Eastern Region Technical Attachment
No. 2005-02
September 2005

THE 2-3 JANUARY 2002 WINTER STORM ACROSS CENTRAL SOUTH CAROLINA AND EAST CENTRAL GEORGIA: A PRECIPITATION TYPE CASE STUDY

Anthony W. Petrolito
NOAA/National Weather Service Forecast Office
Columbia, South Carolina

ABSTRACT

Widespread accumulating snow or freezing rain across central South Carolina and east central Georgia are unusual events. These occurrences may cause substantial disruption in the region by impacting transportation systems and commerce. Accurate and timely precipitation type forecasts for these events are essential to minimize the impact on local communities which are not accustomed to winter storms. On 2-3 January 2002, a substantial winter storm affected central South Carolina and east central Georgia. To study the evolution of the event, the synoptic pattern and Eta model forecast sounding data were examined. Precipitation type forecasting techniques were compared and analyzed for several Eta model runs. This case study reveals improvement in precipitation type forecasts can be made by recognizing the synoptic patterns associated with heavy snow in the southeastern states and incorporating cloud microphysics with various precipitation type forecasting techniques.

1. INTRODUCTION

Winter storms producing widespread accumulating snow or freezing rain across central South Carolina and the Central Savannah River Area (CSRA) of Georgia are rare events. The average annual total snowfall for Columbia, SC (CAE) is only 2.1 inches (NCDC 2003). Harms (1973) reviewed Georgia snowfall records for 74 seasons to construct a heavy snow climatology. Heavy snow was defined as four inches or more and there were only five cases for Augusta, GA (AGS). Since these storms are so infrequent, their impact on the local communities can be extensive, bringing transportation and commerce to an abrupt halt. Timely and accurate winter precipitation type forecasts are essential in order to minimize the effect on local communities.

A substantial winter storm affected central South Carolina and the CSRA on 2-3 January 2002. Light snow began falling at CAE during the morning 2 January and by late in the afternoon, the snow was heavy at times. From 0000 UTC to around 1200 UTC 3 January, the precipitation mixed with or changed to freezing rain and ice pellets across the central and southeastern portion of the CAE county warning forecast area

(CWFA). By late in the day on 3 January, three to six inches of snow covered a large portion of central South Carolina and the CSRA of Georgia (Fig. 1). Eight to ten inches of snow fell over the extreme northern part of the CWFA, from northeastern Fairfield county across Lancaster and Chesterfield counties.

The purpose of this study is to demonstrate the importance of supplementing commonly used precipitation type forecasting techniques with cloud microphysics. The 2-3 January 2002 case was chosen because the synoptic pattern was consistent with heavy snowfall in central South Carolina and east central Georgia. While heavy snowfall did occur with this system, there was also an extended period of freezing drizzle. Supplementing precipitation type forecasting techniques commonly used by National Weather Service (NWS) forecasters with cloud microphysics considerations did a good job in depicting the evolution of precipitation type during the course of the event.

2. DATA AND METHODOLOGY

To study this event, Eta model forecast sounding data for CAE were examined using a local archive of BUFKIT data (Niziol and Mahoney 1997). Precipitation type forecasts using the partial thickness technique (TREND; Keeter et al. 2000), Energy Area technique (AREA; Bourgouin 2000), and the Eta model precipitation type algorithm (referred to as the BTC algorithm; Baldwin et al. 1994) were compared. Four Eta model runs, 0000 UTC 1 January to 1200 UTC 2 January were analyzed and meteograms were developed for both the observed and the forecast precipitation types. In addition, Eta model time-height plots for CAE were examined to determine the role cloud microphysics played in the evolution of precipitation type during the course of the event. Surface weather observations (METAR) at CAE were used to determine the hourly precipitation types. Reports from the media, law enforcement, spotters and cooperative observers were used to determine the total snowfall accumulations across the CWFA.

3. SYNOPTIC SITUATION

On 1 January strong arctic high pressure centered in the northern plains was building east across the Ohio Valley into the Middle Atlantic Region (not shown). By 1200 UTC 2 January, a 1032 hPa area of high pressure, was centered over West Virginia (Fig. 2). This cold and dry air mass began spreading south along the eastern slopes of the Appalachian Mountains. Cold air advection (CAA) and low level stability became enhanced across the Carolinas setting up the potential for a cold air damming (CAD) event (Fig. 3).

Surface data across central South Carolina indicated temperatures were mainly at or above 0^{o}C (32^{o}F) prior to the onset of precipitation (Fig. 4). However, the 1200 UTC sounding at Peachtree City, GA (FFC) showed the air mass was cold and saturated from 830-hPa to 700-hPa (Fig. 5). The temperature of the layer ranged from -3^{o}C (26^{o}F) to -10^{o}C (14^{o}F). The 1200 UTC surface dew point depression (Fig. 4) at CAE was 12^{o}C (22^{o}F) and at AGS it was 14^{o}C (25^{o}F). Therefore, there was potential for evaporational cooling given sufficient precipitation. With surface wet-bulb temperatures across central South Carolina below 0^{o}C (32^{o}F), freezing or frozen precipitation was possible. The 5400 (m) 1000-500-hPa thickness (See Figs. 2-3) was also across the region suggesting a precipitation type problem could be developing.

A succession of 500 hPa short wave troughs moved across the Gulf States late 1 January through 3 January. These disturbances generated cyclogenesis along a baroclinic zone in the central Gulf of Mexico. A surface low pressure area moved east-northeast across central Florida, and then slowly deepened off the South Carolina coast between 0000 and 1200 UTC 3 January (See Figs. 2-3 and 6-7). The intensification was in response to the strong 500-hPa low pressure area moving over the Southeastern States (Fig. 8). This surface low pressure track is favorable for heavy snow in central South Carolina and the CSRA of Georgia (Harms 1973). Keeter et al. (2000) describes this scenario as a Miller type A or classical synoptic situation, i.e., a single surface low along a cold front usually located over the Gulf of Mexico or Southeastern States.

Harms (1973) examined the snowstorm of 9-10 February 1973 which produced record snowfall across Georgia and South Carolina. This storm produced 16.0 inches at CAE and 14.0 inches at AGS (NCDC 2003). For the 1973 case, areas receiving the heaviest snow accumulations were located under the jet streak (70 kt) at 500-hPa. During the morning on 2 January 2002, a coupled polar jet structure at 500-hPa became apparent over the Southeastern states as a strong vorticity maximum moved into the base of the long wave trough (Figs. 8-9). Figure 9 shows an 80 kt jet streak at 500-hPa over the northeast Gulf of Mexico, a 70 kt jet streak off the North Carolina coast and a 65 kt jet streak extending westward across north central South Carolina. An area of 500-hPa to 300-hPa divergence developed between the entrance region of the jet streak off the North Carolina coast and the exit region of the jet streak over the Gulf of Mexico. North central South Carolina, under the 65 kt isotach received the heaviest snow (see Fig. 1).

The 850-hPa isotherm gradient intensified along the South Carolina coast by 0000 UTC 3 January (Fig. 10). The gradient took on an S-shape configuration over the eastern Gulf of Mexico, evidence of cyclogenesis. A 40 kt 850-hPa east-southeasterly jet transporting moisture and increasing the warm air advection and isentropic lift across the CWFA was evident. These processes were contributing to the deepening of the surface low off the South Carolina coast (See Figs. 6-7). Surface observations indicate snow developed during the late morning across the CSRA and Central South Carolina, with periods of moderate to heavy snow reported during the afternoon. Examination of the 1000-hPa to 850-hPa thickness (m) showed some warming of the layer from CAE southeast to the coast from 1800 UTC 2 January to 1200 UTC 3 January (See Fig. 6). It was during this period that freezing rain and ice pellets were reported at CAE and AGS. Despite the fact that the 850-hPa to 700-hPa moisture flux (not shown) shifted off the South Carolina coast by 1200 UTC 3 January, strong 500-hPa-300-hPa differential positive vorticity advection implied upward vertical motion across the CWFA through the afternoon and evening (Fig. 11). The precipitation changed to light snow after 1200 UTC 3 January and continued until late in the evening. Figure 12 shows the hourly observed precipitation type at CAE for the entire event.

4. CLOUD MICROPHYSICS AND PRECIPITATION TYPE

Cloud microphysics play an important role in determining precipitation type at the surface and should be considered by operational forecasters. At temperatures above -4^{o}C (25^{o}F), the cloud remains composed of supercooled liquid drops. Cloud condensation particles tend to support the growth of ice on their surface (ice forming nuclei), as the temperature of the cloud decreases below -10^{o}C (14^{o}F) and the relative humidity increases. When cloud temperatures are between -12^{o}C (10^{o}F) and -14^{o}C (7^{o}F) there is a 70% chance of ice in the cloud. When the cloud temperatures reach -15^{o}C (5^{o}F), there is a 90% chance of ice in the cloud. For heavy snow events, forecasters should look for strong upward vertical motion at the -15^{o}C (5^{o}F) temperature area of the cloud (Baumgardt 1999).

The 1200 UTC 2 January FFC sounding (See Fig. 5), indicated that the temperature at the top of the cloud (550-hPa) was around -15^{o}C (5^{o}F). This temperature is ideal for ice-crystal production and growth (Baumgardt 1999). Examination of the 1200 UTC 2 January Eta model time-height plot for CAE (Fig. 13a), suggests that the temperature in the upper levels of the cloud was around -15^{o}C (5^{o}F) during the morning 2 January and colder than -10^{o}C(14^{o}F) during the afternoon. The -10 *u*m/s omega contour extends to 525-hPa which is the preferred snow growth region of the cloud (Fig. 13a-b). Based on the Eta model time-height plot for CAE and the observed sounding data from FFC, it can be inferred that ice-crystals were growing by deposition and seeding the supercooled liquid drops in the lower levels of the cloud, thus contributing to snowflake growth. It is also suggested that less ice-crystal seeding was occurring during the overnight period, 0000 UTC 3 January to 1200 UTC 3 January as the cloud depth became more shallow, mainly below 600-hPa. Temperatures in the cloud top were forecast above -10^{o}C (14^{o}F), less favorable temperatures for ice-crystal formation and growth. This was also during the period when light freezing rain, freezing drizzle, and ice-pellets were reported at CAE and AGS. The upward vertical motion was forecast to be weaker after 0600 UTC 3 January, thus contributing to the light intensity of the precipitation during the remainder of the event (Fig. 13b). By 1200 UTC 3 January, a shallow but increasingly colder cloud was forecast, due to the development of strong cold air advection. This would render cloud top temperatures more favorable for ice-crystal formation and growth. The precipitation changed to light snow during the morning 3 January and continued into the evening.

