THE MESOSCALE SEEDER-FEEDER MECHANISM: ITS FORECAST IMPLICATIONS

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Abstract

On 12 February 2001, a storm of mixed precipitation was expected over the Raleigh, North Carolina, NWS Forecast Office (RAH), forecast area. The predominant precipitation type was forecast to be sleet, with the heaviest sleet expected during the morning between 1200 and 1800 UTC. Instead, a mesoscale snow event occurred overnight prior to the main precipitation event, which was lighter and more of a mixed variety than expected. Upon examination, it is apparent that the snow resulted from a pronounced seeder-feeder mechanism, in which low-level liquid clouds were seeded with ice crystals from above. This seeding modified the middle and low-level temperature profiles, glaciated the low-level clouds, and produced light snow for several hours in the foothills and northwest Piedmont of North Carolina.

The seeder-feeder mechanism is defined as the introduction of ice condensation nuclei from above into a lower level liquid cloud. The introduction of ice condensation nuclei can initiate precipitation from the low-level cloud layer. As ice is introduced into the lower liquid cloud, the ice crystals grow by deposition, which can cause the low cloud to precipitate. The resulting precipitation type is dependent upon the thermal profile from the cloud to the surface, as well as temperatures of exposed surfaces.

Although the snowfall totals were light for this event and caused few problems, it is evident that the seeder-feeder mechanism alone could potentially produce a significant frozen precipitation event. Since models often have difficulties resolving such a mesoscale event due to the parameterization of microphysics, the seeder-feeder mechanism must be diagnosed by carefully examining the entire depth of observed soundings. The purpose of this case study is to document a seeder-feeder event, explain the processes involved and their evolution, evaluate model performance for the event, and define a conceptual methodology for forecasting the mechanism.

1. Introduction

On 12 February 2001, a storm of mixed precipitation, consisting primarily of sleet, was expected over the Raleigh, North Carolina, NWS Forecast Office (RAH), County Warning Area (CWA). The heaviest sleet was expected during the morning between 1200 UTC and 1800 UTC. The observed precipitation was considerably lighter and more of a mixed variety than expected. Prior to the main precipitation event, an unexpected mesoscale snow outbreak occurred overnight. Upon examination, it is apparent that the snow resulted from a very pronounced seeder-feeder mechanism, in which low-level liquid clouds were seeded with ice crystals from clouds above. This seeding modified the middle and low-level temperature profiles, glaciated the low-level clouds, and produced light snow for several hours in the foothills and northwest Piedmont of North Carolina. Snowfall amounts were not large in RAH's forecast area, ranging from one-half to one inch in the northwest Piedmont, and they were overshadowed by the larger scale icing event which evolved shortly thereafter. However, it is possible that the seeder-feeder mechanism alone could produce a significant frozen precipitation event. The purpose of this paper is to explain how the seeder-feeder mechanism might be foreseen by providing an example for future reference.

The seeder-feeder mechanism was defined by Reinking and Boatman (1986) as the "phenomenon by which the lower cloud is microphysically stimulated by and feeds moisture to the natural ice 'seeds' supplied by the upper cloud." The introduction of ice condensation nuclei from the upper cloud initiates precipitation from the low-level liquid cloud layer. For the seeder-feeder process to occur, the maximum separation distance between the ice cloud above and the liquid cloud below is about 1500 m, but is dependent on the relative humidity of the surrounding environment (Pruppacher and Klett 1997). The upper cloud will likely consist of ice when its temperature is -10 °C or lower (Baumgardt 2001). When ice is introduced into the liquid cloud, the ice will grow by water vapor deposition onto the ice surface as described by the Bergeron-Findeisen process (Rodgers and Yau 1989). The resulting precipitation type that reaches the ground is dependent upon the thermal profile from the cloud to the surface, as well as temperatures of exposed surfaces in the case of freezing rain (Zerr 1997).

Because the seeder-feeder mechanism is mesoscale in size, the time frame of the analysis will be limited to the period between 1200 UTC 11 February 2001 and 1200 UTC 12 February 2001, and will concentrate mainly on forecast soundings and observed data.

a. Initial mesoscale observations at 0000 UTC 12 February 2001

The late evening, Raleigh NWS Forecast Office zone forecast at 0330 UTC 12 February (Fig. 1) indicated precipitation in the form of sleet was expected to begin towards morning. At 0000 UTC 12 February, western North Carolina was blanketed by a uniform deck of stratocumulus based from 1500 to 1800 m, while an altocumulus deck around 3000 m was approaching from the southwest (Fig. 2). An IR satellite image at 0015 UTC 12 February (Fig. 3) shows the leading edge of the midlevel cloud deck entering western South Carolina. This approaching midlevel cloud layer was occurring downstream of a 500-mb vorticity maximum, which was located over Alabama at this time. The 0000 UTC Greensboro, North Carolina (GSO) sounding (Fig. 4) was quite dry, and a significant portion of the sounding was warmer than 0 °C below 700 mb. Of particular note is a warm (> 0 °C) 600 to 900 m thick layer at the midlevels (790-710 mb). The 0000 UTC radar composite (Fig. 5) showed a narrow band of light rain over western South Carolina. The rain was evidently associated with an approaching vorticity maximum, as seen in satellite imagery (Fig. 3). The vorticity max was forecast to move quickly northeast across western North Carolina. Most of the precipitation was not reaching the ground at this time, as surface observations at 0000 UTC (Fig. 2) showed that only one location was reporting rain (KAND; Anderson, SC).

