Analysis of the December 26th, 2004 North Carolina Winter Storm

Bradley N. McLamb*

*Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University

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Abstract

The December 26, 2004 North Carolina winter storm resulted in a complex frozen precipitation pattern across a climatologically unfavorable region of the state. This paper analyzes the cause of the very narrow swath of accumulating frozen precipitation, and finds that it was the result of a complex interaction between the Miller Type A cyclone, Atlantic moisture transport and availability of below freezing air. Together, these storm variables were able to produce a very narrow zone where all ingredients were in place to produce a significant winter storm. Potential vorticity, warm air advection, and partial thicknesses were all examined, and found to be the most significant factors influencing the evolution of this event. It was concluded that this event unfolded as expected, and by looking at the aforementioned parameters, small scale details were resolvable.

I. Introduction

The December 26th, 2004 winter storm for North Carolina was the closest thing to a white Christmas most residents of eastern North Carolina had seen in many years. This storm was a history maker for other parts of the U.S. as well; upon originating from a deep 500mb trough over the central U.S., the storm first dumped unprecedented snow over parts of southeastern Texas and the Gulf Coast states, before turning northward towards the Carolinas. This was certainly not the most orthodox snowstorm for North Carolina either, as the more climatologically favored regions of the state (Piedmont and Mountains) saw little, if any appreciable precipitation, while parts of the Coastal Plain saw upwards of 8 inches of snow accumulation. As evident in Figure 1, only a small swath of the state was delivered a white day after Christmas, and it is the focus of this paper to determine what mechanisms resulted in this narrow band of snowfall in the climatologically less-favored region. It is my hypothesis that the structure and location of this storm system resulted in a rather uncommon early season snowfall for the North Carolina Coastal Plain. The results of this research could provide a useful diagnostic tool to operational forecasters for future events that are similar in atmospheric composition to this one.

II. Background

It is important to recognize well-known features regarding North Carolina winter weather and this particular type of winter storm before beginning analysis. North Carolina presents several unique challenges when it comes to winter weather. The Appalachian Mountains create a boundary that traps cold air, usually resulting in a wide array of precipitation types across the state (Keeter and Cline 1991; Keeter et al. 1995). Another key feature that influences the forecast of wintry precipitation is the warm Gulf Stream, which resides approximately fifty kilometers from the coast and creates a strong baroclinic zone between the warm air over it and the cold air over land. This baroclinicity serves to generate and/or enhance low pressure areas rapidly as they approach from the southeast (Maglaras et al. 1995). When these two factors combine, they become a formidable challenge for meteorologists; the cold air trapped in place along the mountains and wedging eastward combined with a strengthening low pressure system moving north-westward results in a highly variable quantitative precipitation forecast, along with sharp boundaries between rain, snow, sleet, freezing rain, or a mixture of all of these (Gurka et al. 1995; Keeter et al. 1995; Lackmann et al. 2002).

It is apparent that this storm was a Miller Type A storm system from the criteria proposed by James Miller, who first classified these storm types in 1946. Miller Type A cyclogenesis occurs along the front of a cold air outbreak (Miller 1946). They are most often observed along the coast during the winter. Typically, several features are present at the time of origin for a Miller Type A cyclone including: 1) cold anticyclone east of the Rocky Mountains, 2) a cold, continental air mass flowing off the continent, 3) a current of warm, maritime air from a southerly or southeasterly direction in the western Atlantic, 4) a retardation of part of the cold front so that the front is distorted into a wave form, 5) a spreading (or overrunning) of clouds and precipitation above the cold wedge associated with cold air damming (Miller 1946). Miller Type A cyclones such as the one in Figure 16, normally form over the ocean and track long a baroclinic zone (such as the Gulf Stream) in a northeastward motion. It is clear from the aforementioned criteria, and looking at Figures 8-11 that the December 26th, 2004 snowstorm was a Miller Type A event, which has certain implications on the expected precipitation type(s) and gradient that will be discussed further in this paper.

III. Methodology and Data

The methodology and data used to research this storm system were crucial to recognizing the synoptic and mesoscale features responsible for the sharp precipitation gradient. NARR data was obtained from the National Climatic Data Center (NCDC), and displayed in the Integrated Data Viewer. NARR data was obtained for December 23-26, and was used to analyze the formation, evolution, and eventual impacts on North Carolina. Level II radar data was also obtained from NCDC, and was displayed using the GR LEVEL II software package. This was vital for determining precisely where the precipitation gradient was located, and how it evolved during the course of the event. The National Weather Service Raleigh Office provided invaluable plots in their case study such as potential vorticity, model forecasts, surface wet-bulb plots, and hand analyses all of which were used to analyze the dynamic features of this event. RAOB sounding data was obtained from the University of Wyoming, but was not that helpful in analyzing the thermal profile of the affected region since the closest site was located in Greensboro, a location that received no precipitation from the event.

III. Analysis

A) Model Performance and Analysis of the Synoptic Scale Evolution of the Storm

Initially, a digging 500mb trough dove southward through the Plains into southern Texas, where a strong vorticity maximum (Figure 12) interacted with an inverted trough over the Gulf of Mexico to induce cyclogenesis and form a low pressure system at the surface. From this point the system traversed the central Gulf of Mexico, before turning northeastward in response to a strong baroclinic zone located over the Gulf Stream as evident in Figures 8-11. As Maglaras et al. (1995) points out, this is when storms typically begin to intensify, as was the case with this system. It is from this point that the model performance will be evaluated.

The December 25th 12z GFS and NAM both portrayed a potentially wintry scenario across North Carolina for the following day, but not without significant errors. The 12 hour forecast for both models (valid at 00z 12/26), depicted the area of low pressure beginning to cross the Florida peninsula, with strong potential vorticity (PV) associated with latent heat release from convective precipitation occurring well to the northeast of the storm according to the GFS (Figure 4), and to the west in the case of the NAM (Figure 3). This had a significant impact on both model's depiction of precipitation over North Carolina by 12z 12/26.

Due to the northeastward placement of convective precipitation and the associated PV maximum, by 12z on the morning of the event, the GFS had the surface low shifted farther east, with northeasterly 850mb winds over central and eastern North Carolina (Figure 6). This would have resulted in much less moisture flux from the Atlantic, and thus much lighter QPF as predicted by the GFS.

Meanwhile, the NAM, which had placed the PV maximum to the west of the low, was forecasting the surface low to transition from the PV maximum over the Gulf of Mexico to a newly developing PV maximum over the Gulf Stream. This was in response to convection and the strongly baroclinic zone just offshore of the Carolinas (Figure 5). Accordingly, the entire system was shifted closer to the coast causing the NAM to forecast easterly to southeasterly 850mb winds, which would enhance moisture transport and thus explain why the NAM was forecasting more precipitation over the Coastal Plain of North Carolina.

The 12z RUC model was used to verify which NCEP model had more accurately depicted the complex cyclone location, and resultant wind and precipitation fields. Analyzing Figure 7, it is evident that neither model was entirely correct in it's representation of the PV field. According to RUC analysis, the main PV maximum at 12z 12/26, was located over the Florida peninsula with a lobe of PV stretching across the baroclinic zone to offshore Cape Hatteras, NC. Also of importance, the NARR 12z analysis in Figure 23 shows that all of the absolute vorticity was located in the base of the 500mb trough, which would also favor further cyclone strengthening ahead of the trough where the surface low was at the time. The RUC also indicated that the low pressure system was closer to the Carolina shore than indicated by the GFS, which resulted in a more onshore flow from the Atlantic, aiding in precipitation generation. The end result was that the NAM had more accurately depicted an onshore flow, enhanced moisture flux, and more precipitation over the region; however, this does not account for the tight gradient of wintry precipitation over the region. For that, a closer examination of multiple factors including the thermal structure associated with the storm is necessary.

