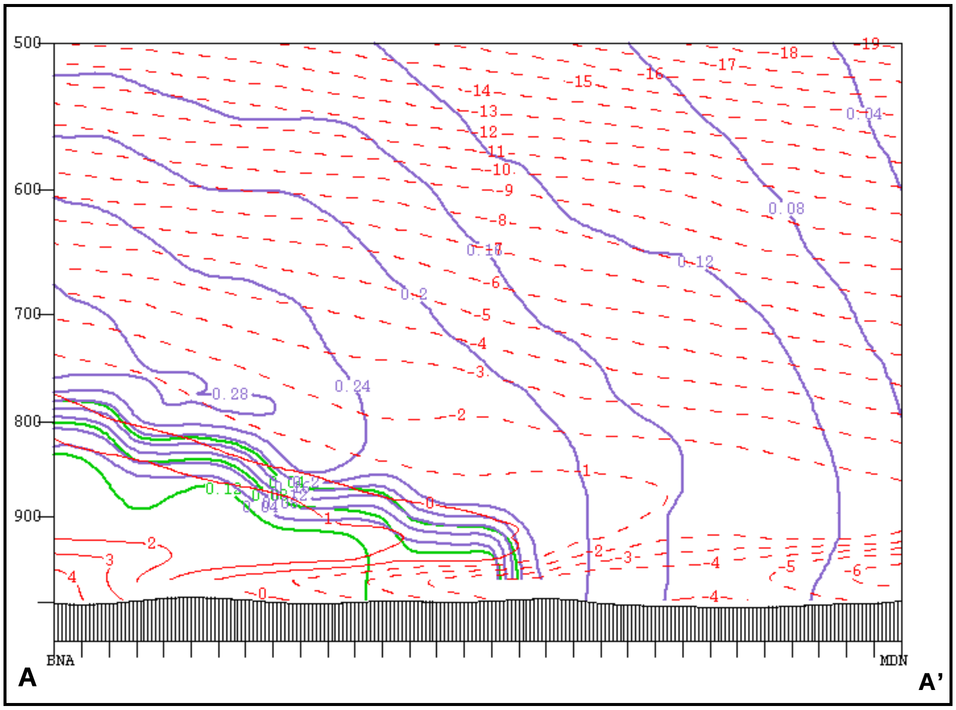


**Figure 5.** *Vertical cross-section taken roughly along the black line (A-A’) in Fig. 4, from Nashville, Tennessee (BNA) to Madison, Indiana (MDN), with data interpolated to above ground pressure surfaces. Snow and rain hydrometeor mixing ratios are shown the same as in Fig. 4, with the addition of temperature (°C) in red (dashed lines denote below zero values).*

generally consistent with observations of precipitation type. The “rain-snow” line in the MM5 data generally was 30-60 km too far south compared to the observations. However, these and subsequent discrepancies described in this paper are due to the model solution of the event and are not due to the technique’s application.

The standard experimental precipitation type chart used by operational forecasters at the NWS in Louisville is shown in Fig. 4. With this particular case, a band of snow is suggested in the model data across northern Kentucky and southern Indiana, where only snow crystal mixing ratios are present on the 0.995 sigma surface and where ground temperatures are well below freezing. This also is evident in Fig. 5, where snow mixing ratios reach to near the ground in the northern half of the vertical cross-section. Given precipitating conditions, the thermal profile in this part of the cross-section would also suggest all snow at the surface. Note the “tongue” of high snow mixing ratios just poleward (to the right) of the 0°C isotherm around 925 hPa (Fig. 5). This is likely an area of higher intensity snows at the surface. Across far southern Kentucky, a zone of only rain mixing ratios are present coincident with ground temperatures above freezing (Fig. 4), indicating a surface precipitation type of rain coincident with a relatively deep near-surface above freezing layer (Fig. 5). A mix of precipitation is seen across parts of central Kentucky. Freezing rain is implied in the areas where only rain mixing ratios are forecast collocated with below freezing ground temperatures (Fig. 4).