5. PRECIP-TYPE FORECASTS

NWS forecasters routinely use the TREND technique, AREA technique, and BTC algorithm to assist in the prediction of winter precipitation type. Forecasters must be aware of the strengths and limitations of these tools and be able to incorporate their solutions with other considerations when forecasting winter precipitation type. The TREND precipitation type forecast technique was developed by correlating observations of precipitation types with 1000 hPa to 850 hPa and 850 hPa to 700 hPa thicknesses (m) derived from sounding data at Greensboro, North Carolina (Keeter et al. 2000). The strength of the surface-based cold air and the extent of warm air flowing atop the cold dome are described by these partial thicknesses. Nomograms are used to specify the predominant precipitation type for a 6-h period based on the combination of 1000-hPa to 850-hPa and 850-hPa to 700-hPa thickness (m). TREND does not forecast freezing drizzle events.

The AREA technique is a statistical method for predicting precipitation type which relies on the thermal structure of a sounding (Bourgouin 2000). The technique was developed using data from across North America. The predictors used include the positive and negative areas on a sounding associated with an above or below freezing layer respectively. The size of these areas is proportional to the mean temperature and depth of the layers. In contrast to the TREND technique, which produces a forecast of the predominant precipitation type for a 6-h period ending at the valid time, the AREA method provides a forecast of a specific precipitation type at the instantaneous time the data is valid. The specific precipitation types forecast by the AREA method include rain, snow, freezing rain, and ice pellets. The AREA method does not predict freezing drizzle or mixed freezing rain and ice pellets with snow.

The BTC algorithm, similar to the AREA technique, also relies on the thermal structure of a sounding. The scheme identifies above or below freezing layers and computes the area between 0^oC (32^oF) and the wet-bulb temperature. The areas associated with the warm and cold layers are used, along with the surface temperature to predict a single precipitation type at the surface. If the area with a wet-bulb temperature greater than -4^oC (25^oF) is greater than 3000 deg.-m, then snow is not permitted to be the precipitation type. This test increases the probability of detecting freezing rain and ice pellet events and results in over-prediction (Cortinas and Baldwin 1999). The BTC algorithm also does not predict mixed precipitation events or freezing drizzle.

For this case, the Eta time-height plot for CAE and the observed sounding from FFC suggested that ice-crystals were abundant in the cloud and located in the preferred region for snow growth during the morning and afternoon 2 January. Between 0000 UTC and 1200 UTC 3 January, the Eta time-height plot for CAE suggested the cloud depth was decreasing and supercooled water droplets were likely dominating over ice crystals. During this period, light freezing rain and freezing drizzle were the dominant precipitation type (see Figs. 12-13). It should be noted that both the TREND and AREA techniques do not explicitly take into account the depth of the cloud and do not account for freezing drizzle. These are important limitations to consider, especially when the depth of the cloud is expected to be shallow and cloud temperatures warmer than -10^oC (14^oF). With no ice crystals present in the cloud the precipitation type will be either liquid or freezing depending on the temperature at the surface.

The TREND, AREA, and BTC precipitation type meteograms for each Eta model run during the event are shown in Figs. 14-17. All three techniques do not account for shallow clouds with minimum temperatures below those required to support ice crystal growth, so the techniques had to be modified. For example, both the AREA and BTC techniques from the 0000 UTC 1 January Eta model forecast mainly forecasted snow through the forecast period (see Fig. 14b-c). However, the Eta time-height plot for

CAE suggested the cloud would become more shallow and warmer than -10^{o}C (14^{o}F) after 0600 UTC 3 January. The upward vertical motion was weaker during this period as well, so a modification of the precipitation type from snow to light freezing rain or drizzle was needed after considering cloud microphysics.

Overall, TREND verified well by forecasting snow as the predominant precipitation type and was more consistent with suggesting a period of freezing precipitation during the overnight period 2-3 January. Although both the TREND and AREA techniques take into account the depth of the cold air near the surface, TREND may produce better results since the technique was developed specifically for the Carolina region.

6. SUMMARY

Wintry precipitation is rare in central South Carolina and the CSRA of Georgia. It is important that forecasts of precipitation type be accurate and timely. The 2-3 January 2002 winter storm produced substantial snowfall accumulations across the WFO CAE CWFA.

A number of factors must be considered by forecasters when diagnosing precipitation type in the Carolinas and Georgia:

- The strength of the surface based cold air.
- CAD configuration (location of surface high pressure)
- The cold air in place prior to the onset of precipitation
- Track of surface low pressure
- Presence of dry air at the surface and aloft
- Intensity of forecast precipitation and resulting evaporational cooling
- Amplitude and tilt of the 500-hPa trough
- Location and strength of polar jet
- The 850-hPa thermal advection pattern
- Climatology
- Cloud microphysics considerations.

This winter storm case was an example of an event that was climatologically consistent with substantial snowfall in central South Carolina. A strong area of arctic high pressure centered in the Middle Atlantic region and building south across the Southeastern States was a source of low-level cold air and helped set up a baroclinic zone in the Gulf of Mexico. Dry air at the surface and aloft was available to support evaporational cooling once the precipitation developed. The surface low pressure track northeast across central Florida is a climatologically favorable storm track for heavy snow across central South Carolina and the CSRA of Georgia. The location of the polar jet at 500-hPa was helpful in determining the location of heavy snow bands. Forecasters should also look for strong low level moisture advection, warm air advection and isentropic lift from the Atlantic.

To accurately predict winter precipitation type, cloud microphysics need to be assessed in order to determine whether ice crystals are present in the cloud. Temperatures colder than -10^{o}C(14^{o}F) near the top of the cloud are necessary for ice crystal formation and growth. In addition, strong upward vertical motion in this snow growth region is essential for heavy snowfall events. In addition to using BUFKIT soundings and time-height plots to analyze cloud microphysics, LAPS and ACARS soundings may also prove useful.

The TREND, AREA and BTC precipitation type forecasting methods were analyzed for this case. These tools are all widely used by NWS forecasters for the prediction of precipitation type in winter storms. Forecasters must be aware of the strengths and limitations of these tools. The TREND, AREA and BTC techniques are limited in predicting mixed precipitation events. AREA and BTC do not predict mixed precipitation, only a single type at the ground. Even though the TREND method explicitly predicts mixed precipitation, local adjustments to the nomograms may be needed. Incorporating cloud microphysics with these techniques will help diagnose these events. When the precipitating cloud is shallow, upward vertical motion is weak and temperatures in the cloud are in the 0^{o}C (32^{o}F) to -10^{o}C (14^{o}F) range, freezing drizzle or light freezing rain is the preferred precipitation type forecast.

For this case study, incorporating cloud microphysics with the precipitation type techniques suggested a period of heavy snow during the morning and afternoon 2 January due to sufficient ice crystal growth and strong upward vertical motion. As the cloud became shallower during the overnight hours 2-3 January, a period of light freezing rain and drizzle developed as supercooled liquid drops dominated over ice crystals. The precipitation changed to light snow during the morning 3 January as cold air advection developed and temperatures in the cloud cooled below -10^{o}C (14^{o}F). Of the three precipitation type techniques discussed in this paper, the TREND technique appeared to have the best overall forecasts of precipitation type. For this event, CAE forecasters used a blend of the techniques to assist in the precipitation type forecast. However, more weight was placed on the TREND technique primarily because it was developed for the Carolina region and familiar to the forecasters. Cloud microphysics and synoptic features were considered by examining both observed and model data.

ACKNOWLEDGMENTS

The author would like to thank Mike Cammarata, WFO CAE Science Operations Officer, and Heather Hauser, NWS Eastern Region Scientific Services Division, for their review and suggestions.

REFERENCES

Baldwin, M., R. Treadon, and S. Contorno, 1994: Precipitation type prediction using a decision tree approach with NMC's mesoscale Eta model. Preprints, *10th Conf. On Numerical Weather Prediction*, Portland, OR, Amer. Meteor. Soc., 30-31.

Baumgardt, D., 1999: Wintertime Cloud Microphysics Review. [Available on-line from http://www.crh.noaa.gov/ arx/micrope.html]

Bourgouin, P., 2000: A Method to Determine Precipitation Types. *Wea. Forecasting*, **15**, 583-592.

Cortinas, J. V., and M. E. Baldwin, 1999: A preliminary evaluation of six precipitation-type algorithms for use in operational forecasting. Proceedings, *6th Workshop on Operational Meteorology*, Halifax, Nova Scotia, Canada, Environment Canada, 207-211.

Harms, R. W., 1973: Midwestern snowstorm models and the February 1973 storm over Georgia. *NOAA Technical Memorandum,* NWS SR-74, National Weather Service, Fort Worth, TX, 13pp.

Keeter, K., J. Blaes and L. Lee, 2000: Introduction to Forecasting Predominate Precipitation Type Trends (TREND). [Available on-line from http://www2.ncsu.edu/eos/service/pams/ meas/sco/research/nws/trend/index.html.]

National Climatic Data Center (NCDC), 2003: Local Climatological Data Columbia South Carolina. *Normals, Means, and Extremes*, 8pp.

Niziol, T. A., and E. A. Mahoney, 1997: The use of high resolution hourly soundings For the prediction of lake effect snow. Preprints, *13th Int. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology,* Long Beach, CA, Amer. Meteor. Soc., 92-95.