B) QG Approach to Understanding Westward Extent of Precipitation Shield

It has been established that an onshore flow advected Atlantic moisture into the Carolinas, and by looking at the wind profile and forcing for ascent it will become evident as to why the precipitation shield was oriented the way that it was. Figures 20-22, which show the 09z, 12z, and 15z radar displays, reveal that there is a very sharp dividing line between moderate precipitation, and no radar returns. The period of Figures 20-22 depict the period when the majority of wintry precipitation fell across the region, and it is clear that from central Wake County westward, little precipitation fell.

Dual jet streams played a significant role in enhancing precipitation across parts of North Carolina during this event. Figure 13 shows the NAM analysis of the two jet cores at play across North Carolina at 12z 12/26. The northern jet stream associated with an upper level trough places North Carolina in the right entrance region of a strong 130+ kt jet maximum, while the southern jet stream was oriented so that North Carolina was in the left exit region of a weaker 90+ kt jet. The results were significant upper-level divergence, and strong forcing for ascent aloft.

With an onshore flow from the Atlantic, and upper-level forcing for ascent across the entire region, precipitation would fall in areas where there was enough warm air advection. Examining Figures 27-29, strong veering of winds from 1000mb up to 850mb was present from Wake County eastward, and this correlates precisely to where Figures 19-21 show that precipitation was occurring. When the shield of precipitation was most widespread, between 09-12z, there appears to be at least 45° of veering between the surface and 850mb winds, while at 15z the amount of veering decreases and the precipitation shield begins to diminish in coverage. The other significant factor to be considered was the direction of the 850mb winds, which was from the east in locations that received measurable precipitation. This goes back to the fact that the 850mb low, like the surface low discussed earlier, was closer to the coast and thus allowed for a more onshore flow (Figure 15). Thus, it is no coincidence that areas with an eastward 850mb wind, which allowed Atlantic moisture the opportunity to advect over the cold dome of air at the surface, received measurable wintry precipitation.

C) Using the Thermal Profile to Determine Eastward Extent of Wintry Precipitation

Looking at the radar (Figures 20-22), there are clear signals that a changeover from frozen/freezing precipitation was occurring across the Coastal Plain region of North Carolina. The high dbz reflectivity seen in Figures 20 and 21 across Wayne, Sampson, Lenoir and even Johnston County are referred to as bright banding. This phenomenon occurs when a snowflake partially melts on its trip to the surface, producing a larger droplet size and thus giving off a higher reflectivity value. Not only that, but it can also indicate that ice is in the falling droplet, which also produces a higher reflectivity.

The fact that this storm system was characterized my multiple precipitation types and very narrow transition zones is supported by Gurka et al. (1995) and Miller (1946), and is further supported by an analysis of the partial thicknesses across the region. The GSO sounding shown in Figure 14 is ordinarily an appropriate place to begin when analyzing the thermal profile, but in this case it was too far west and much colder than areas receiving warm air advection and precipitation farther east. The next step is to look at partial thicknesses; Figures 24-26 show that the theoretical rain/snow 1000-850 thickness of approximately 1300m lies across the western side of the precipitation shield.

The result was a diabatically driven snowfall, in which precipitation rates significantly influenced the amount of evaporational cooling initially, and melting afterwards, which resulted in a predominant precipitation type of snow across the western edge of the precipitation shield. In some areas of northeastern NC, where thicknesses at 1000-850mb were below 1300m, and 850-700mb thicknesses were below 1550m, which are supportive of all snow on the partial thickness nomogram, saw all snow and received 8 to 10 inches of snow out of this event. Farther east, the precipitation type was a predominant mix of freezing rain and sleet, which reduced snowfall accumulation totals significantly, although some snow did mix in during heavier bursts. Along the immediate coast, the air column was warm enough to support only rain as the warm, moist Atlantic air eroded any shallow cold air in place there. Figures 17-19 support this as they show the 1000-850mb thickness overlaid with 850-700mb thickness, (which were also very marginal for snow), along with surface observations which confirm the precipitation type distribution.

The end result, as evident from the accumulation maps seen in Figure 2, was an event with multiple precipitation types with snow being predominant over a narrow swath across the western Coastal Plain region of North Carolina, with a mix of freezing rain and sleet being predominant farther east. The relatively sharp edge to the eastern snow line seen on satellite imagery was the result of the changeover to rain across eastern North Carolina. This was a great example of a case where the partial thickness technique was extremely valuable in determining the precipitation types across the region.

IV. Conclusions

The December 26th, 2004 winter storm produced an intricate array of meteorological processes that resulted in a complex precipitation distribution across climatologically unfavorable snowfall regions. The event was driven by a dual jet structure that placed North Carolina in a favorable region for upper-level forcing for ascent, combined with Atlantic moisture influx. Widespread snowfall was limited by two important factors that resulted in a narrow area receiving accumulating frozen precipitation. The narrow gradient of wintry precipitation was controlled by the westward extent of warm air advection and 850mb easterly flow, and by an above freezing air column to the east. In the end, a fortunate few (or unfortunate depending on your viewpoint), received a significant early season winter storm that would be remembered for being a near-miss white Christmas, and for delivering wintry precipitation to regions of North Carolina that aren't accustomed to receiving any.

Acknowledgements: A special thanks to the National Weather Service of Raleigh for providing an exceptional case study on this event, without which some of the information I used in this research would not have been possible. The data provided by the National Center for Environmental Prediction (NCDC) - North American Regional Reanalysis (NARR) was vitally important to analyzing this system as well. Unidata, whose IDV program was used extensively, was also a valuable tool in analyzing the model data and reanalysis files. Finally, the Level II radar data provided by NCDC was an important tool in evaluating the precipitation shield, and the GR Level II Software program provided an excellent graphical radar display of the event.