Farther north, a narrow transition zone is found, where both snow and rain mixing ratios mingle. This zone likely is an area where rain, snow, and freezing rain exist (Fig. 4). The transition area will be of particular interest in further assessments of this technique, particularly with regard to sleet and ice pellets.

### 3.2 *15-16 February 2003*

Over the weekend of 15-16 February, a major winter storm struck parts of the Lower Ohio Valley. Much of central Kentucky and southern Indiana was impacted with heavy freezing rain, sleet, rain, and snow; the ice storm around the Lexington area reached historical levels. The true magnitude of the event was not anticipated until several hours before the onset of significant freezing rain, when ice storm warnings were issued. A testament to the tight precipitation type gradient was the fact that simultaneously flood watches were in effect across all of south central Kentucky. The societal

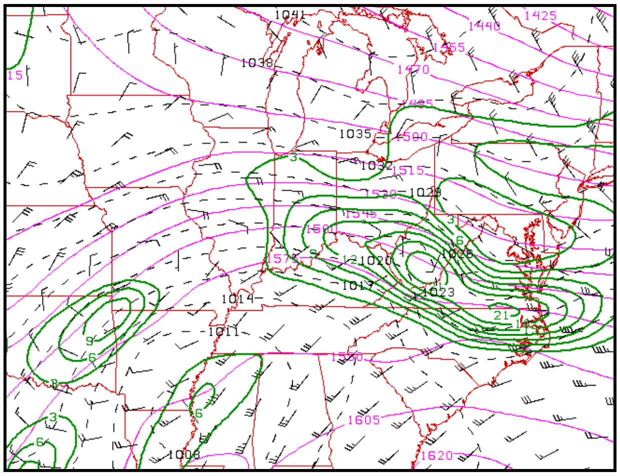

**Figure 6.** *Eta analysis at 00 UTC 16 February 2003. 850-700 hPa thickness (m) pink lines, layer mean wind (kts) in barbs, 850 hPa frontogenesis (K 100 km$^{-1}$ 3 hr$^{-1}$) in green, and MSLP (hPa) dashed lines.*

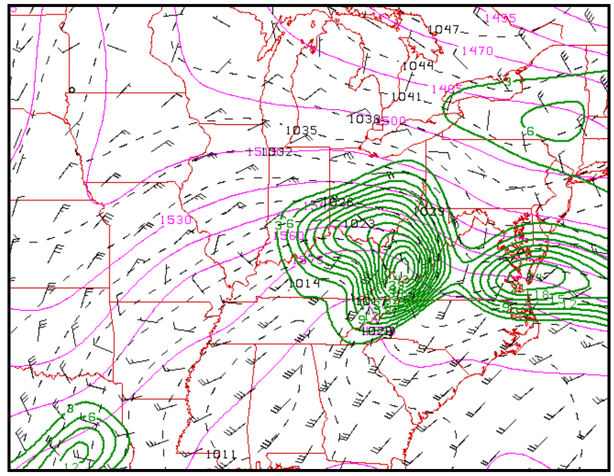

**Figure 7.** *Same as Fig. 6 except Eta 12-hour forecast valid at 12 UTC 16 February 2003.*

impact was tremendous: up to 125,000 people were without power with many interstate and primary roads closed for days due to ice accumulations and downed power lines. The widespread damage to trees due to the icing could still be seen into the summer season.