Figures

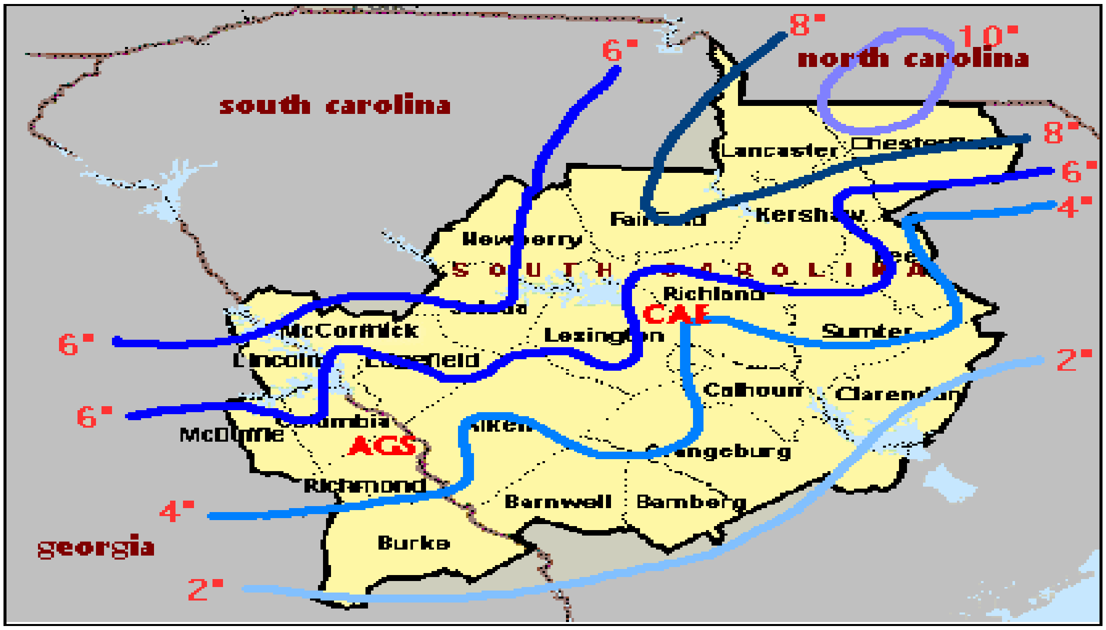


Figure 1. Total snowfall accumulation (in) across the Columbia County Warning Forecast Area (CWFA; shaded yellow) from 1200 UTC 2 January 2002 to 0500 UTC 4 January 2002. CWFA county names in black. AGS and CAE location donated in red. Data from local and county law enforcement, Skywarn spotters, cooperative observers, and the media were used to compile this map.

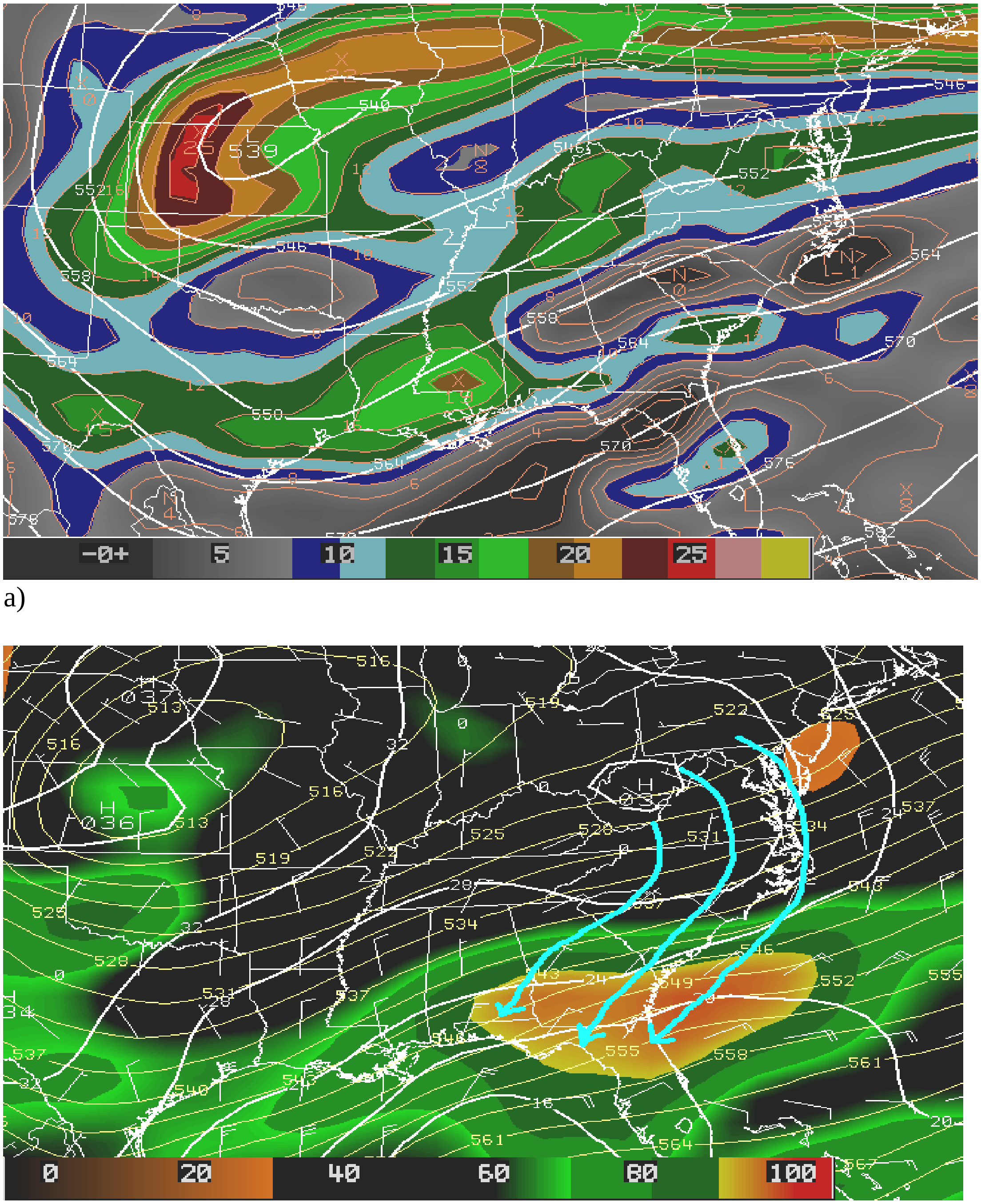


Figure 2. Eta 00-hr forecast valid 1200 UTC 2 January 2002. a) 500-hPa geopotential heights (m x 10; thick solid) and vorticity (s^{-1}; thin solid and shaded). b) mean sea level surface pressure (hPa; thick solid), wind (kt), 1000-hPa to 500-hPa relative humidity (%; shaded), and 1000-hPa to 500-hPa thickness (m x 10; thin solid). Note green is relative humidity greater than 70 % and yellow is 95 % or greater. Blue arrows depict cold air advection (CAA).

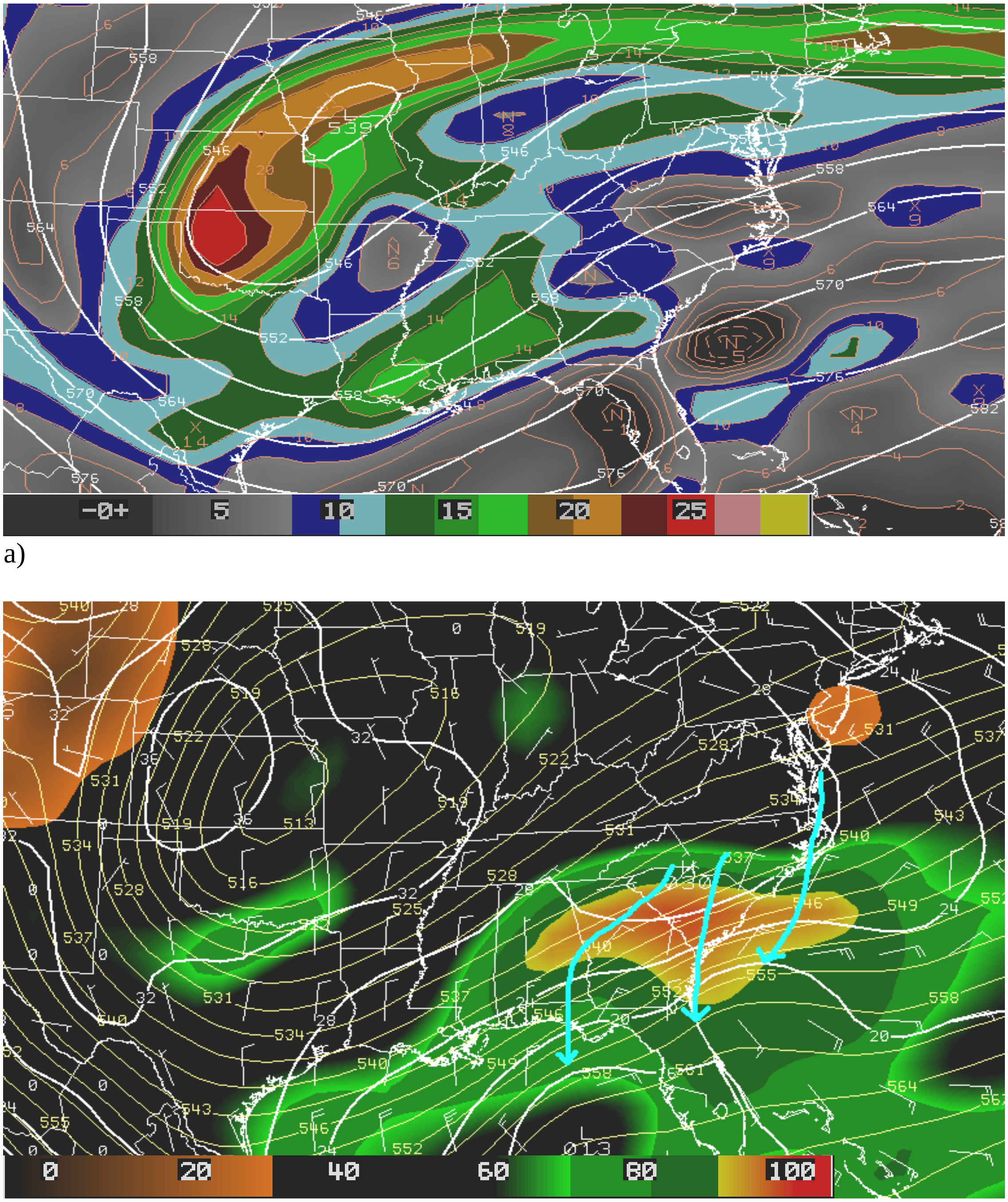


Figure 3. Eta 00-hr forecast valid 1800 UTC 2 January 2002. a) 500-hPa geopotential heights (m x 10; thick solid) and vorticity (s^{-1}; thin solid and shaded) b) mean sea level surface pressure (hPa; thick solid), wind (kt), 1000-hPa to 500-hPa relative humidity (%; shaded), and 1000-hPa to 500-hPa thickness (m x 10; thin solid). Note green is relative humidity greater than 70 % and yellow is 95 % or greater. Blue arrows depict cold air advection (CAA).