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Figures

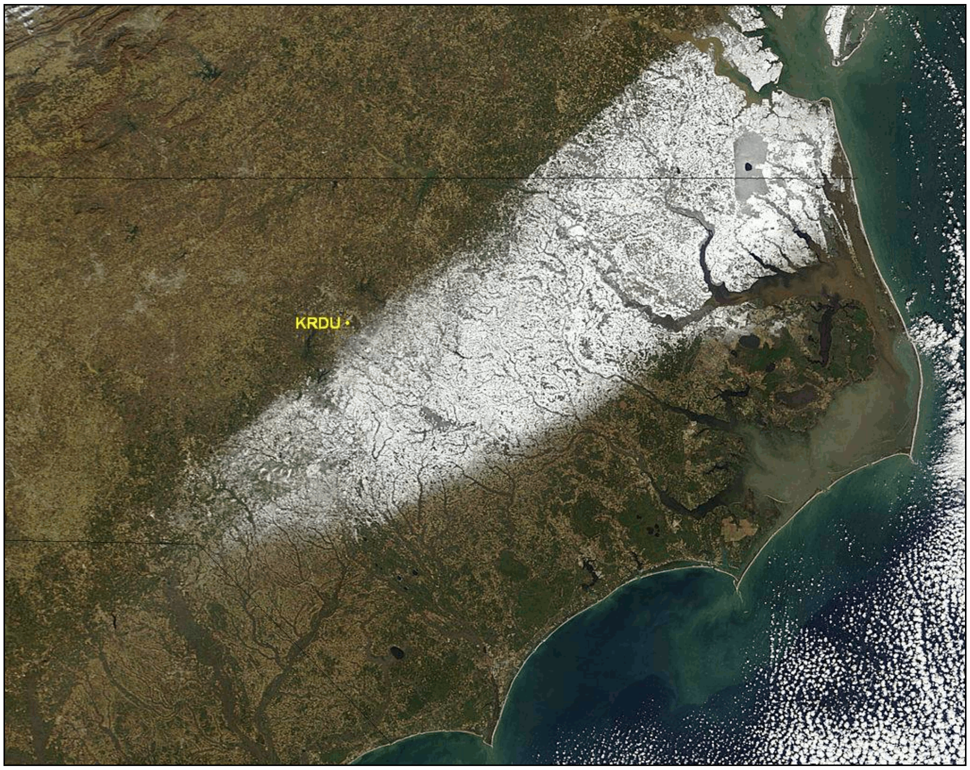

Figure 1. Terra MODIS Satellite Imagery from 12/27/2004

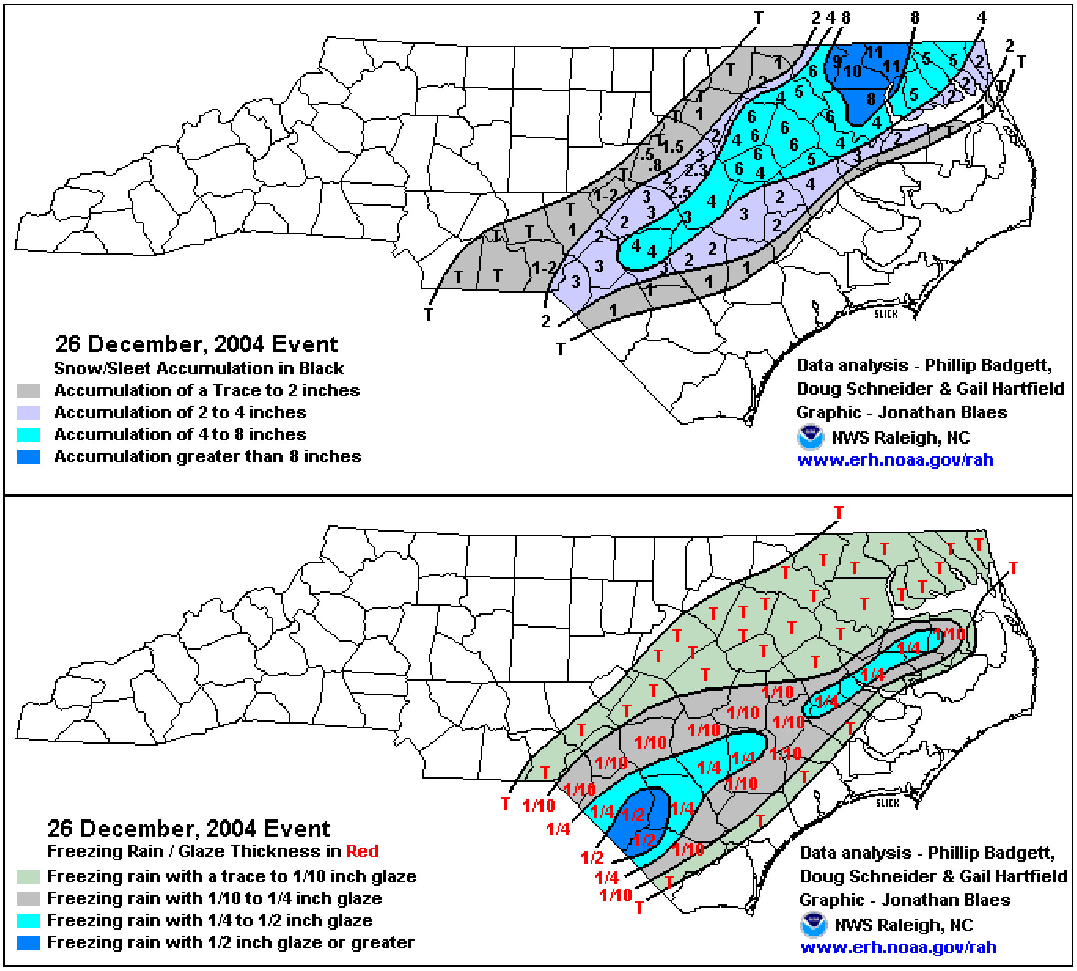

Figure 2. National Weather Service Accumulation Map

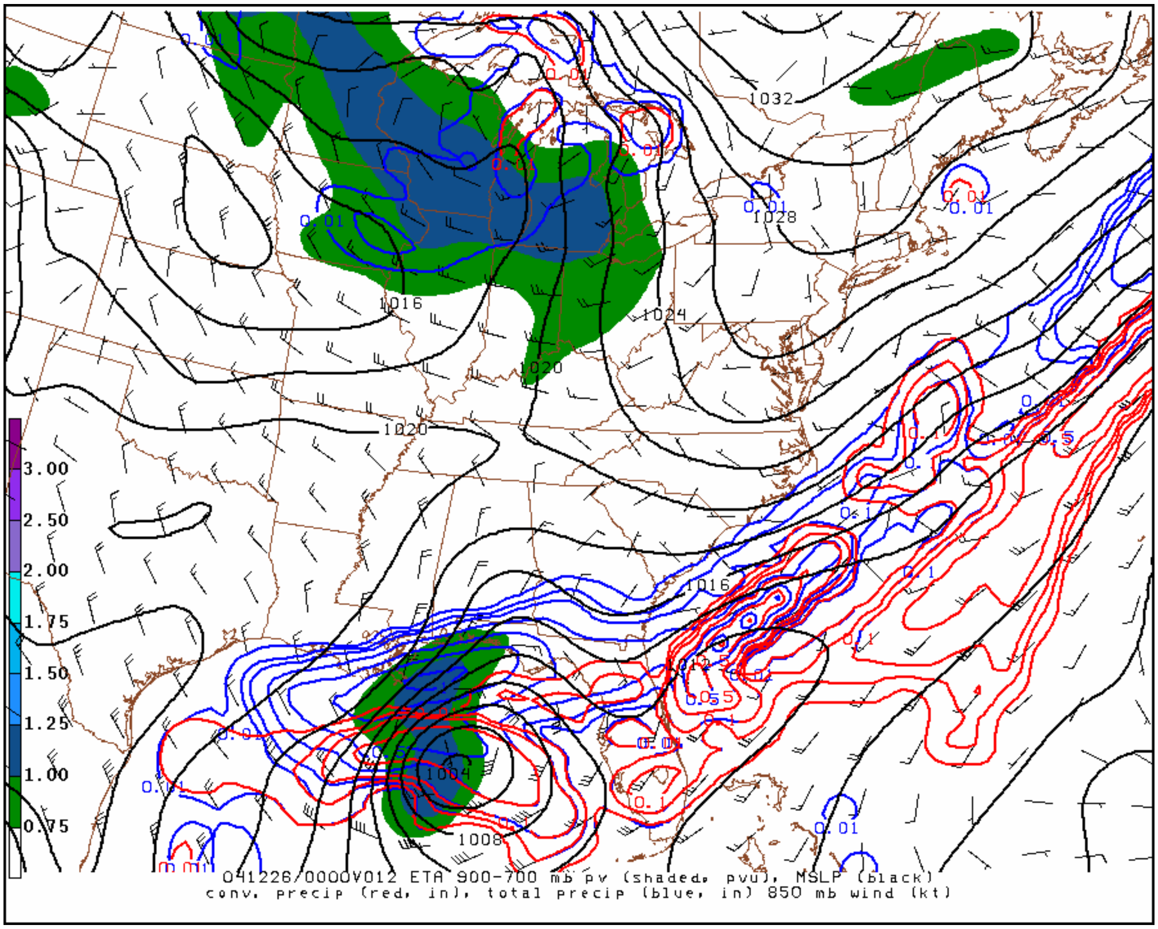

Figure 3. 12/25 12z NAM 12/26 00z forecast PV (shaded), MSLP (black), Conv. Precip (red), Total Precip (blue), 850 mb wind; Courtesy of National Weather Service - Raleigh