ZONE FORECAST PRODUCT...UPDATED
NATIONAL WEATHER SERVICE RALEIGH, NC
1030 PM EST SUN FEB 11 2001

NCZ007-021>023-038-039-121100-
UPDATED
ALAMANCE-DAVIDSON-FORSYTH-GUILFORD-PERSON-RANDOLPH-INCLUDING THE CITIES OF...BURLINGTON...GREENSBORO...HIGH POINT... WINSTON-SALEM
1030 PM EST SUN FEB 11 2001

...WINTER STORM WARNING LATE TONIGHT THROUGH MONDAY...

.TONIGHT...CLOUDY. SLEET DEVELOPING TOWARD MORNING. LOW IN THE UPPER 20S. NORTHEAST WIND 5 TO 10 MPH. CHANCE OF PRECIPITATION 80 PERCENT.
.MONDAY...SLEET...CHANGING TO FREEZING RAIN AROUND MIDDAY. SIGNIFICANT ACCUMULATION OF ICE LIKELY. COLD. TEMPERATURES STEADY NEAR 30. NORTHEAST WIND 5 TO 10 MPH. CHANCE OF PRECIPITATION 80 PERCENT.
.MONDAY NIGHT...CLOUDY WITH WIDESPREAD FOG. TEMPERATURES STEADY NEAR 30.

Fig. 1. Zone forecast product from RAH for the northwest Piedmont area issued at 2230 EST 11 February 2001 (0330 UTC 12 February 2001).

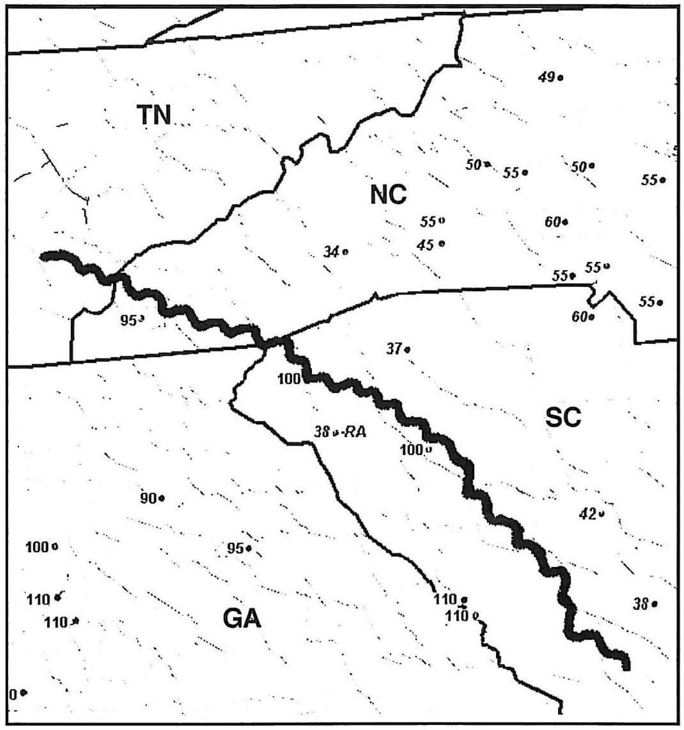

Fig. 2. Plot of METAR ceiling and precipitation valid at 0000 UTC 12 February 2001. Ceiling heights are in hundreds of feet. The scalloped line highlights the leading edge of the midlevel cloud deck, which was moving northeast. Note the presence of a stratocumulus deck in place over North Carolina. Precipitation began shortly after the midlevel clouds moved over lower level clouds that were already in place.

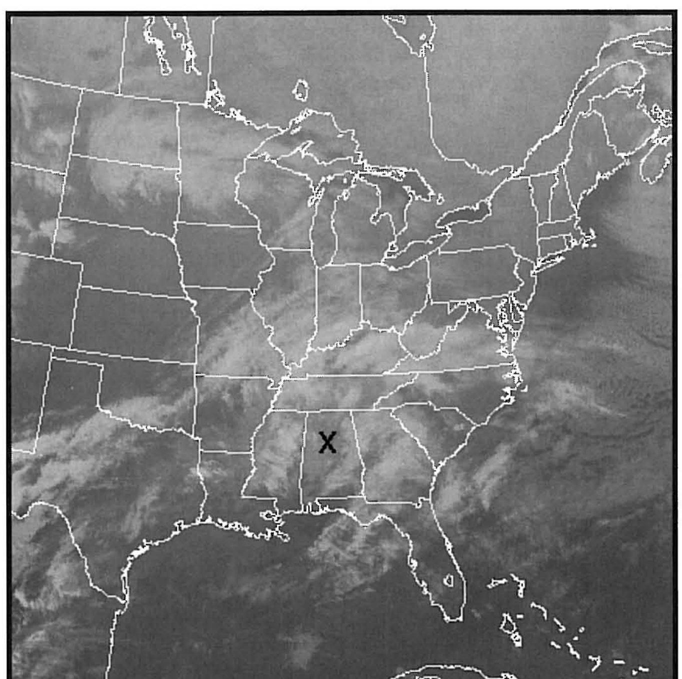

Fig. 3. GOES IR satellite image at 0015 UTC 12 February 2001. At this time, the leading edge of the midlevel cloud deck has moved into western South Carolina and is moving northeast. The area of midlevel clouds was occurring downstream of a 500-mb vorticity maximum (labeled X) over Alabama.