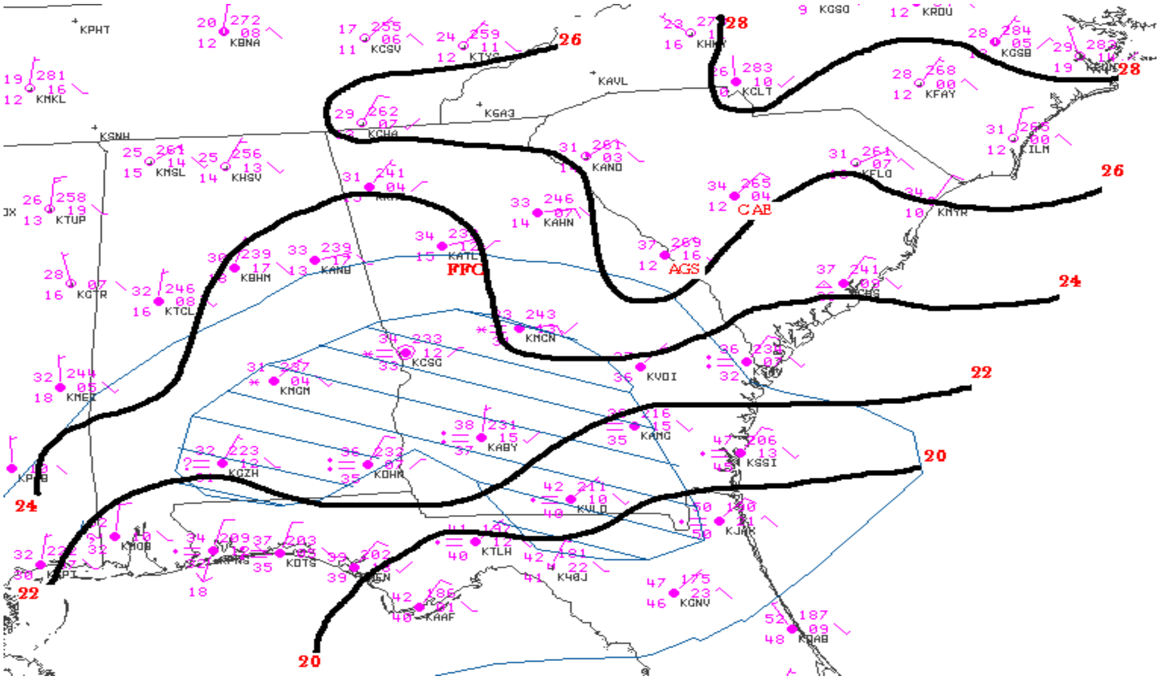


Figure 4. METAR observations standard plot, mean sea level pressure (hPa; thick solid), and weather depiction analysis (precipitation area; contoured and hatched) valid 1200 UTC 2 January 2002. FFC (Peachtree City, GA) labeled in red.

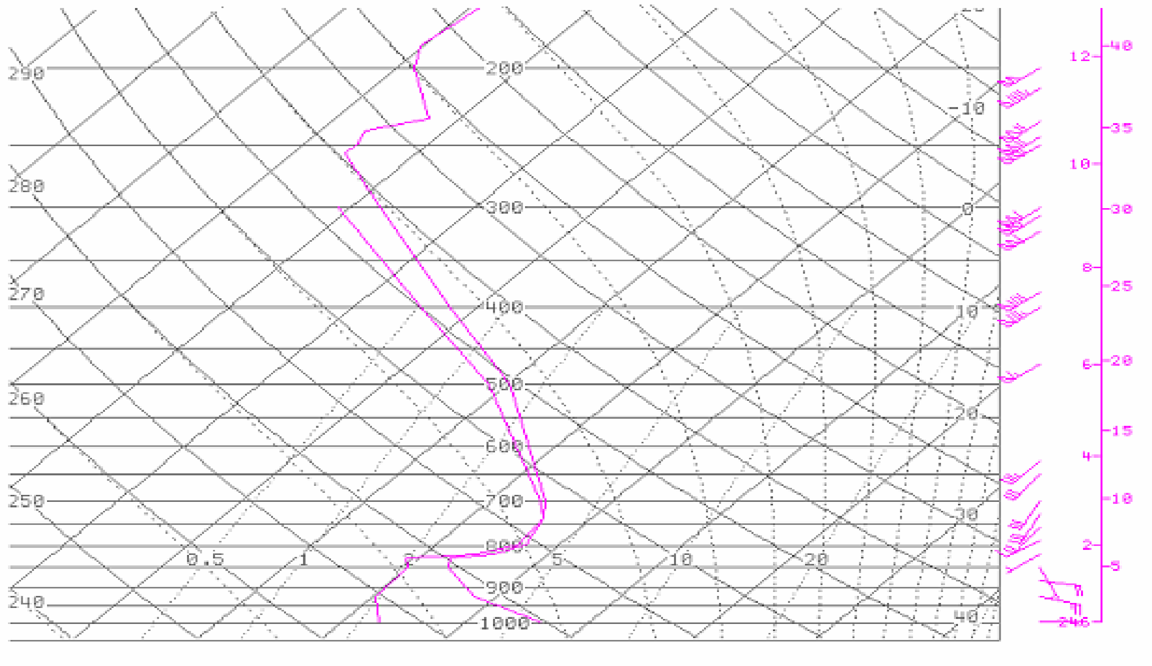
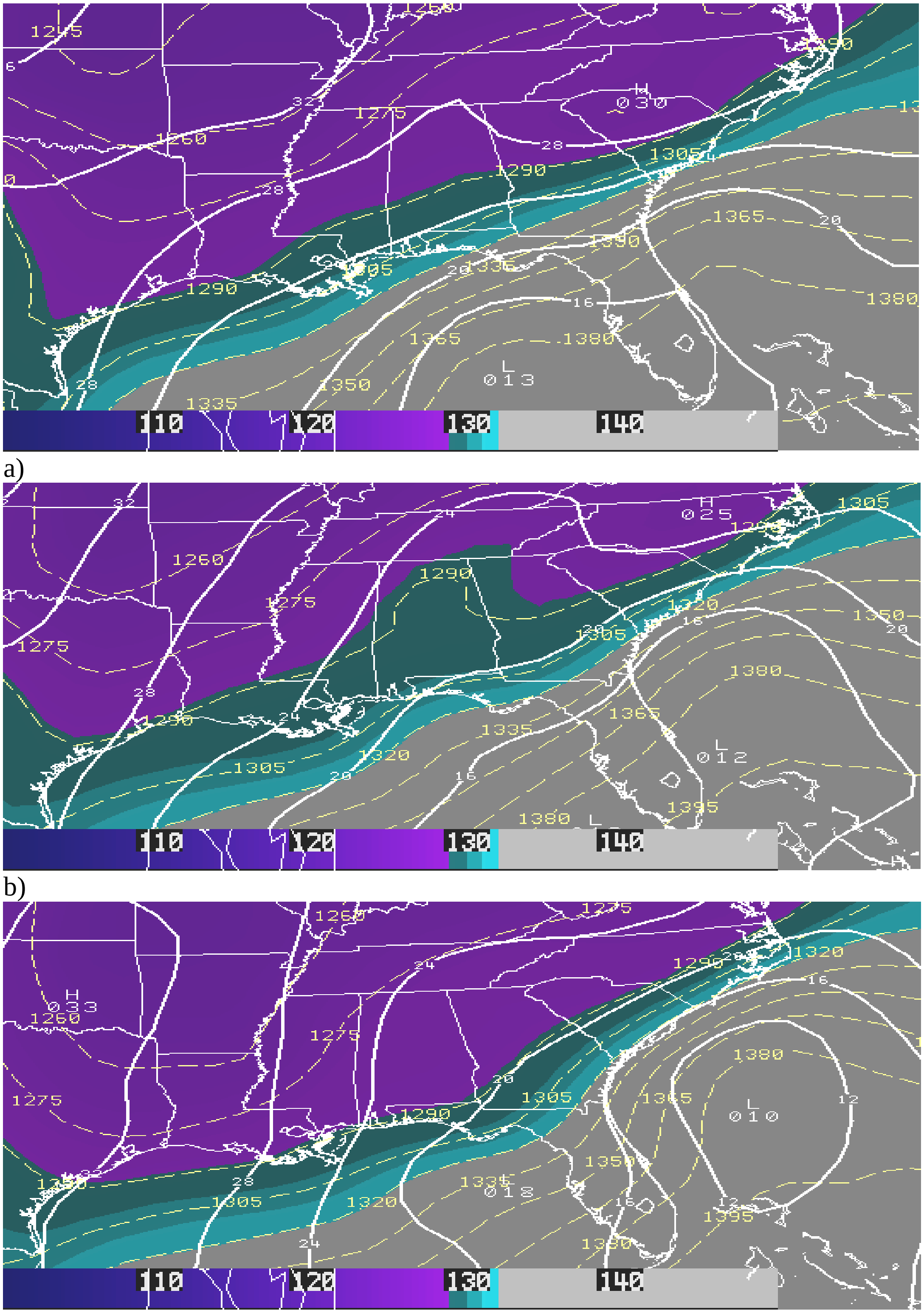


Figure 5. The 1200 UTC 2 January 2002 sounding from Peachtree City, Georgia (FFC). Note the dry layer below 850-hPa and the deep midlevel moisture. Above 650-hPa the cloud layer was below -10^{o}C, which suggests ice crystals are dominating over supercooled liquid droplets.



a)

b)

c)

Figure 6. Eta 00-hr forecast mean sea level surface pressure (hPa; thick solid) and 1000-hPa to 850-hPa thickness (m; thick dashed) a) valid 1800 UTC 2 January 2002. b) valid 0000 UTC 3 January 2002. c) valid 0600 UTC 3 January 2002.