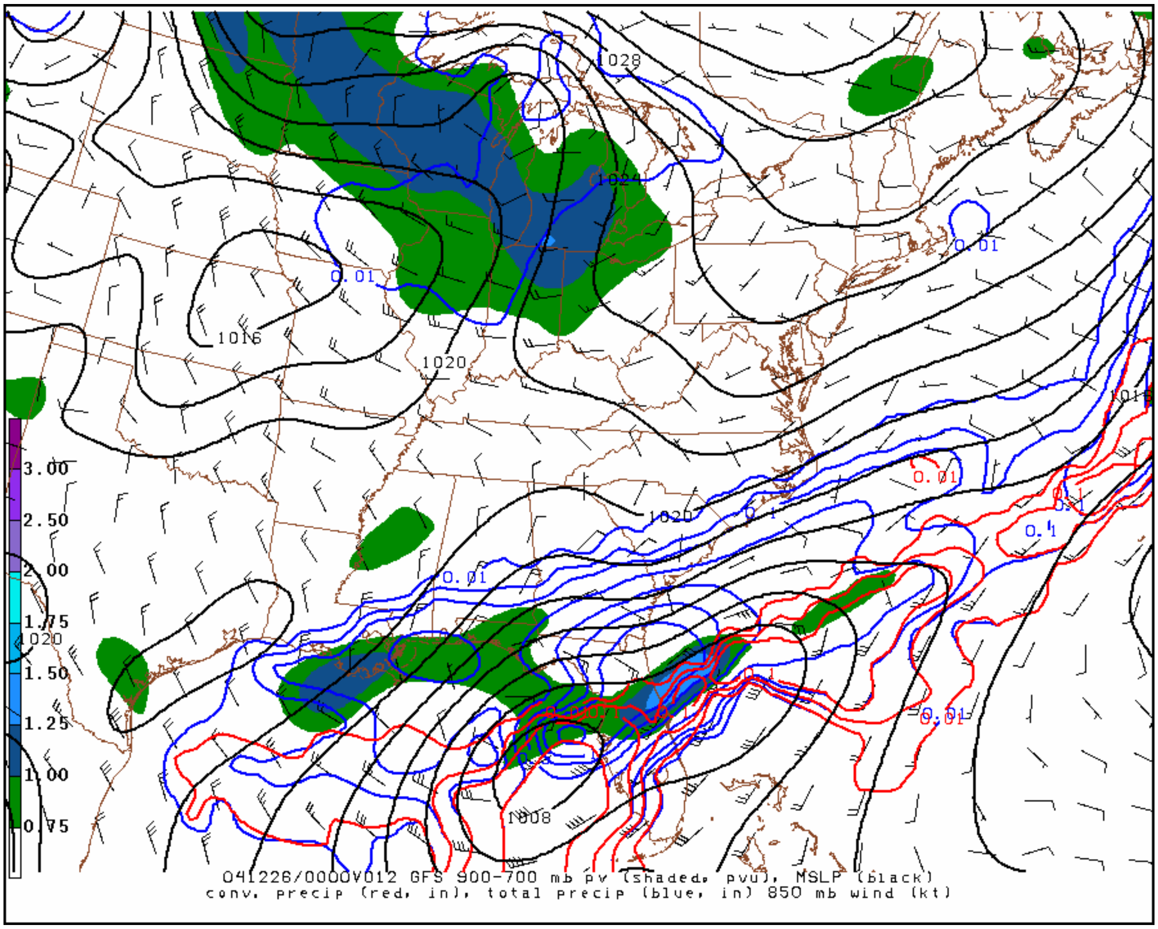

Figure 4. 12/25 12z GFS 12/26 00z forecast PV (shaded), MSLP (black), Conv. Precip (red), Total Precip (blue), 850 mb wind; Courtesy of National Weather Service - Raleigh

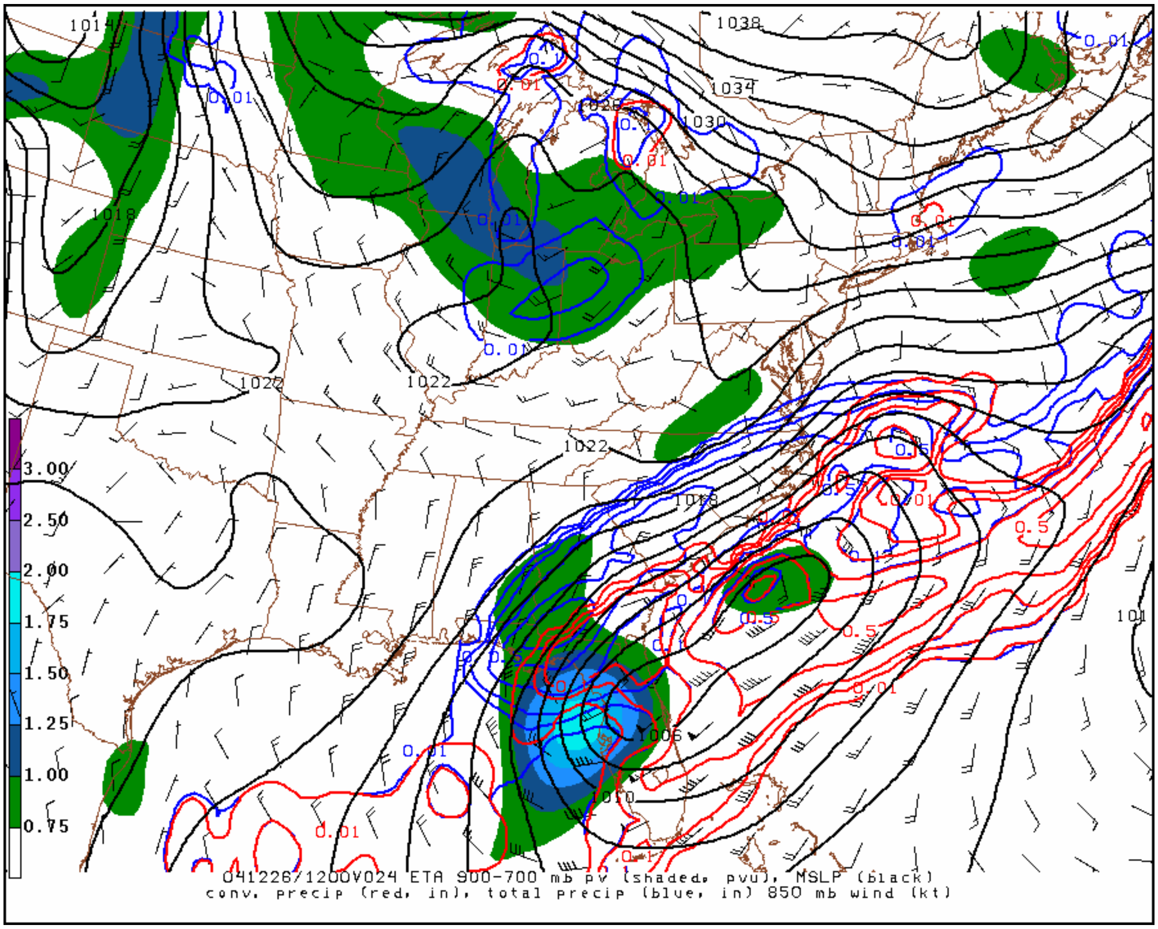

Figure 5. 12/25 12z NAM 12/26 12z forecast for PV (shaded), MSLP (black), Conv. Precip (red), Total Precip (blue), 850 mb wind; Courtesy of National Weather Service - Raleigh