The mid-level flow pattern over much of the U.S. Valentine's Day weekend was stagnant, with a slow moving positively-tilted trough covering the central states. Ahead of this wave, a filling surface low translated unhurriedly eastward across the Gulf Coast states. The associated low-level wind flow allowed for a direct transport of high moisture values from the Gulf of Mexico northward up the sloping warm frontal interface over central Kentucky. Moderate to occasionally heavy precipitation centered on a persistent 850 hPa frontogenetic band over Kentucky (Figs. 6 and 7). Beneath the warm front, northeasterly surface winds increased over northern Kentucky as a 1048 hPa surface high dropped into southern Ontario. The resultant strong cold air advection allowed for a classic freezing rain situation to develop across central Kentucky, with more of a sleet profile farther north into southern Indiana where a deeper

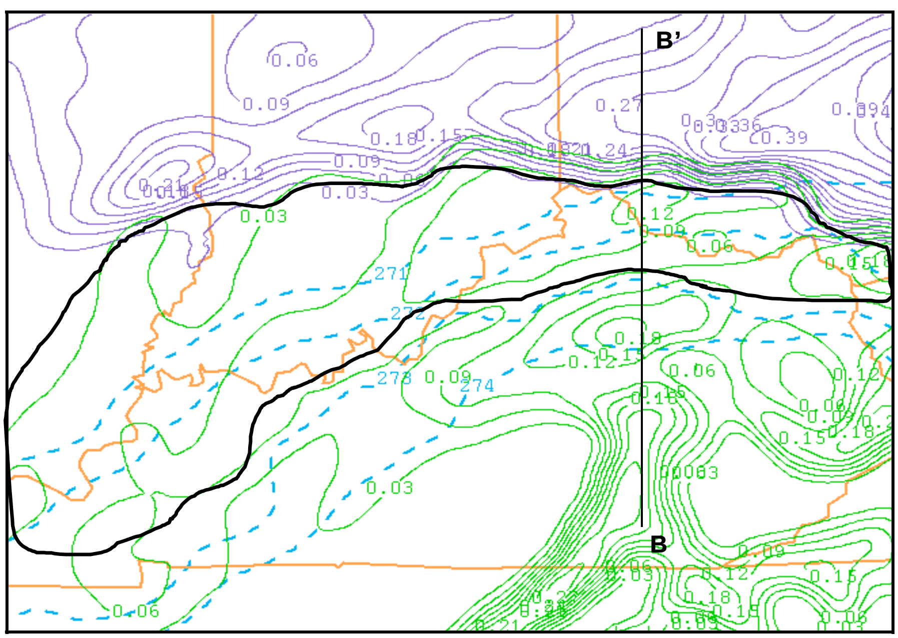


**Figure 8.** *Experimental precipitation type chart valid at 12 UTC 16 February 2003, a 12-hour forecast from the 00 UTC 16 February MM5 initialization. Contours are the same as in Fig. 4. The general area of forecast "freezing rain" is highlighted with the freehand black line. The black line (B-B') represents the vertical cross-section in Fig. 9.*

surface cold layer and shallower warm-layer aloft resided (Bernstein 2000).

In summary, over the Valentine's Day weekend, from 25-75 mm of sleet and snow fell from around Louisville northward, while up to 32 mm of ice accumulated in and around the Lexington area. Rainfall exceeding 75-100 mm fell in some southern Kentucky counties. We chose the 00 UTC 16 February 2003 initialization for this example. The solution was reasonable in terms of the low-level precipitable hydrometeor distributions. However, the ground temperature freezing line, and consequently the southern extent of the observed freezing rain, was in reality located about 80 km farther south than depicted in the LMK-MM5 solution. This data is suitable for a freezing rain event example in this paper, although operational forecasters should certainly take into account observed ground temperature trends to modify the experimental precipitation type chart forecast. This points out a strength of these charts since