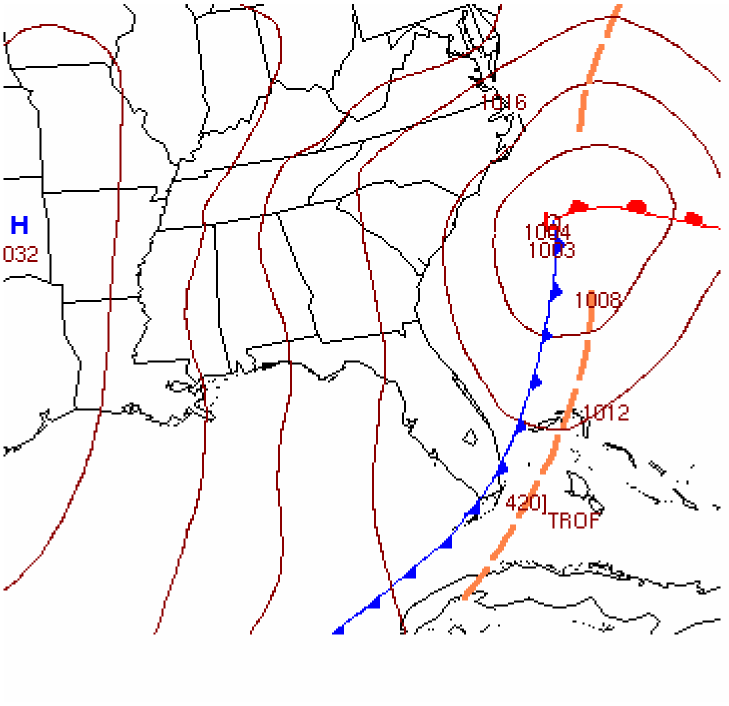


Figure 7. NCEP/HPC mean sea level surface pressure (hPa) and frontal analysis valid 0900 UTC 3 January 2002.

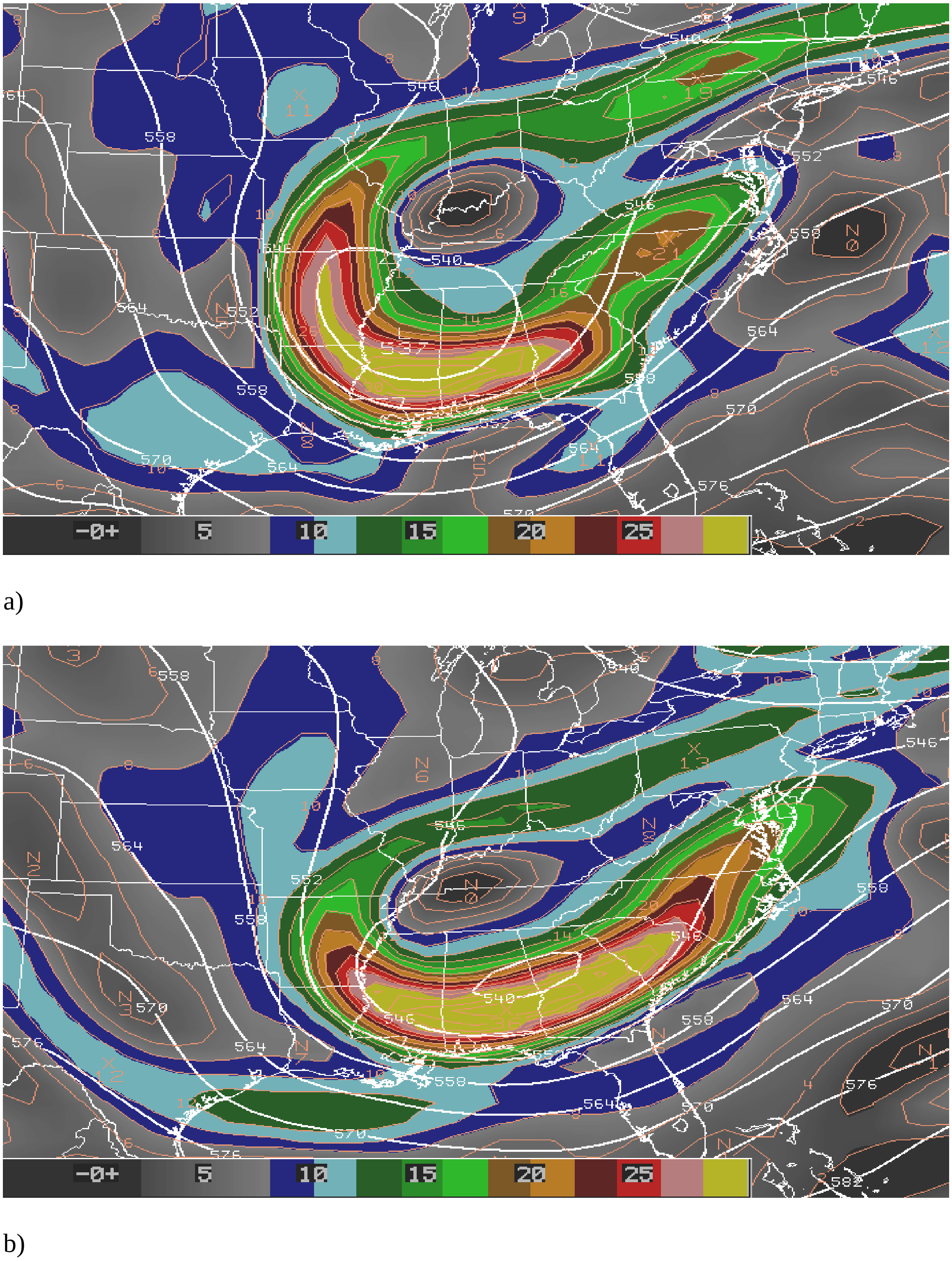


Figure 8. Eta 00-hr forecast 500-hPa geopotential heights (m x 10; thick solid) and vorticity (s^{-1}; thin solid and shaded) a) valid 1200 UTC 3 January 2002. b) valid 1800 UTC 3 January 2002.

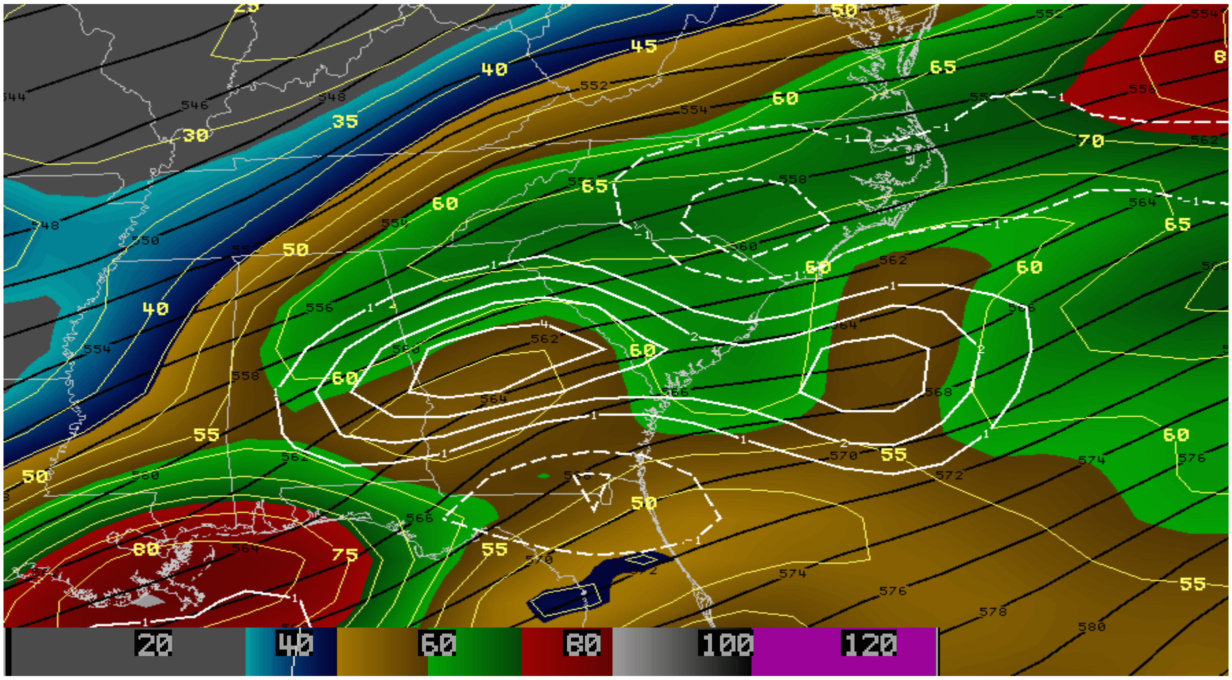


Figure 9. Eta 00-hr forecast 500-hPa geopotential heights (m x 10; thick solid black), isotachs (kt; thin solid yellow and shaded), and 500-hPa to 300-hPa divergence (s^{-1}; thick solid and dashed white) valid 1200 UTC 2 January 2002.