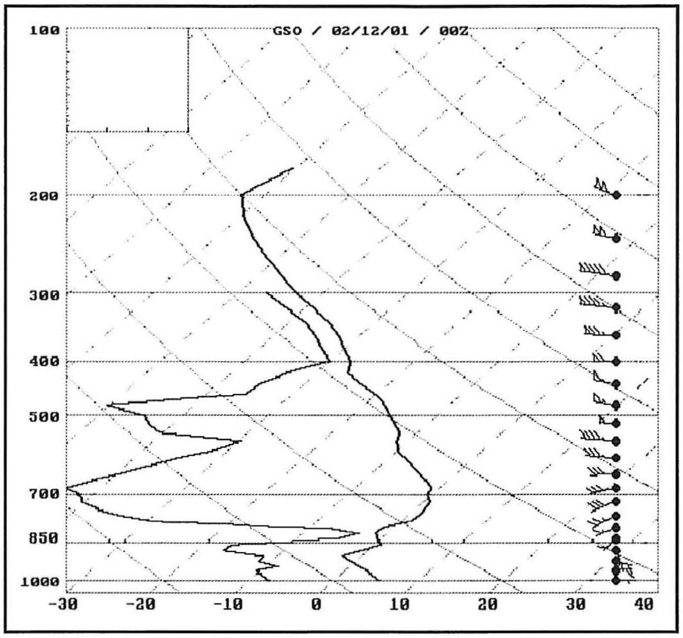

Fig. 4. The 0000 UTC 12 February 2001 sounding from GSO. Note the presence of a very dry warm layer between 790 and 710 mb. Precipitation from the approaching midlevel clouds (around 560 mb) precipitated into this warm layer, which cooled the layer to freezing and seeded the stratocumulus deck (around 810 mb) with ice crystals.

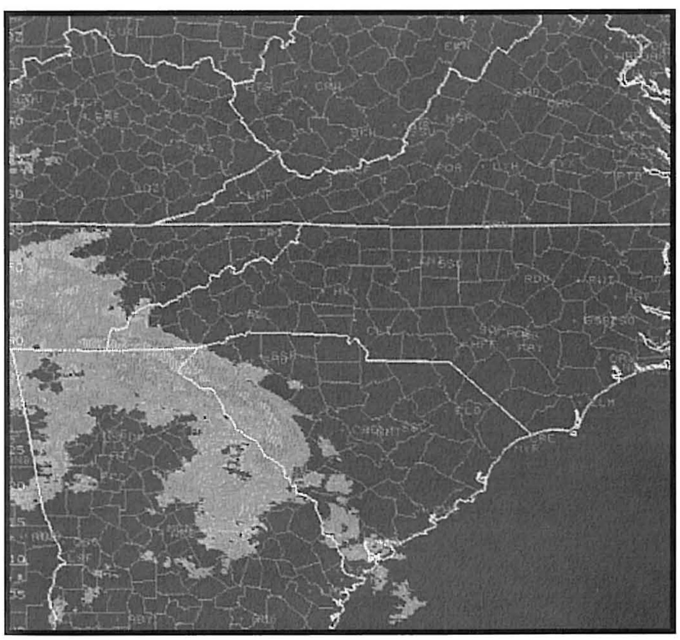

Fig. 5. Radar composite image at 0000 UTC 12 February 2001. Note that the leading edge of precipitation corresponds well to the leading edge of the midlevel cloud deck (indicated by scalloped line in Fig. 2). This precipitation was falling aloft, likely as ice crystals from the midlevel cloud. Little precipitation was being reported at the surface at this time (see surface observations in Fig. 2).

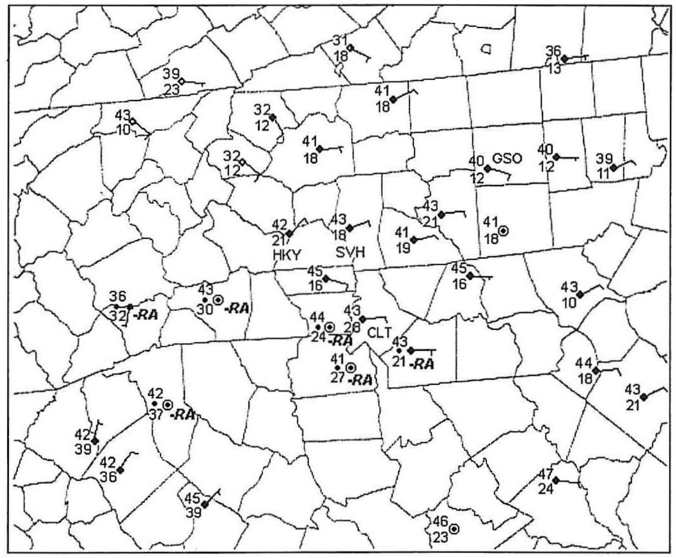

Fig. 6. METAR plot of temperature, dewpoint, wind barbs, and precipitation type at 0400 UTC 12 February 2001. Stations mentioned in text are labeled.