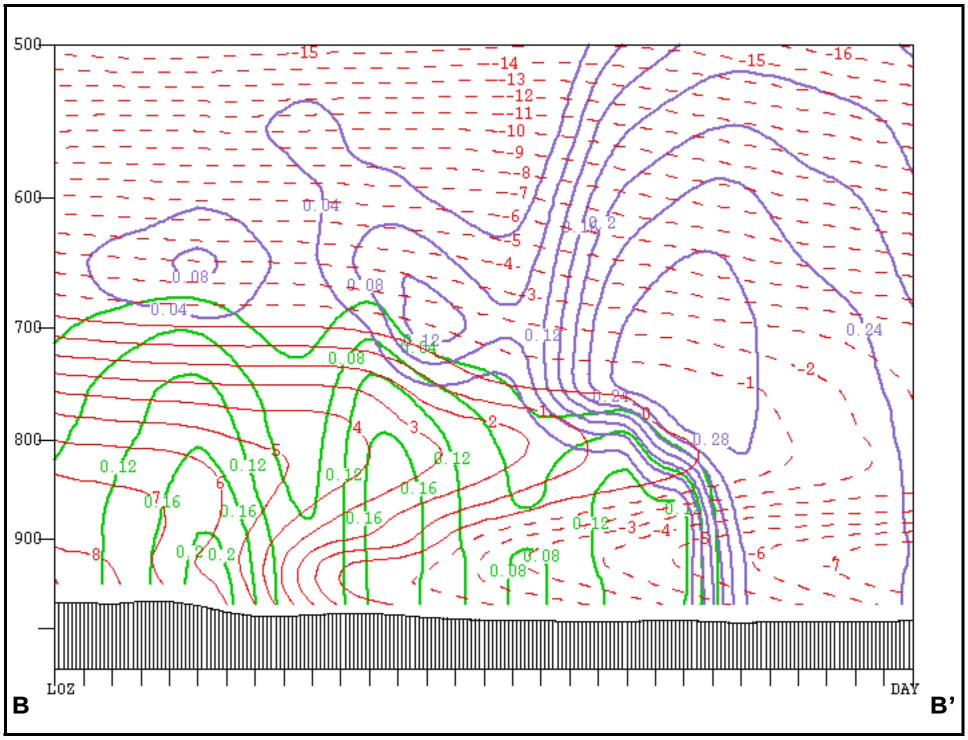


**Figure 9.** *Vertical cross-section taken along the black line (B-B') in Fig. 8, with data interpolated to*

forecasters can view the actual (raw) mixing ratio and ground temperature distributions, and compare these fields to observations. The precipitation type chart in Fig. 8 suggests a widespread area of freezing rain, where both near-surface rain hydrometeor mixing ratios are greater than zero, without the accompaniment of snow hydrometeors, and ground temperatures are below freezing (area within freehand black line). Also note the particularly high rain drop mixing ratios across far southern Kentucky, indicating more significant rainfall rates corresponding to the flooding situation there. Coupled with an elevated layer where temperatures are between 0 and 2°C, the depth of the sub-freezing near surface layer seen in Fig. 9 could suggest, again, a possibility for sleet, not accounted for explicitly in the current precipitation type charts.

### 3.3 *29 March 2003*

The final case from the 2002-2003 winter season involves a relatively minor, but challenging episode of rapid precipitation type changeover. East of a deep and slow moving 500 hPa trough over the central U.S., severe thunderstorms were followed by an area of rain along a surface cold front as it pushed through the Ohio River Valley during the evening of 28 March into the early morning hours of 29 March.

About 300 km behind the surface front, associated with a 700 hPa frontogenesis maximum and $\theta_e$ ridge axis, a stripe of moderate to locally intense vertical motion developed. A time-series of forecast soundings (Fig. 10) taken within the vertical motion maximum as it pressed towards the Ohio River showed a saturated air mass between 925 and 700 hPa