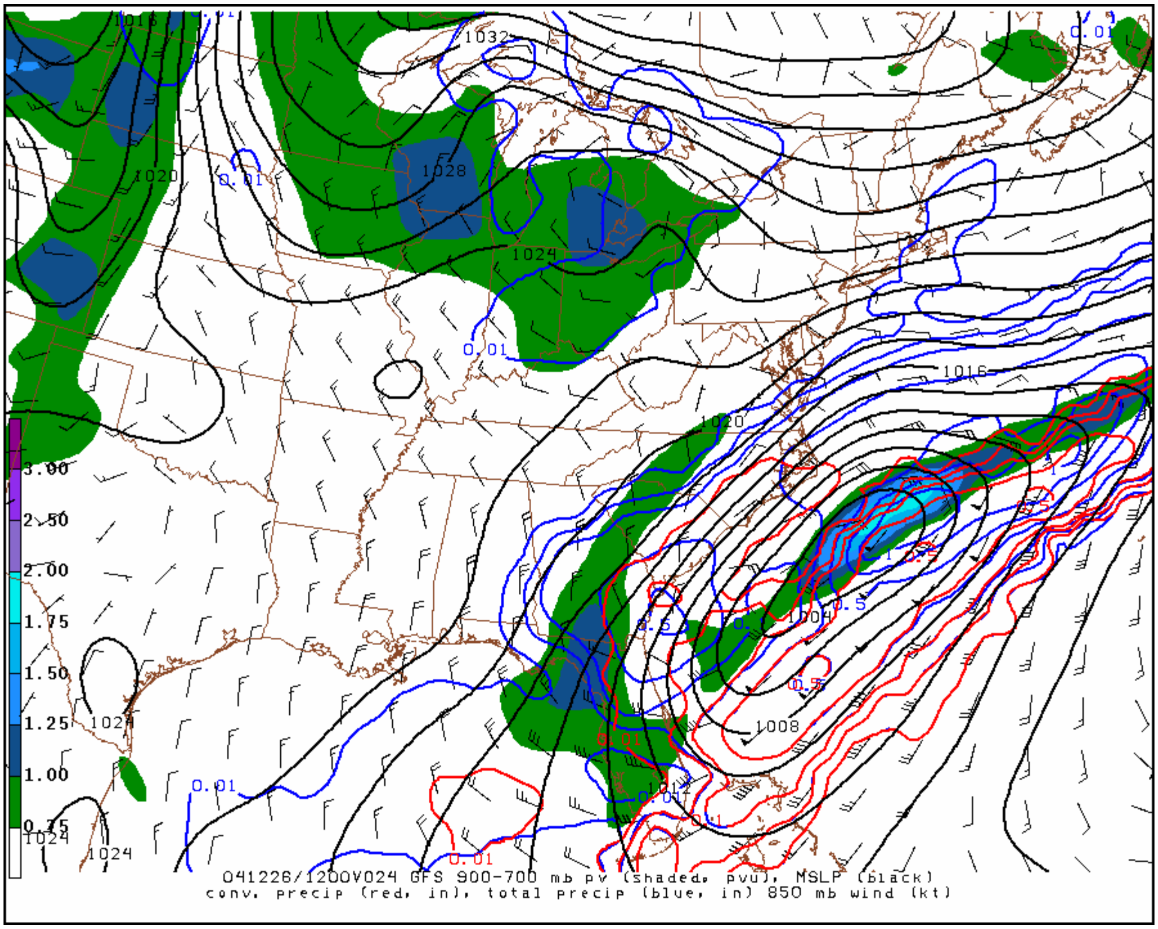

Figure 6. 12/25 12z GFS 12/26 12z forecast for PV (shaded), MSLP (black), Conv. Precip (red), Total Precip (blue), 850 mb wind; Courtesy of National Weather Service - Raleigh

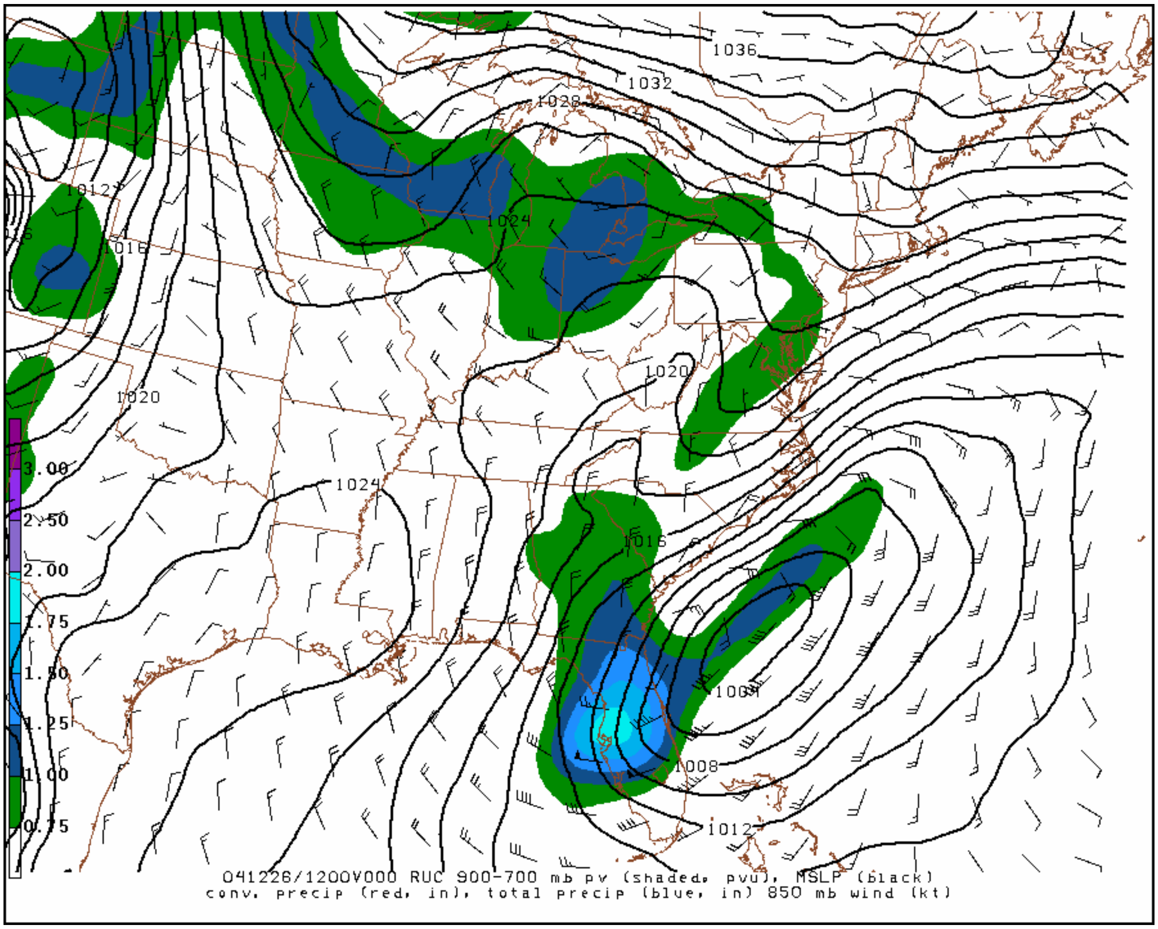

Figure 7. 12/26 12z RUC analysis of PV (shaded), MSLP (black), Conv. Precip (red), Total Precip (blue), 850 mb wind; Courtesy of National Weather Service - Raleigh