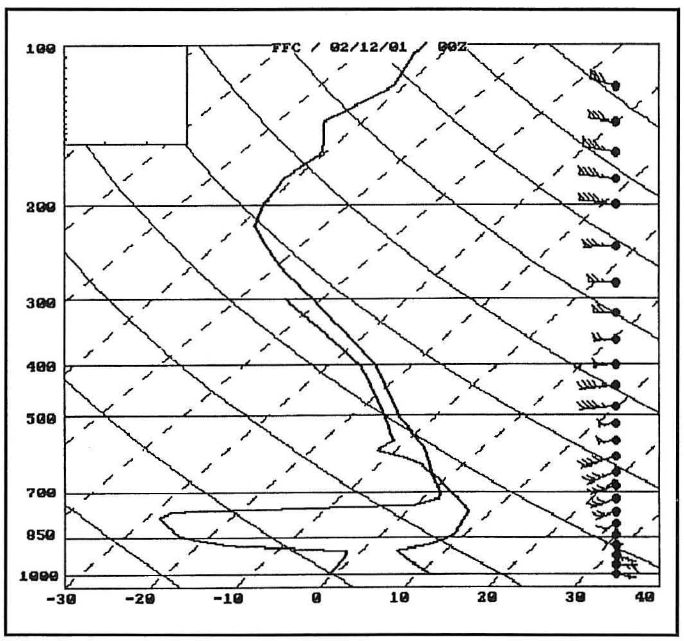

Fig. 7. The 0000 UTC 12 February 2001 sounding from Peachtree City, Georgia. Note that the midlevel moisture was deep and much of the cloud layer was below -10 °C, which allows ice crystals to dominate over supercooled liquid droplets.

b. Event mesoscale observations from 0400 UTC to 1200 UTC 12 February 2001

Temperatures at 0400 UTC across the area were in the 40 to 45 °F degree range (Fig. 6) and, given significant precipitation amounts, would likely fall rapidly due to evaporative cooling as dewpoints were in the teens, and wet bulb temperatures were near freezing. Light rain moved into the southern Piedmont near Charlotte (CLT) shortly before 0500 UTC 12 February. This initial surge of precipitation was not expected to be significant, as evidenced by the lack of its inclusion in the evening forecast update (Fig. 1). The precipitation's early arrival would not appear to pose a problem for the forecast of sleet, as evaporative cooling would quickly lower surface temperatures to freezing or below as the rain moved north of Charlotte

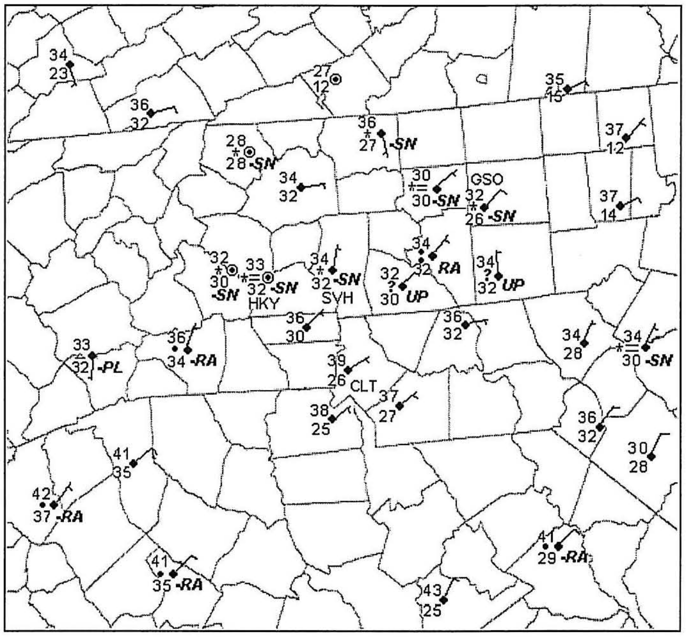

Fig. 8. METAR plot of temperature, dewpoint, wind barbs, and precipitation type at 0800 UTC 12 February 2001. Stations mentioned in text are labeled. UP represents unknown precipitation, and PL indicates sleet.

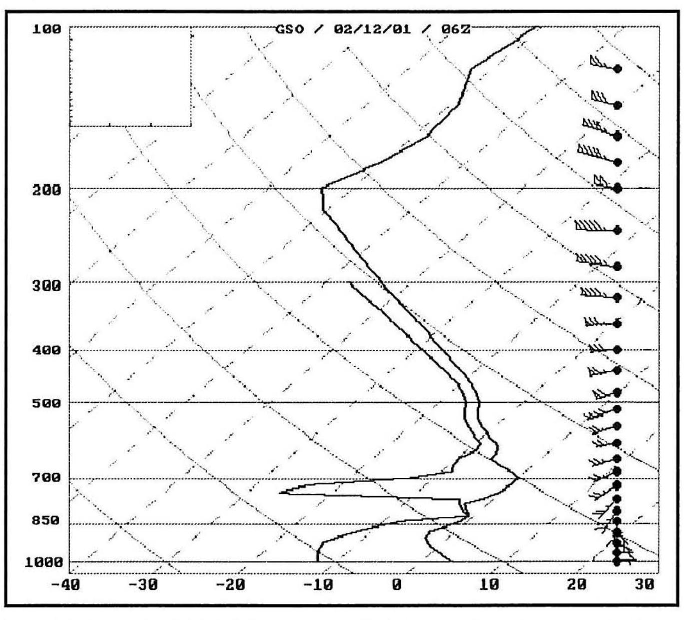

Fig. 9. The 0600 UTC 12 February 2001 sounding from GSO. Note that the layer between 750 and 700 mb, which was above freezing at 0000 UTC (Fig. 4), has cooled to freezing and is isothermal. Also note that the moisture above 650 mb has increased, which indicates that the approaching midlevel cloud deck has moved over GSO at 0600 UTC. Snow began to be reported at GSO at 0800 UTC.