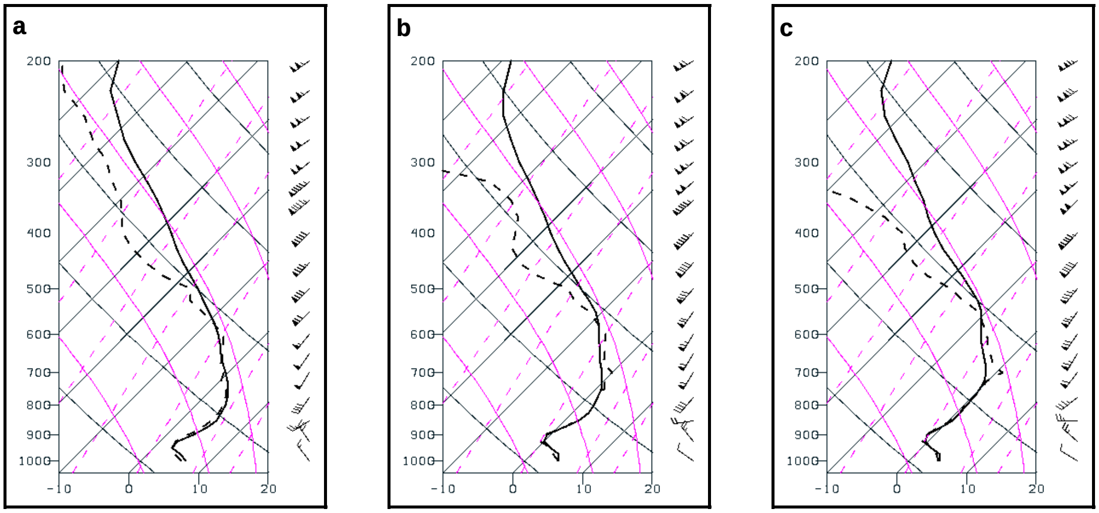


**Figure 10.** *Sample point soundings (skew-t) taken within axis of 700 hPa upward vertical motion associated with 700 hPa frontogenesis maximum. Eta initialized at 00 UTC 29 March 2003; (a) 3 hour forecast, (b) 6 hour forecast, and (c) 9 hour forecast. Temperature (°C) is shown with solid lines, dew point in dashed lines, and wind (kts) in barbs. Advections were taken into account within the south-southwesterly flow above a cold frontal interface to determine the locations of each sounding. This gives one a "crude" Lagrangian view. Note the supersaturation in the soundings, occasionally seen in Eta output during strong vertical motion events.*