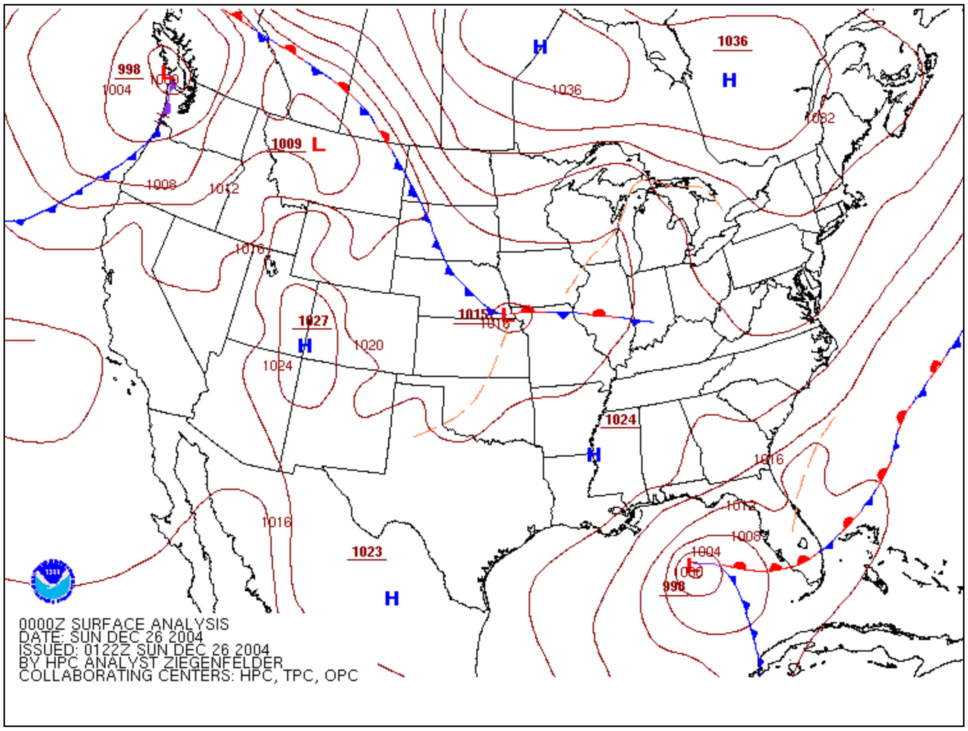

Figure 8. HPC 00z December 26, 2004 Surface Analysis

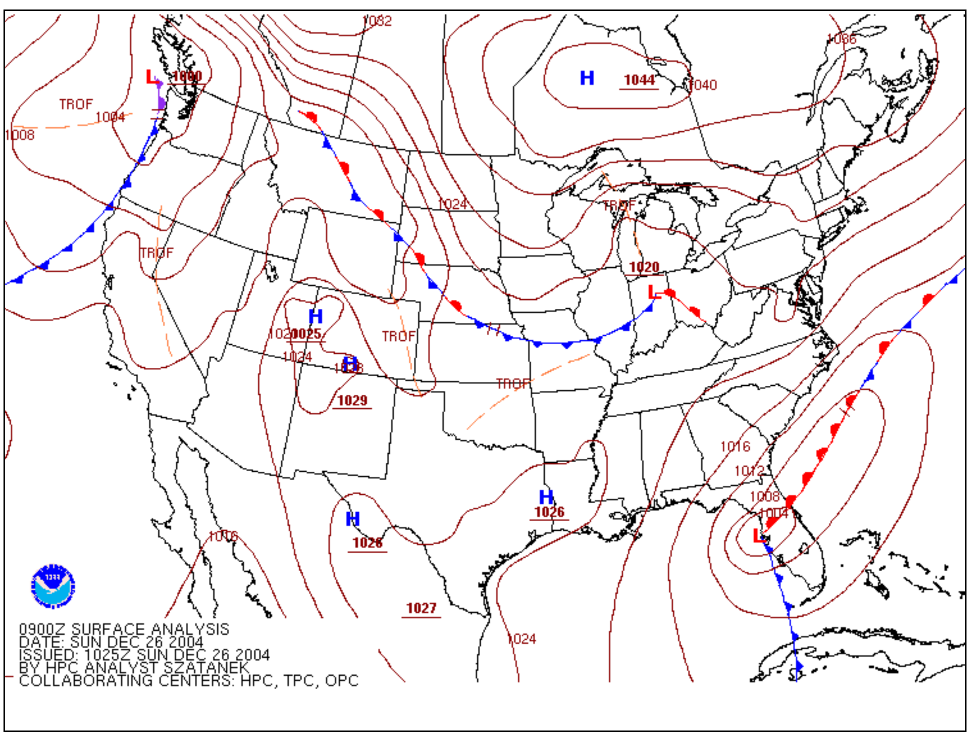

Figure 9. HPC 09z December 26, 2004 Surface Analysis

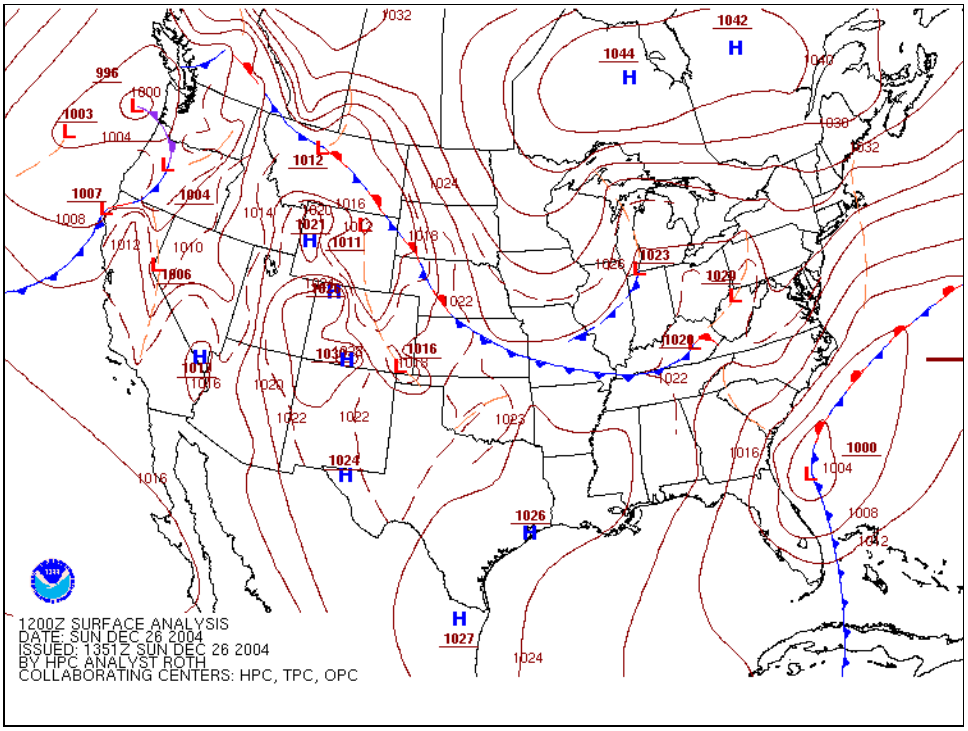

Figure 10. HPC 12z December 26, 2004 Surface Analysis

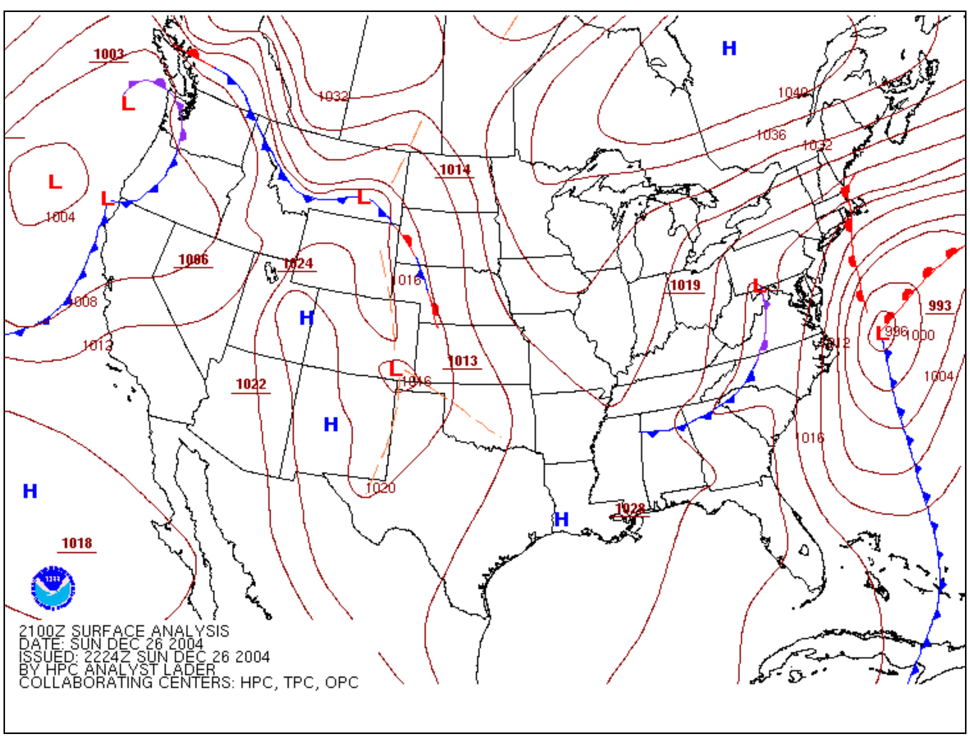