into the foothills and northwest Piedmont. Meanwhile, a veering wind profile at GSO (Fig. 4) and at Peachtree City, Georgia (Fig. 7), indicated that warm advection would likely reinforce, and even strengthen, the warm air already in place at the lower to midlevels. Thus, a changeover to primarily sleet as forecast was expected that evening as the evaporatively-cooled surface based air would be sufficiently cold and deep to re-freeze liquid precipitation falling from the warm layer. However, the precipitation unexpectedly began to fall as snow (Fig. 8). Observations at Hickory (HKY) and Statesville (SVH) showed the precipitation beginning at 0500 UTC as rain, then changing to snow by 0600 UTC and remaining snow until around 0900 UTC. At Greensboro (GSO), the precipitation began as snow at 0800 UTC and continued until around 1030 UTC when it changed over to freezing rain, which lasted through the afternoon. The snow accumulated up to an inch to the west of Greensboro, in the northwest Piedmont and foothills region.

2. Diagnosing the Seeder-Feeder Mechanism Responsible for the Snow

a. 0000 UTC soundings

The GSO sounding at 0000 UTC (Fig. 4) exhibits an 80-mb deep warm layer aloft (790 - 710 mb) as well as the potential for significant diabatic cooling at the surface. These features would suggest a sleet/freezing rain scenario. However, there are other more subtle details to note: 1) the warm layer, while deep, is only one to two degrees above freezing and very dry – thus, we should expect evaporative cooling here as well; 2) there is midlevel moisture noted near 560 mb and with temperatures at this level below -10 °C, indicates the possible presence of ice condensation nuclei; and 3) the cloud layer temperature at 800 mb is around -2 °C, which indicates the presence of a supercooled cloud layer favorable for efficient seeding from above.

The upstream sounding from Peachtree City, Georgia in Fig. 7 shows that the midlevel moisture to arrive in the RAH CWA had a base near 750 mb and was extremely deep, extending above 500 mb. Thus the midlevel moisture at 560 mb in the 0000 UTC GSO sounding would be expected to increase over the next few hours.

b. 0600 UTC GSO sounding

The 0600 UTC sounding from GSO (Fig. 9) showed that the midlevel moisture had deepened above 600 mb, with the vast majority of the layer colder than -10 °C. The prior midlevel melting layer had cooled to less than 0 °C as well, and only the surface layer remained above freezing.

At this point, the low-level liquid cloud had been seeded with ice from above, and snow began to fall in GSO shortly before 0800 UTC. Observations of ceilings indicate that the midlevel cloud deck had progressed to GSO by 0600 UTC. Rain had begun in the Charlotte, North Carolina area around 0400 UTC, shortly after the arrival of the midlevel cloudiness there. It appears that the midlevel cloudiness was responsible for seeding the clouds below, thus causing the unexpected surge of precipitation prior to the principal, more widespread precipitation. Approximately two hours separated the arrival of the midlevel cloud deck and the onset of snow at GSO.

3. Comparison of Observed Soundings and Eta-Model Forecast Soundings

Forecast soundings for GSO from the NWS Eta-model 1200 UTC run on 11 February and the 0000 UTC run on 12 February 2001 were analyzed and compared to the actual soundings that were taken during the event. The presence of a warm nose, above freezing layers, low-level winds, and dry layers were noted.

a. Eta-model forecast sounding at 0000 UTC 12 February 2001

Figure 10 shows the Eta-model 12-h forecast sounding valid at 0000 UTC 12 February 2001 at GSO. The observed sounding in Fig. 4 showed a thin moist layer evident at 560 mb. This layer was the leading edge of the midlevel cloud deck that was approaching from the southwest. The model sounding did not pick up on the approach of a midlevel cloud deck from the southwest near 560 mb at this time, as the model sounding remained very dry at this level. The observed sounding showed the presence of moisture associated with a stratocumulus deck at 800 mb, while the model sounding had a 12 degree dewpoint depression at this level. The model sounding also underestimated the amount and depth of the dry air from 800 to 600 mb. Precipitation at the surface was forecast to begin around 0900 UTC in the 0000 UTC model run.

These model inaccuracies had large implications on its precipitation-type forecast. The observed cloud layer that was approaching from the southwest near 560 mb, which was not depicted in the model sounding, began to precipitate into the dry warm nose between 0000 UTC and 0600 UTC. This caused evaporative cooling in that layer, and reduced the temperature of the warm nose to near freezing and isothermal. Because the model underestimated the amount of dry air that the precipitation was falling into (between 800 and 600 mb), it also underestimated the potential for evaporative cooling in that layer. The precipitation from the midlevel clouds proceeded to seed the stratocumulus deck at 810 mb with ice, which later produced snow. Since the model did not account for the stratocumulus deck, the midlevel cloud layer, or the very dry air between 800 and 600 mb, it did not correctly portray the seeder-feeder process.