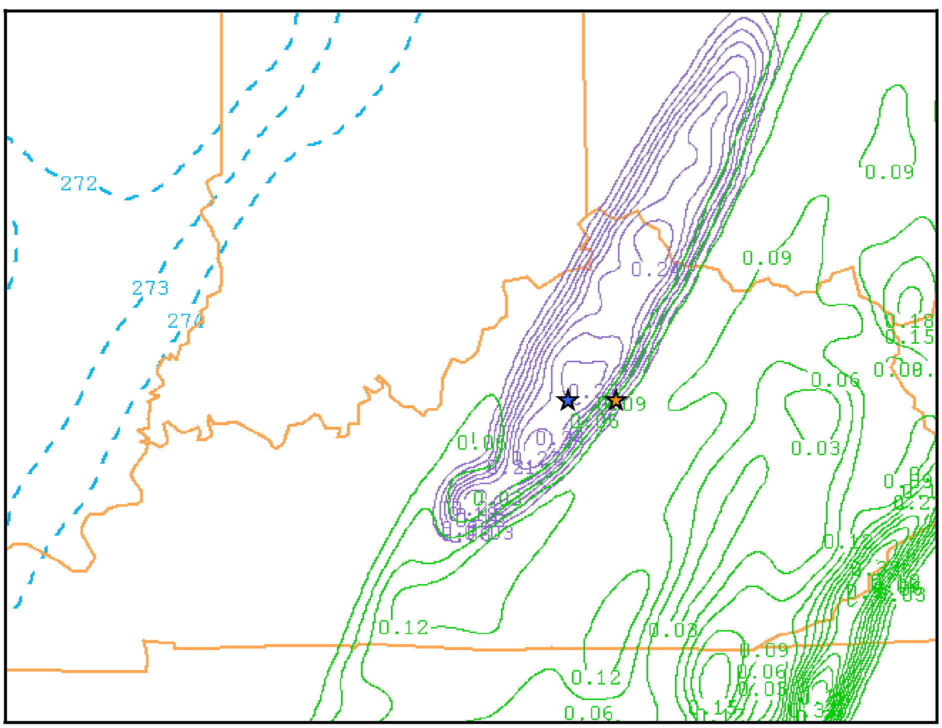


**Figure 11.** *Experimental precipitation type chart valid at 12 UTC 29 March 2003, a 12 hour forecast from the 00 UTC 29 March MM5 initialization. Contours are the same as in Fig. 4. All ground temperatures to the right of the 274 K line are at or above 274 K. The approximate location of Frankfort is shown by the blue star and Lexington by the orange star.*

cooling to around or just below 0°C, a classic heavy snow profile.

The quick burst of heavy snow, however, occurred over a shallow above-freezing near surface layer, leading to a wet snow that only stuck to grassy surfaces. With only trace amounts of official accumulation and the fact that this occurred early on a Saturday morning,

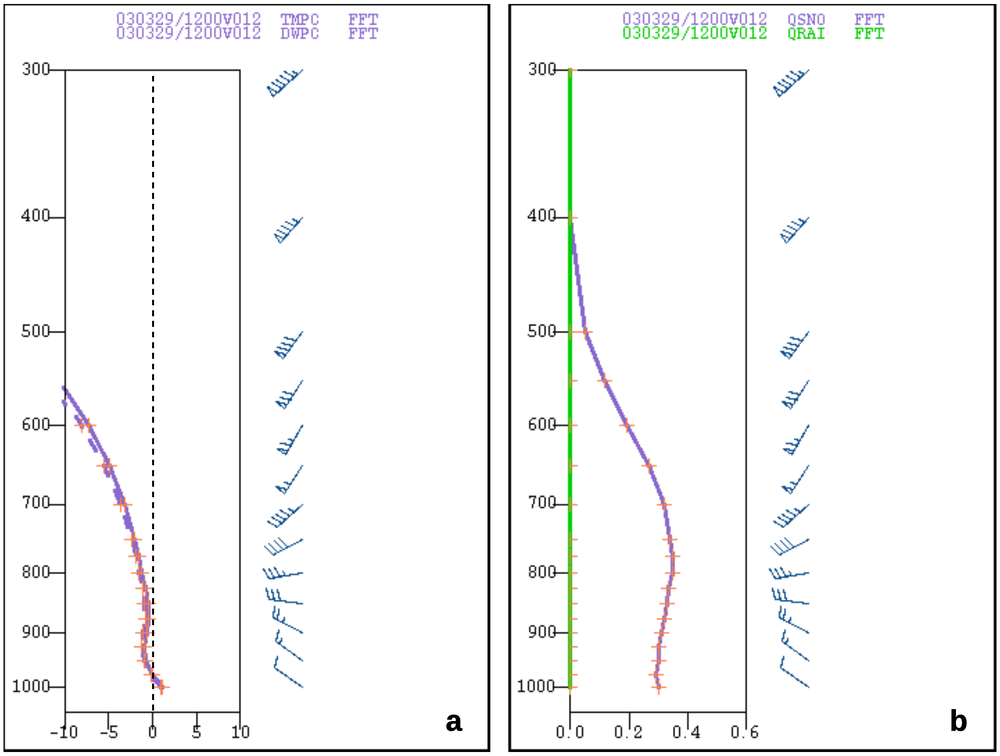


**Figure 12.** *Point sounding at Frankfort, KY (FFT) of the MM5 data at the same time as in Fig. 11. The left-hand plot (a) is a log-p plot of temperature (solid) and dew point (dashed). The right-hand chart (b) is a log-p plot of the snow (purple) and rain (green) hydrometeor mixing ratios (g kg$^{-1}$). The approximate location of FFT is noted in Fig. 11 by the blue star.*