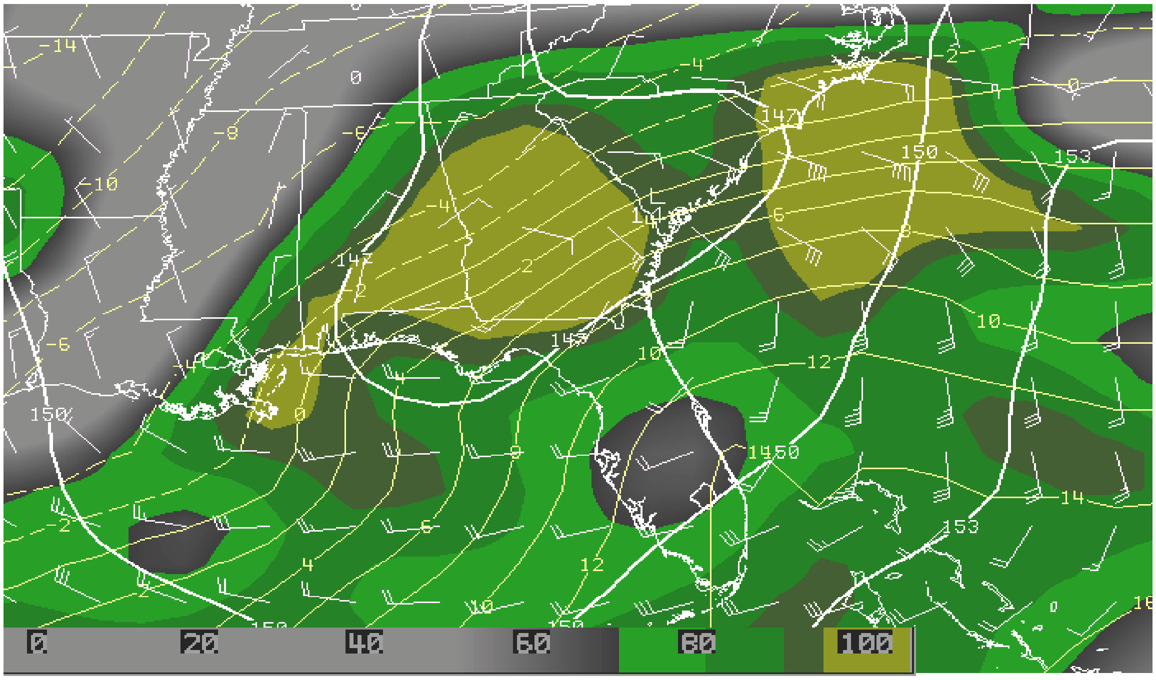
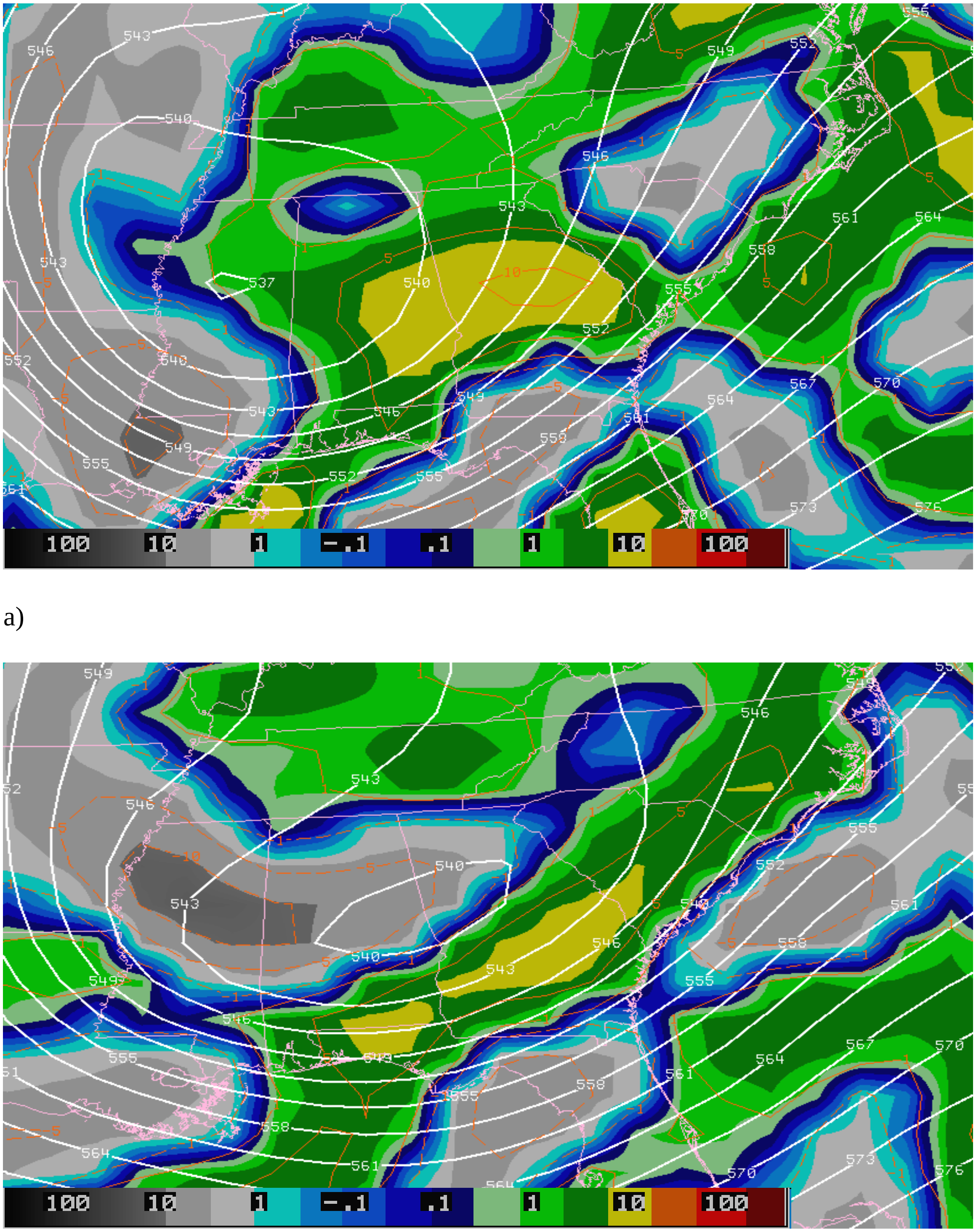


Figure 10. Eta 00-hr forecast 850-hPa geopotential heights (m x 10; thick solid), relative humidity (%; shaded), wind (kt), and temperature (^{o}C; thin solid & dashed) valid 0000 UTC 3 January 2002. Note green is relative humidity greater than 70 % and yellow is 95 % or greater.



a)

b)

Figure 11. Eta 00-hr forecast 500-hPa geopotential heights (m x 10; thick solid) and 700-hPa to 500-hPa differential vorticity advection (s^{-1}; thin solid and shaded) a) valid 1200 UTC 3 January 2002 b) valid 1800 UTC 3 January 2002.