b. Eta-model forecast sounding at 0600 UTC 12 February 2001

The 6-h forecast sounding valid at 0600 UTC 12 February is shown in Fig. 11. At this time, the actual sounding (Fig. 9) showed a 0 °C isothermal layer between 750 and 700 mb with the rest of the sounding below freezing, except at the surface. However, the model forecast (Fig. 11) showed that the layer was not near-freezing and isothermal; it remained near 2 °C. Because the model forecast the layer to be too warm (underestimated the amount of evaporative cooling), the model precipitation-type forecast of freezing rain at 0900 UTC was incorrect. A warm nose between 1 °C to 3 °C will produce a snow/sleet mix if ice is introduced, and freezing rain if ice

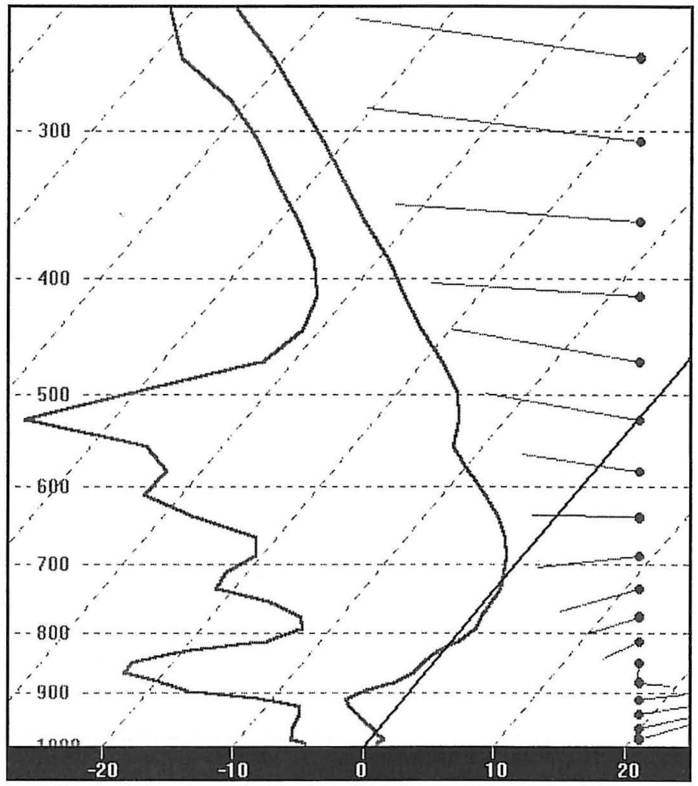

Fig. 10. Eta 12-h forecast sounding valid at 0000 UTC 12 February 2001. The Eta model forecast did not indicate the increasing moisture at 560 mb, which was the midlevel cloud deck approaching from the southwest. It also did not show the stratocumulus deck at 810 mb, which was seeded by the ice crystals from the midlevel cloud deck (compare observed sounding in Fig. 4). The model also overestimated the amount of moisture between 800 and 600 mb, which led to an underestimation of the amount of evaporative cooling in that layer.

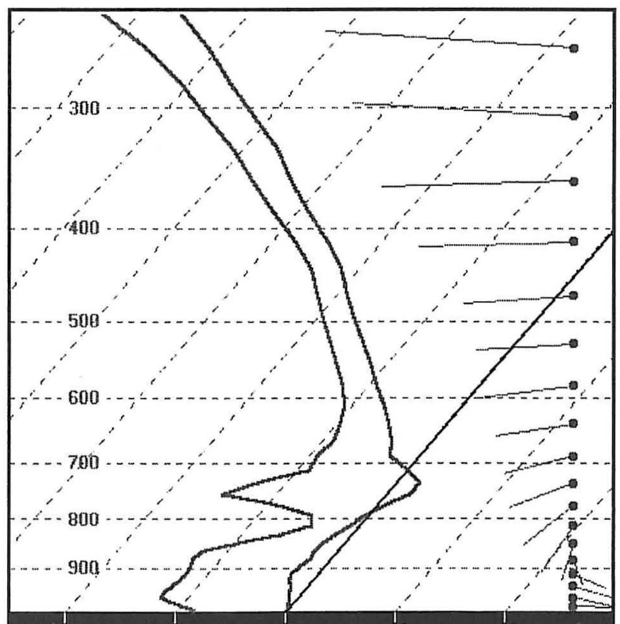

Fig. 11. Eta 6-h forecast sounding valid at 0600 UTC 12 February 2001. The model did not accurately forecast the presence of a near-freezing isothermal layer between 750 and 700 mb, instead showing a 2 °C warm nose (compare to observed sounding in Fig. 9). This led to a forecast of freezing rain by the model.

is not introduced (Baumgardt 2001). Since the Eta did not properly account for the midlevel cloud layer that introduced ice into the stratocumulus deck between 0000 UTC and 0600 UTC, the model did not account for ice seeding into the lower cloud layer early enough. This resulted in the model showing the warm layer to be too warm, and freezing rain was the predominant precipitation-type that was forecast by the Eta model.

4. Evaluation of Partial Thickness Scheme

The 1000-850 mb thicknesses and 850-700 mb thicknesses were computed from the actual soundings and compared to the Eta-model forecast thicknesses from the model run closest to the observed soundings. The partial thicknesses from the observed soundings and the forecast soundings were plotted on a partial thickness nomogram created by Keeter et al. (2000). The observed thickness nomogram correctly portrayed snow changing to mainly freezing rain (FZRA) and a little sleet (PL). However, the model forecast thicknesses portrayed a different precipitation-type scenario – one that was dominated by only freezing rain and sleet. Very subtle differences in the model forecast soundings from observed conditions led to inaccurate forecasts of precipitation type based on the nomogram.