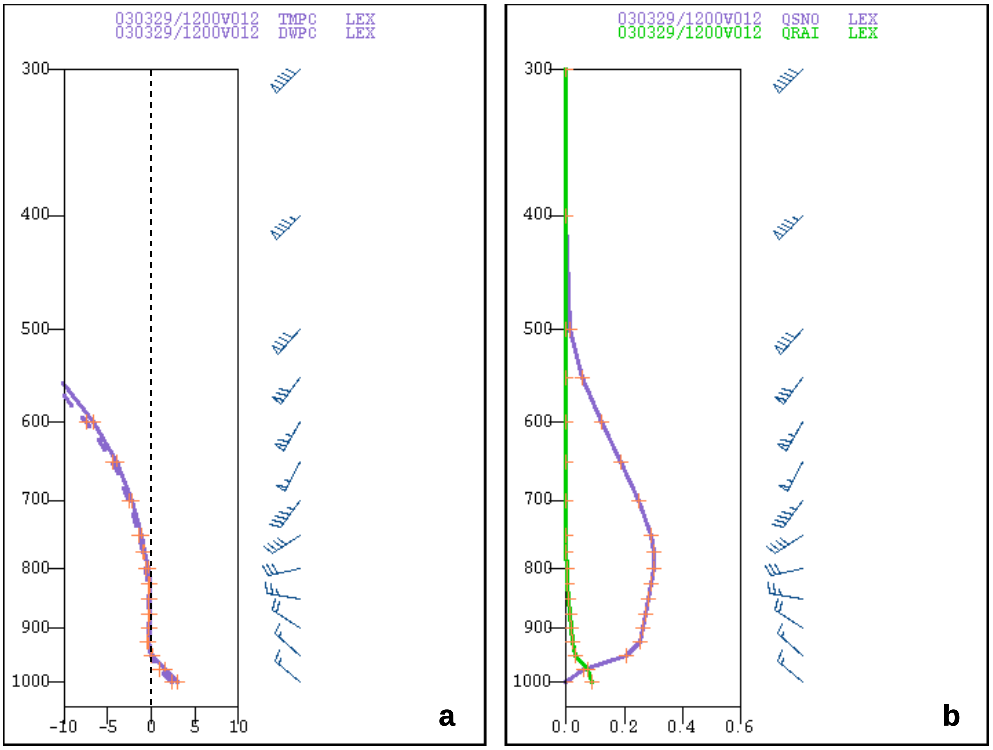


**Figure 13.** *Same as Fig. 12, except at Lexington, KY (LEX). The approximate location of LEX is noted in Fig. 11 by the orange star.*

societal impact was minimal.

MM5 data from the 00 UTC 29 March 2003 initialization is used for this case. Possibly due to "spin up" issues in generating precipitation since this event occurred early in the model cycle, the model generation of the snow band was about 2-4 hours slower compared to observations. However, the solution in generating a small-scale band of snow was correct, and provided the forecasters with a "situational awareness" that the event could occur.

The precipitation type chart in Fig. 11 suggests a small-scale band of snow developing over central Kentucky behind a larger area of rain over eastern Kentucky. Most significantly, notice that the ground temperatures where the frozen precipitation is occurring are above freezing. This would suggest that barring high intensity snowfall rates, any snow would tend to melt upon impact with the ground, which is consistent with observations that night, and thus have a generally negligible societal impact.