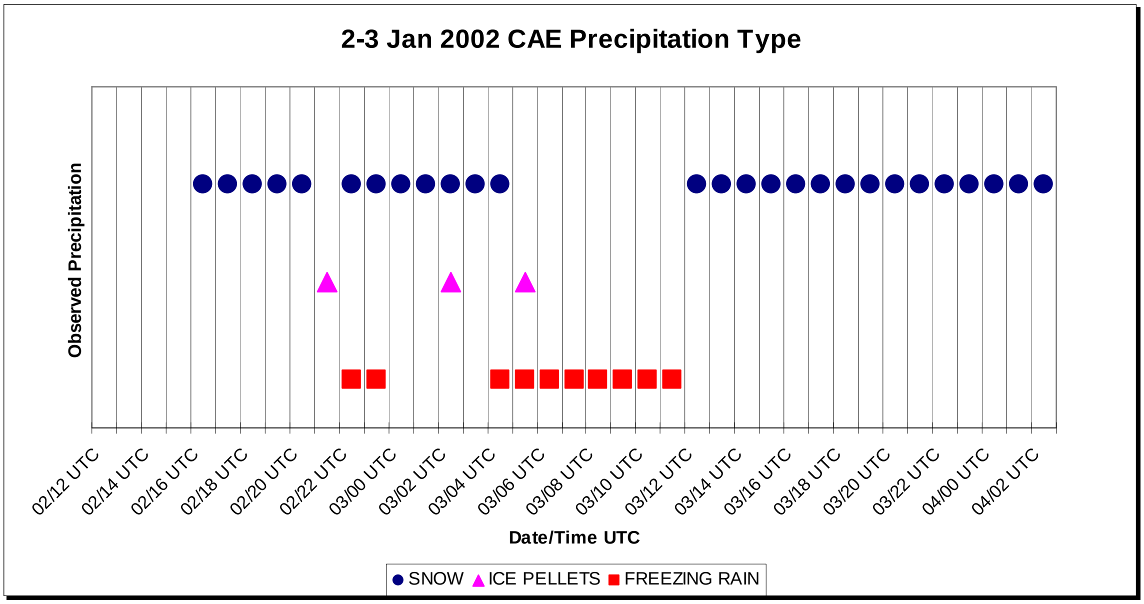
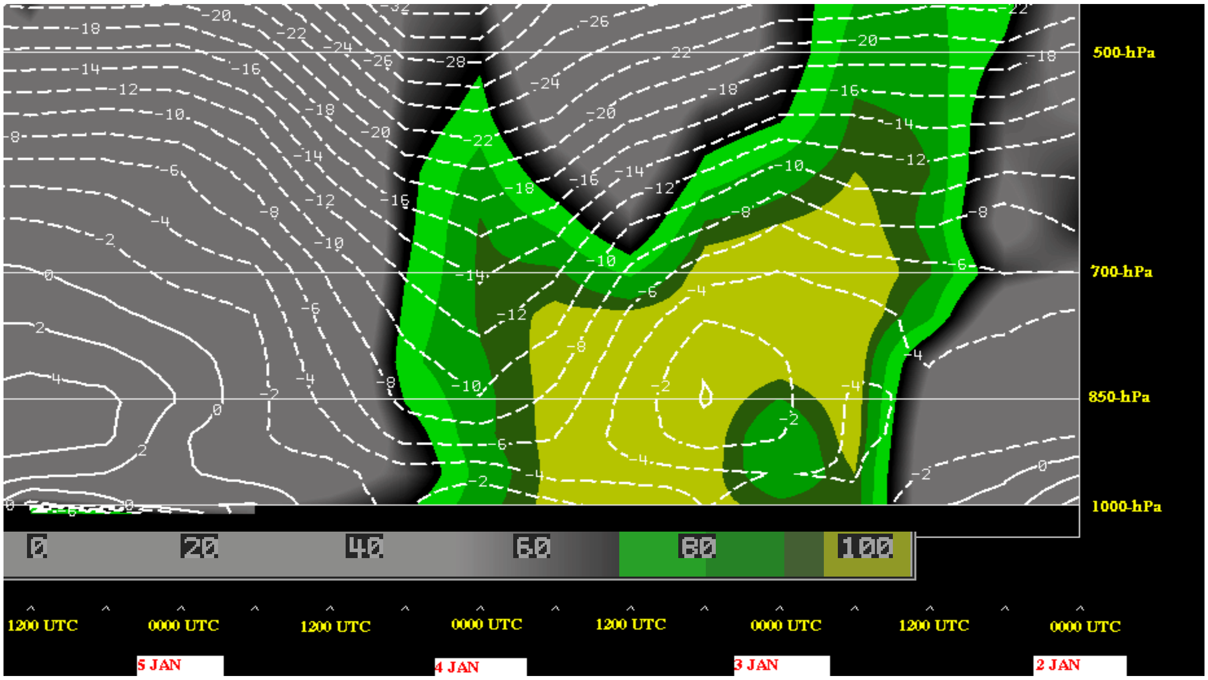
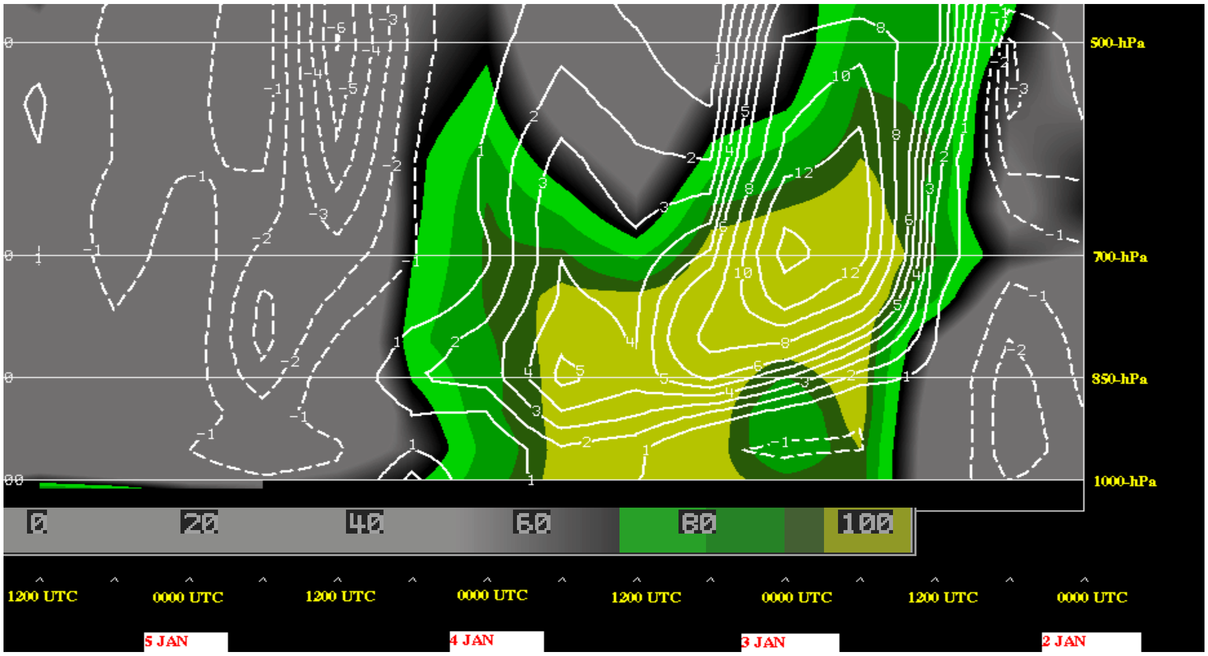


Figure 12. The hourly observed precipitation-type at Columbia, South Carolina for the 2-3 January 2002 winter storm.



a)



b)

Figure 13. Eta 1200 UTC 2 January 2002 time-height plot at Columbia, SC a) of relative humidity (%) image and temperature (^{o}C) contours. b) of relative humidity (%) image and omega *(u*m/s) contours. Note green is relative humidity greater than 70 % and yellow is 95 % or greater.

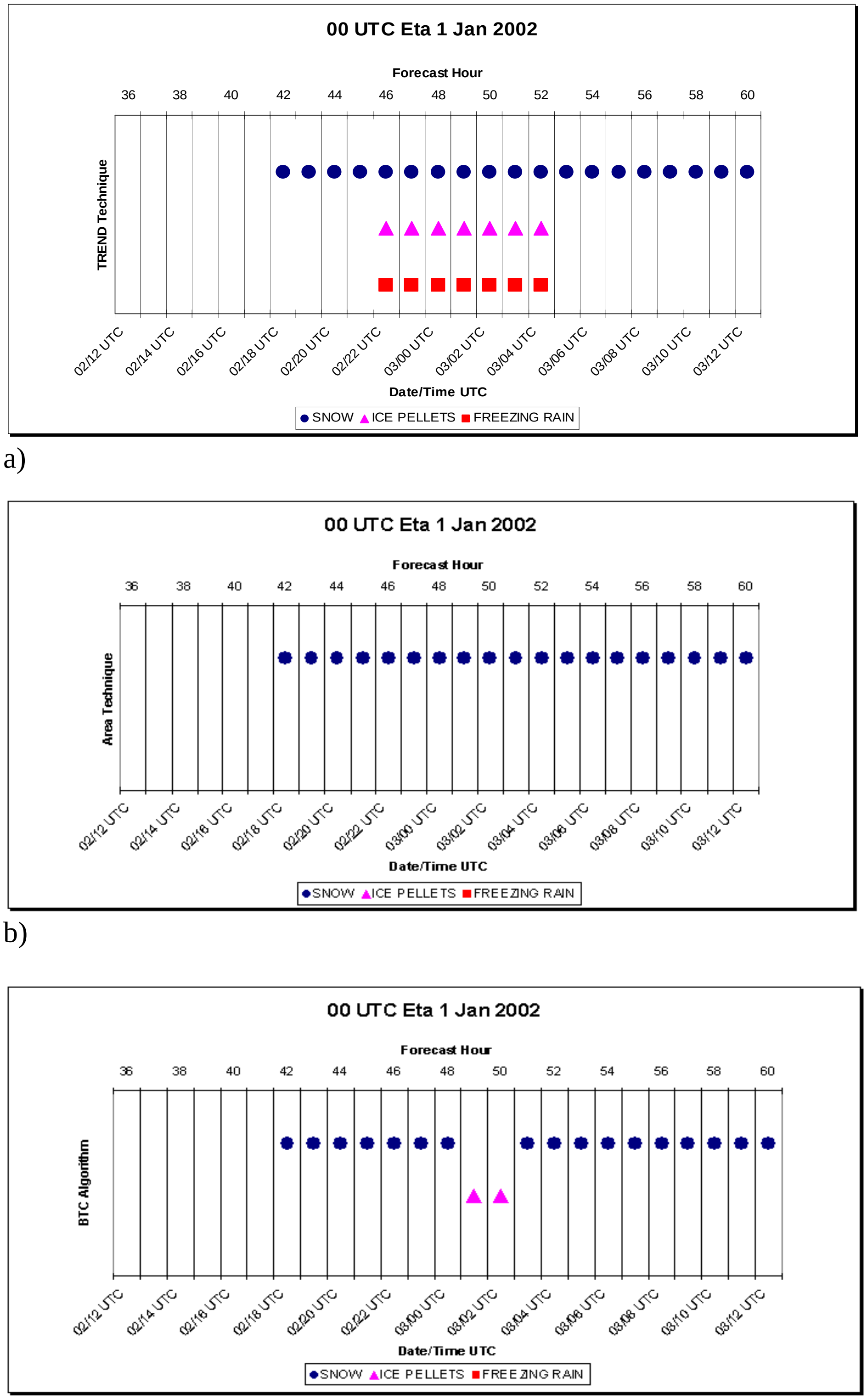
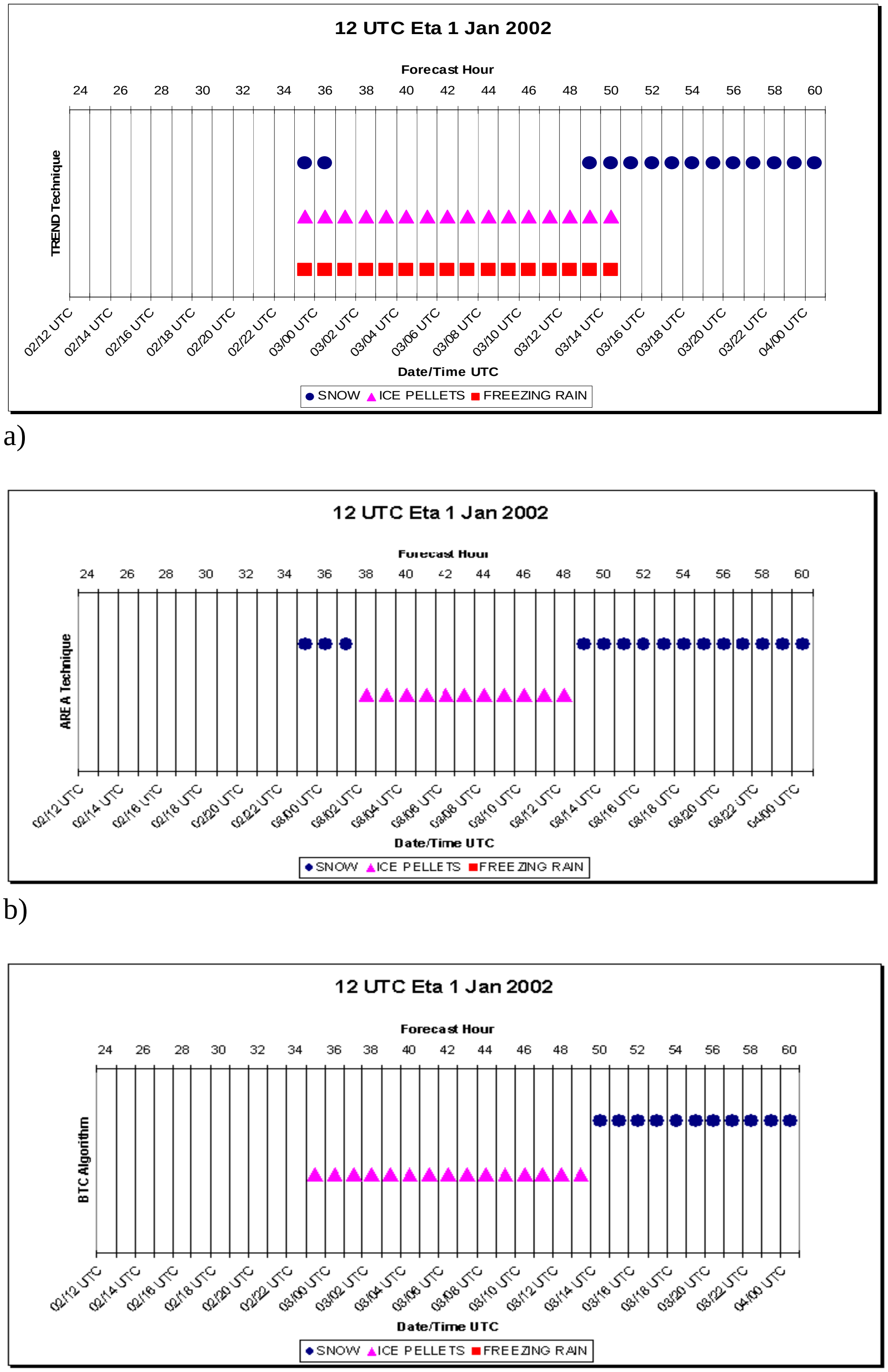