Table 1 shows the comparisons of the actual partial thicknesses and their corresponding p-type based on the nomogram with the model forecast thicknesses and p-type.

Figure 12 shows the low-level thicknesses from the observed soundings plotted on the nomogram from Keeter et al. (2000). The corresponding Eta-model thicknesses were also plotted on the nomogram, which is shown in Fig. 13. Note that at 1800 UTC, the Eta overestimated the thickness of the above-freezing layer and underestimated the low-level thickness. Although the model correctly lowered the thickness in the above-freezing layer at the initialization time of 0000 UTC, it was still too warm compared to reality. From 0000 to 0600 UTC, the observed 850-700 mb thickness decreased slightly, from 1553 m to 1549 m, placing the sounding in the "snowy nose" category of the nomogram. In this area of the nomogram, the precipitation-type will be snow if a near-freezing isothermal layer is present; otherwise freezing rain and sleet will be the dominant precipitation-type. In the observed sounding at 0600 UTC, a near-freezing isothermal layer was present, and snow was able to reach the ground at 0700 UTC. At the same time, the model forecast 850-700 mb thickness did not change, while the 1000-850 mb thickness dropped by 11 m. A near-freezing isothermal layer was not present in the 0600 UTC forecast sounding. Instead, the Eta-model forecast sounding showed a 2 °C warm nose between 800 and 700 mb. This overestimation of temperature in the layer led to an incorrect model precipitation-type forecast of mostly freezing rain with a trace of sleet, based on the partial thickness nomogram.

Between 0600 UTC and 1200 UTC, the model forecast 850-700 mb thickness dropped 5 m, while the observed drop in 850-700 mb thickness occurred between 0000 UTC and 0600 UTC. The model may have underestimated evaporative cooling in this layer, which was due to the model neglecting to portray the midlevel clouds that approached GSO at 0000 UTC and later precipitated into the above-freezing layer.

The partial thickness nomogram based on observed data performed very well in predicting precipitation-type, even though the thickness changes were very subtle. While the Eta forecast thicknesses were close to the observed thicknesses, they were off just enough to cause an incorrect precipitation-type forecast. The percent error in the Eta forecast thickness is small (less than 1%), but the sensitivity is such that even small errors can have a dramatic impact on precipitation-type. The model underestimated the effects of evaporative cooling in the warm nose layer because it did not account for the presence of the midlevel clouds, which precipitated into the layer and seeded the stratocumulus deck.

5. Conclusions

The seeder-feeder mechanism can be diagnosed by carefully examining the entire depth of the soundings.

Table 1. Comparison of the observed 1000-850 mb layer thickness (m) and 850-700 mb layer thickness (m) with the forecast thickness (m) of the same layers from the Eta model. The resultant precipitation types are based on the partial thickness nomograms developed by Keeter et al. (2000; Figs. 12 and 13).

Time and Date	Observed thickness	Eta forecast thickness	Observed p-type from nomogram	Eta forecast p-type from nomogram
1800 UTC 11 Feb	1297/1556	1292/1561	Mostly FZRA, trace PL	Mostly FZRA, trace PL
0000 UTC 12 Feb	1305/1553	1305/1557	Mostly FZRA, trace PL	Mostly FZRA, trace PL
0600 UTC 12 Feb	1298/1549	1294/1557	Snow if isothermal near 0°	Mostly FZRA, trace PL
1200 UTC 12 Feb	1294/1551	1292/1552	Mostly FZRA, trace PL	Measurable PL w/FZRA

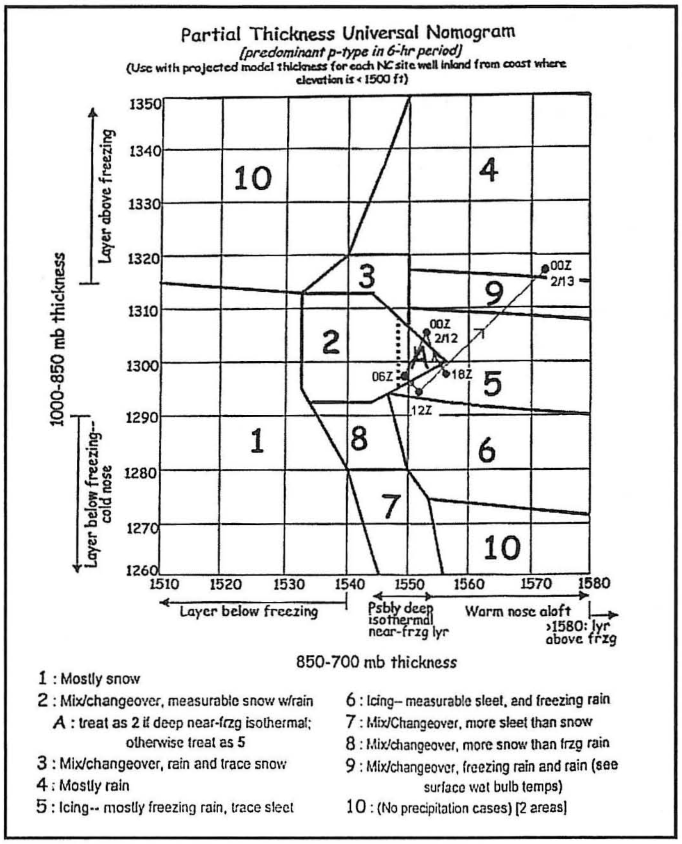

Fig. 12. Plot of partial thickness from the GSO soundings from 1800 UTC 11 February to 0000 UTC 13 February. Evaporative cooling in the 850 to 700 mb layer lowered the thickness into area "A", which resulted in a precipitation type of snow, since a near-freezing isothermal layer was present in the observed sounding.