The transition zone again is highlighted in Figs. 12 and 13. Point soundings of the precipitable hydrometeor mixing ratios show the change from all snow (where rain mixing ratios (green line) equal zero; Fig. 12b) near the surface to a rain/snow mixture (where both rain and snow mixing ratios exist; Fig. 13b) within a relatively short distance. A heavy snow thermal profile is shown in the log-p plot for Frankfort (Fig. 12a), where a saturated atmosphere is just below 0°C for a considerable vertical distance, allowing for enhanced aggregation of "wet" snow flakes (Pruppacher and Klett 1996). In comparison, a very subtle increase in the temperatures between 950 and 800 hPa is seen in Fig. 13a compared to Fig. 12a, most likely allowing for more liquid hydrometeors to be present at the surface at Lexington. Notice, in both Figs. 12 and 13, the existence of an above freezing near-surface layer. This warm layer is deeper at Lexington (Fig. 13a), presumably permitting a percentage of the wet snowflakes aloft to melt and become liquid hydrometeors, as the mixing ratio distributions in both the experimental precipitation type chart (Fig. 11) and the point soundings (Figs. 12 and 13) would suggest.

## 4. FUTURE DIRECTION AND GOALS

We envision future projects to gauge this experimental precipitation type charts viability and flexibility. Three relevant paths are suggested to direct, enhance, and possibly unlock new operational applications. This exploration would include (a) research using archived data for past significant winter storms that affected the Ohio Valley, including the record snow event of January 1994, (b) examining additional real-time cases during the 2003-2004 winter season across a wider domain of the continental U.S., and (c) collaboration with any interested educational and operational institutions.

Furthermore, graupel mixing ratios are produced with the Schultz moisture scheme configuration in the MM5 model. However, due to local data conversion issues, those values have not been available. The frequent variability of precipitation types across the Ohio Valley, in both time and space, suggests forecaster interpretation of near-surface graupel mixing ratios could reveal another tool to enhance winter precipitation type forecasting, including perhaps a correlation to sleet and ice pellet occurrences.

Such efforts and collaboration between the NWS and its partners may effectively allow forecasters to more accurately determine winter precipitation types in the short term using mesoscale MM5 data, thus helping communities better prepare for those upcoming winter weather elements.

## 5. ACKNOWLEDGEMENTS

The authors would like to thank Ted Funk, Science and Operations Officer, NWS Louisville; Dr. Michael Morgan, Atmospheric and Oceanic Sciences, University of Wisconsin-Madison; and Karen Smallcomb for their helpful comments and reviews of this manuscript.

## 6. REFERENCES

Baldwin, M., R. Treadon, and S. Contorno, 1994: Precipitation type prediction using a decision tree approach with NMCs mesoscale Eta model. Preprints, *10th Conf. On Numerical Weather Prediction*, Portland, OR, AMS 30—31.

Bernstein, Ben C., 2000: Regional and local influences on freezing drizzle, freezing rain, and ice pellet events. *Weather and Forecasting*, *Vol. 15*, pp. 485-508.

Bourgouin, Pierre, 2000: A method to determine precipitation types. *Weather and Forecasting*, *Vol. 15*, pp. 583-592.

Brown, J.M., T. Smirnova, and S. Benjamin, 1998: Introduction of MM5 Level 4 microphysics into the RUC-2. Preprints, *Twelfth Conf. On Numerical Weather Prediction*, Phoenix, AZ, Amer. Meteor. Soc., 113-115

Grell, G. A., J. Dudhia, and D. R. Stauffer, 1994: A description of the fifth-generation Penn State/NCAR mesoscale model (MM5). *NCAR Technical Note*, NCAR/TN-398+STR, 117 pp.

Hong, Song-You, and Pan, Hua-Lu, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Monthly Weather Review*, *Vol. 124*, pp. 2322–2339.

Kain, John S., Goss, Stephen M., Baldwin, Michael E., 2000: The melting effect as a factor in precipitation-type forecasting. *Weather and Forecasting*, *Vol. 15*, pp. 700–714.

Pruppacher, H.R., and J.D. Klett, 1996: Microphysics of Clouds and Precipitation, 2nd Revised Edition. Kluwer Academic Publishers, Boston, 976 pp.

Schultz, Paul., 1995: An explicit cloud physics parameterization for operational numerical weather prediction. *Monthly Weather Review*, *Vol. 123*, pp. 3331–3343.