Figure 14. Hourly precipitation type forecasts from 0000 UTC 1 January 2002 Eta model run a) TREND technique. b) AREA technique. c) BTC algorithm.



a)

b)

c)

Figure 15. Hourly precipitation type forecasts from 1200 UTC 1 January 2002 Eta model run a) TREND technique. b) AREA technique. c) BTC algorithm.

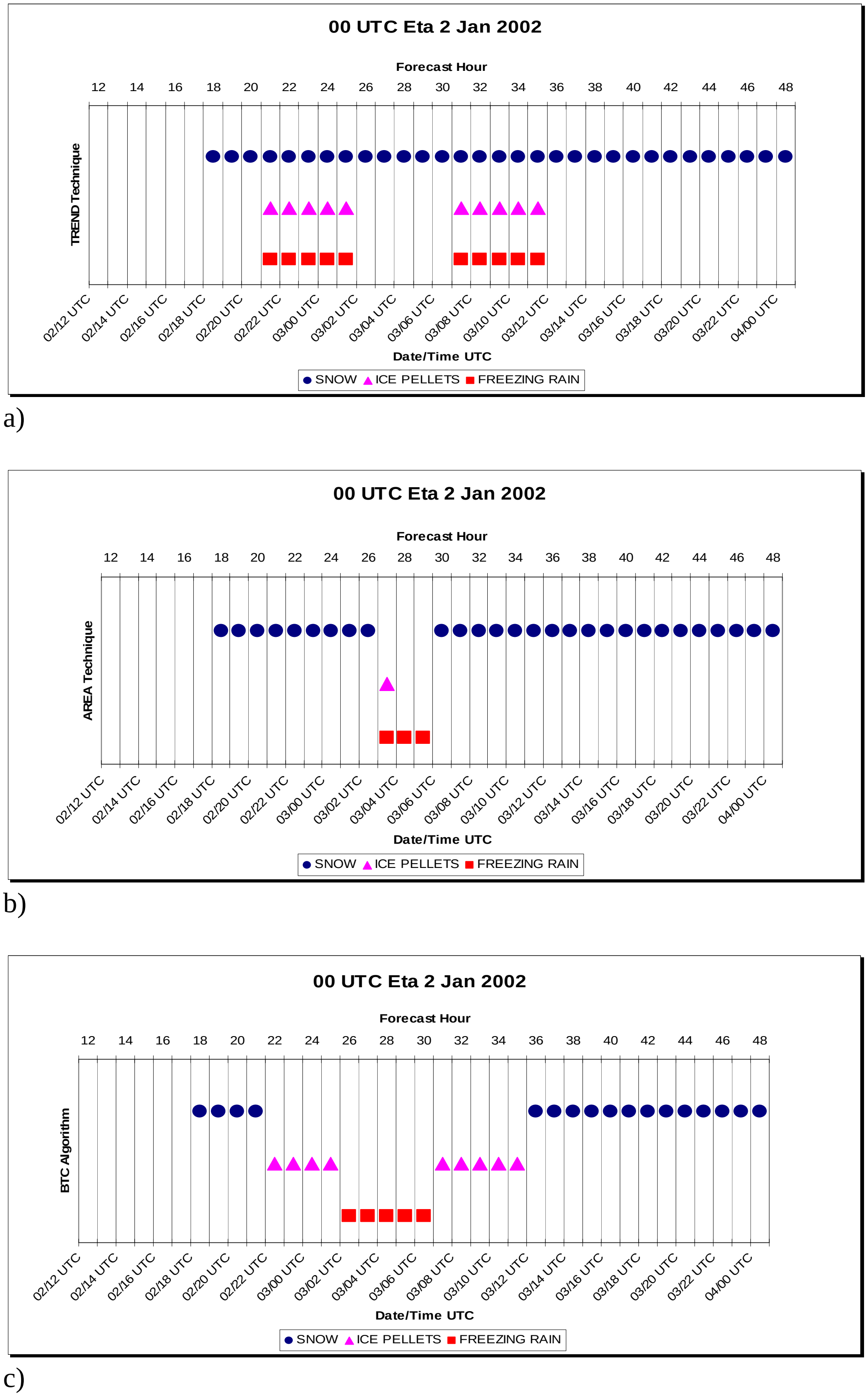


Figure 16. Hourly precipitation type forecasts from 0000 UTC 2 January 2002 Eta model run a) TREND technique. b) AREA technique. c) BTC algorithm.

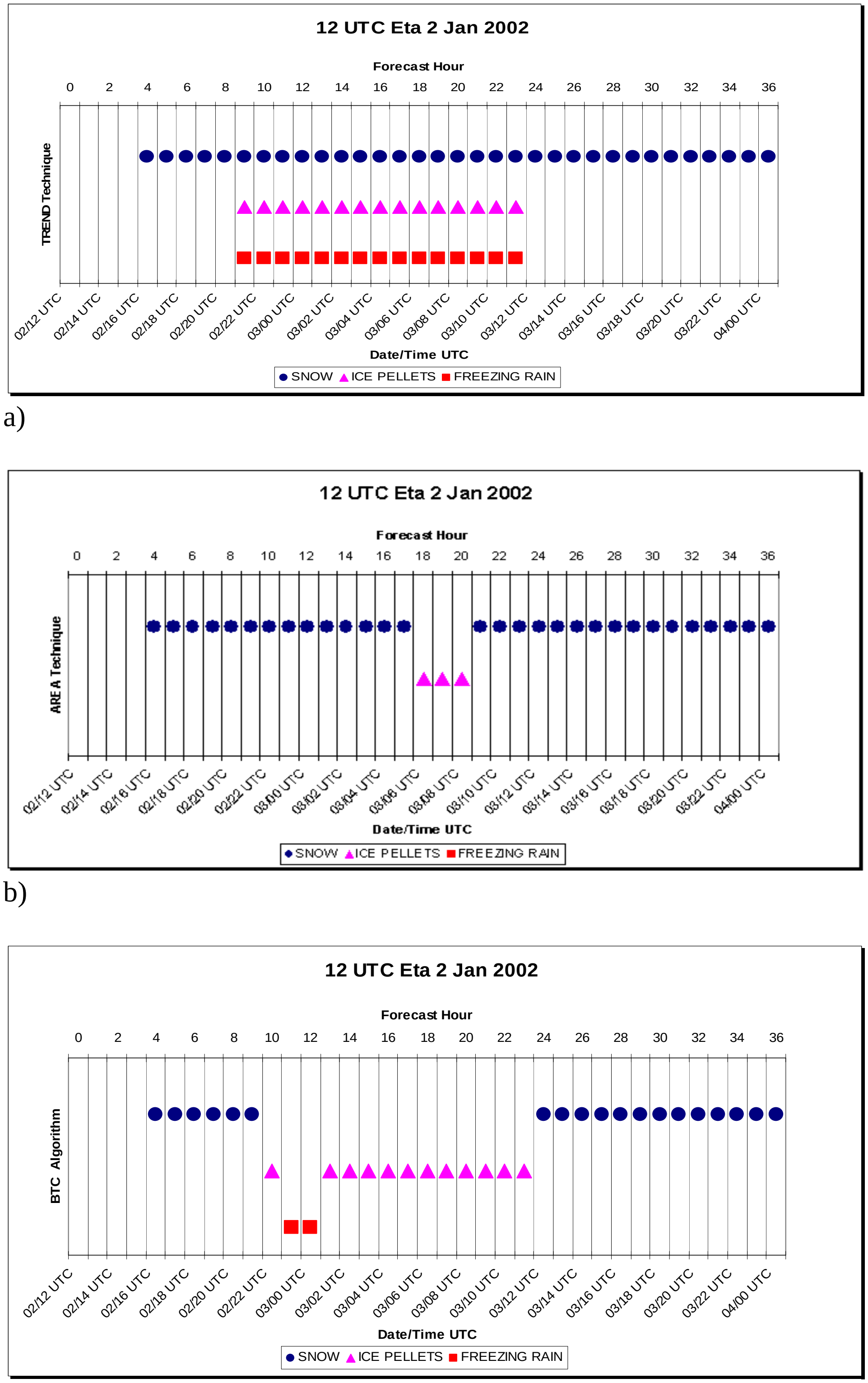


Figure 17. Hourly precipitation type forecasts from 1200 UTC 2 January 2002 Eta model run a) TREND technique. b) AREA technique. c) BTC algorithm.