Figure 11. HPC 21z December 26, 2004 Surface Analysis

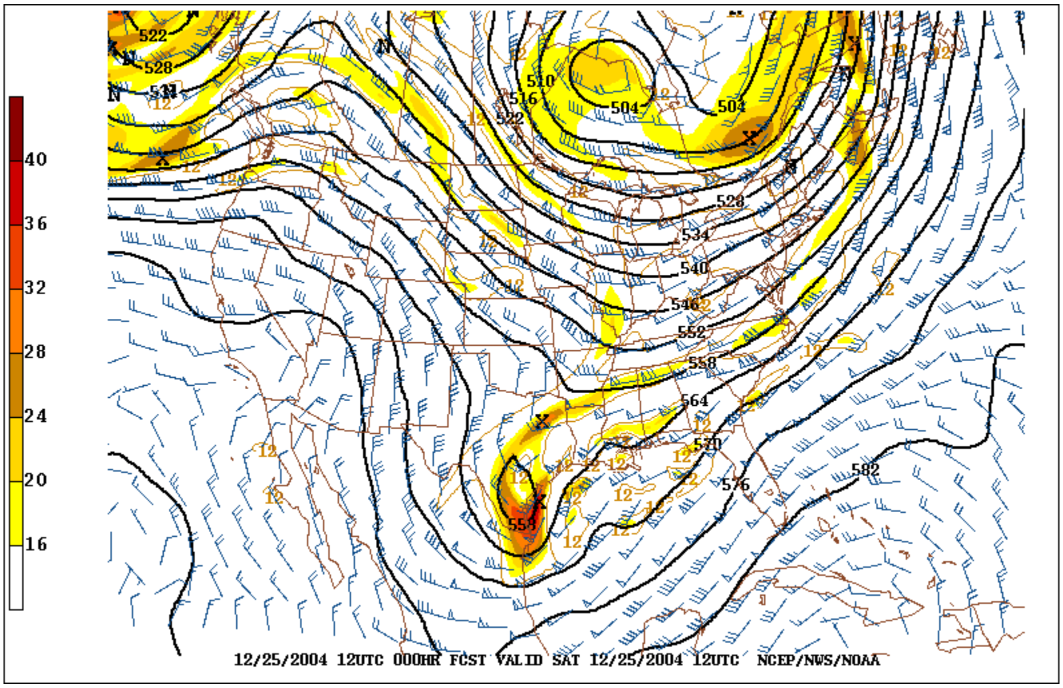

Figure 12. 12/25 12z NAM analyzed 500mb Geopotential Hght., Abs. Vorticity, and Wind;

Courtesy of National Weather Service - Raleigh

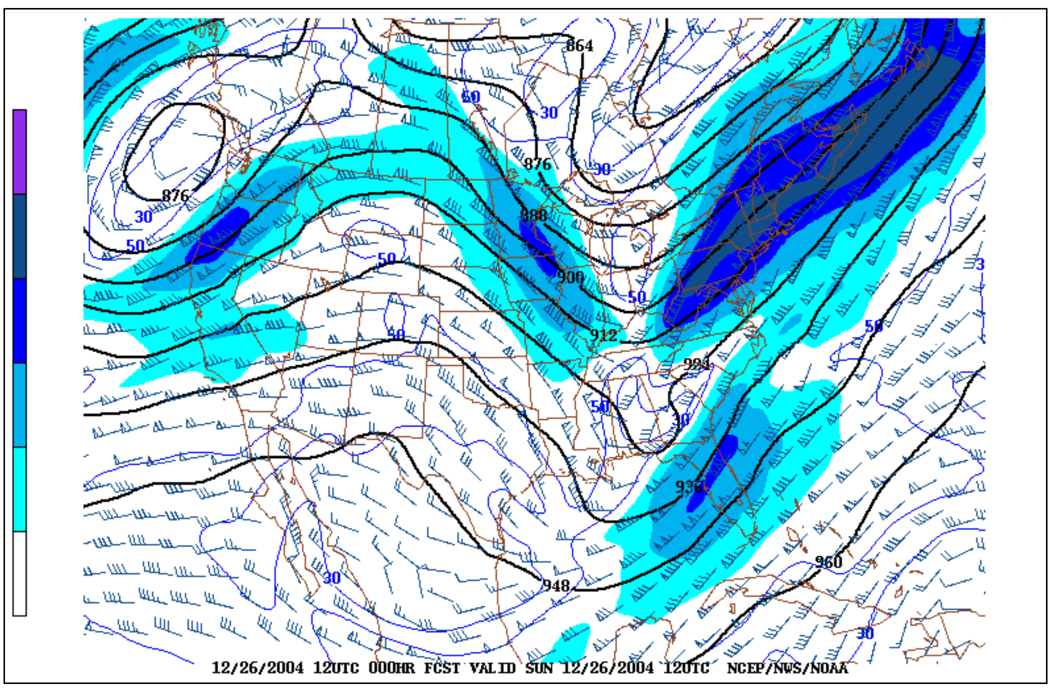

Figure 13. 12/26 12z NAM analyzed 300mb Geopotential Hght., and Wind;