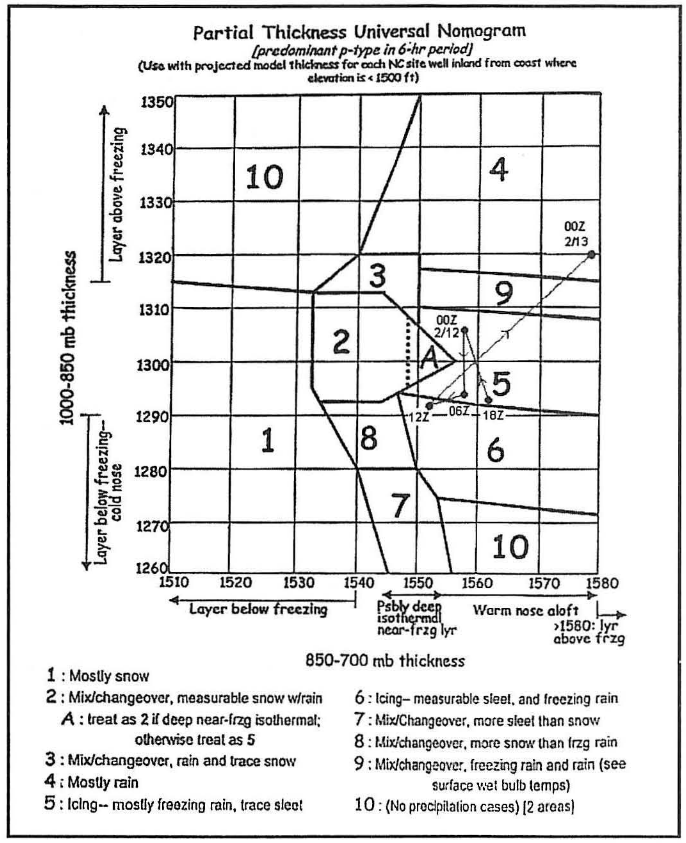

Fig. 13. Plot of partial thickness from the Eta model for the same time period as in Fig. 12. Thicknesses at each time were taken from the closest model run to the time shown. The model forecast the warm nose to be too warm because it did not correctly account for evaporative cooling caused by the midlevel cloud layer. This led to a freezing rain and sleet forecast.

Very small changes in the vertical temperature profile can profoundly affect the precipitation-type, and models often cannot resolve these details since microphysical processes are parameterized by the models. Therefore, observed data must be analyzed intensively to produce more accurate precipitation-type forecasts over the models. There are features in the observed soundings and surface observations that can alert a forecaster to the potential for the seeder-feeder process to occur within 12 hours. An approaching midlevel cloud deck that is -10 °C or colder (the temperature at which ice crystals are likely to dominate over supercooled droplets) moving over a lower level, below-freezing cloud deck with up to 1500 m of separation can be diagnosed from regional surface observations, satellite data, and upstream soundings. The presence of an above-freezing warm nose can change the precipitation-type from snow to rain or sleet. However if the warm nose is dry, there is the potential for evaporative cooling which must be considered. This can cool the warm nose temperature enough (less than 1 °C) to produce snow. Near-surface temperature and moisture will also affect the precipitation type, especially in the case of freezing rain.

Comparing the differences between the observed sounding and the forecast sounding is critically important to determining when the model is deficient or accurate. The presence of any moist layers, dry layers, or inversions that the model is not accounting for must be carefully considered when making a precipitation-type forecast. The use of a partial thickness nomogram can also be very useful for forecasting precipitation-type in the short term. Comparing the trend of observed partial thickness with a trend of model forecast partial thickness can quickly indicate if the model is too warm or too cold.

This type of event is not particularly difficult to diagnose beforehand — if one is familiar with the mechanism responsible and thoroughly analyzes the observed and forecast soundings accordingly. This case study was drafted for such a purpose — to show that the seeder-feeder mechanism does exist and can cause potentially significant precipitation-type problems, and that it can be forecast, at least in the short term.

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References

Baumgardt, D., 2001: Precipitation-type Forecasting: The Top-Down Approach. VISIT tele-training session presented 13 Jan 2001. Online work: Wintertime Cloud Microphysics Review http://www.crh.noaa.gov/arx/micrope.html.

Keeter, K., J. Blaes and L. Lee, 2000: Introduction to Forecasting Predominate Precipitation Type Trends (TREND), Online work: http://www4.ncsu.edu:8030/~nwsfo/trend/index.html

Pruppacher, H. R., and J. D. Klett, 1997: *Microphysics of Clouds and Precipitation*. D. Reidel Publishing Company, Boston, 714 pp.

Reinking, R. F., and J. F. Boatman, 1986: Upslope Precipitation Events. In *Mesoscale Meteorology and Forecasting*, P. Ray (Ed.), Amer. Meteor. Soc., Boston, 437-471.

Rodgers, R. R., and M. K. Yau, 1989: *A Short Course in Cloud Physics*. Pergammon Press, New York, 293 pp.

Zerr, R. J., 1997: Freezing Rain: An Observational and Theoretical Study. *J. Appl. Meteor.*, 36, 1647-1661.