Courtesy of National Weather Service - Raleigh

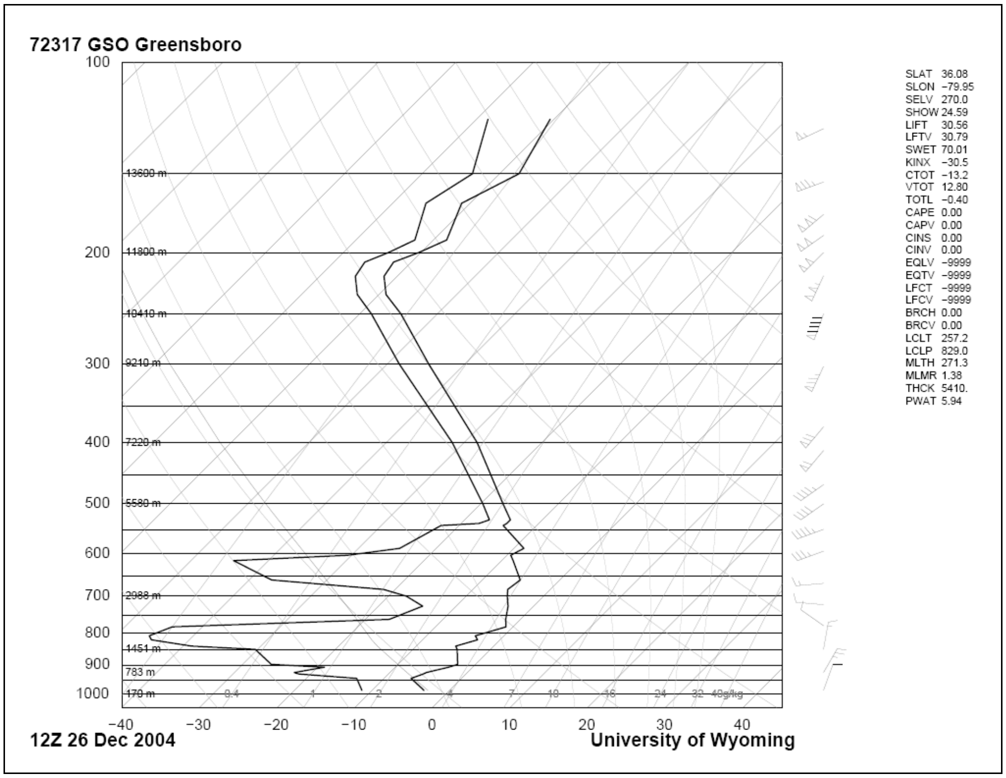

Figure 14. 12/26 12z GSO Sounding

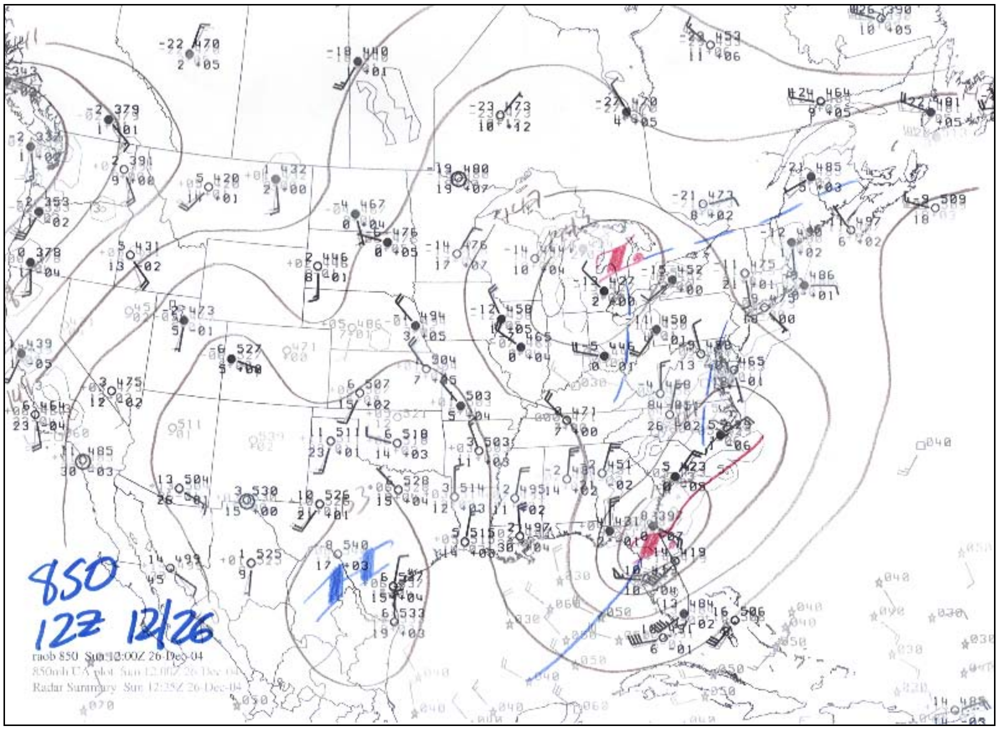

Figure 15. 12/26 12z 850mb Analysis of MSLP, and Wind;

Courtesy of National Weather Service - Raleigh

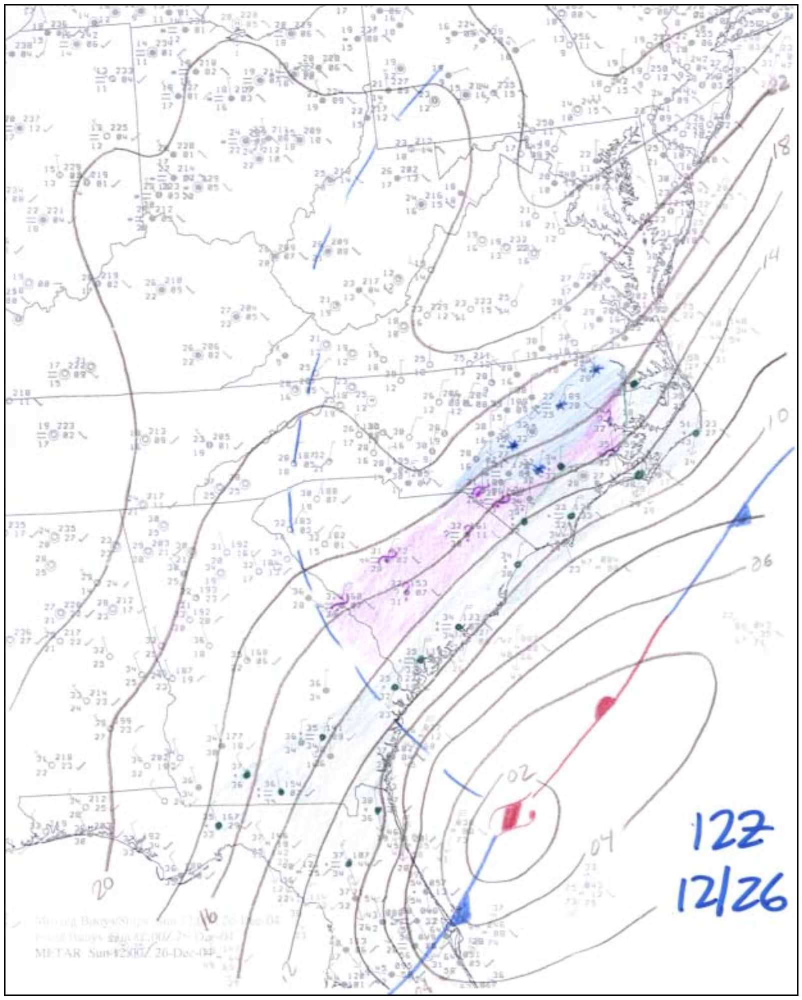

Figure 16. 12/26 12z Surface Analysis of MSLP, snow (blue), mix (purple), rain (green);

Courtesy of National Weather Service - Raleigh

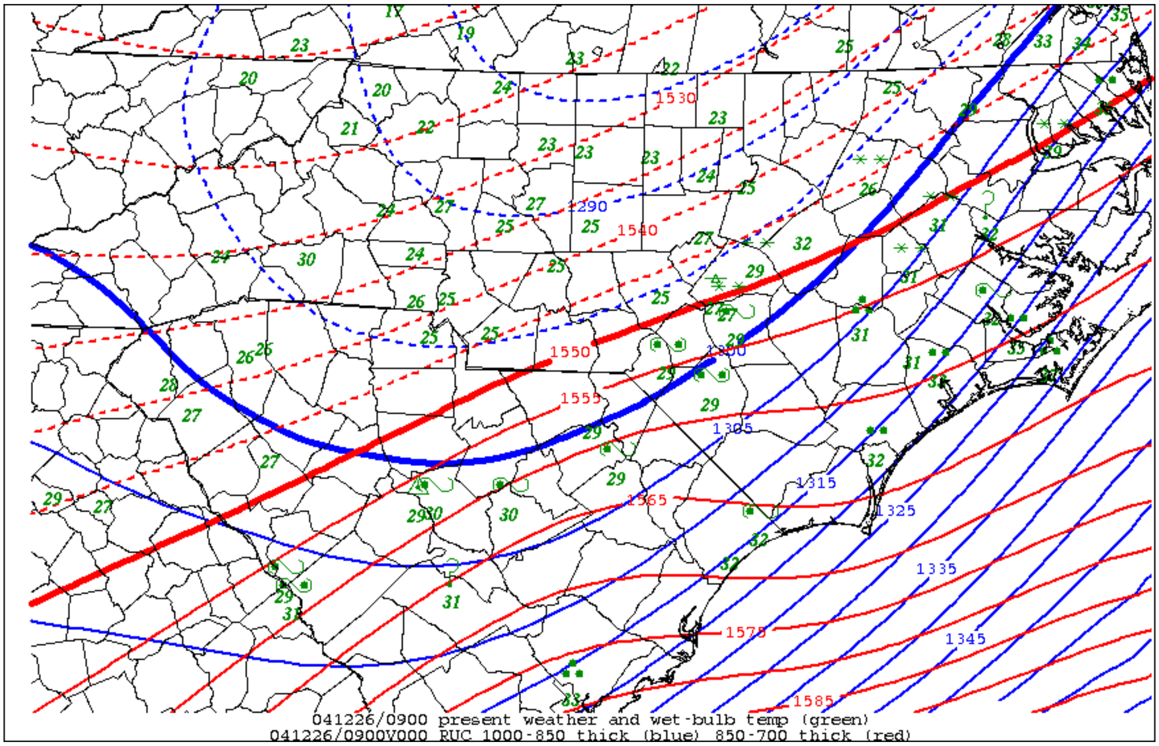

Figure 17. 12/26 09z RUC Analyzed wet-bulb (green), 1000-850mb thickness (blue), 850-700mb thickness (red) ;

Courtesy of National Weather Service – Raleigh

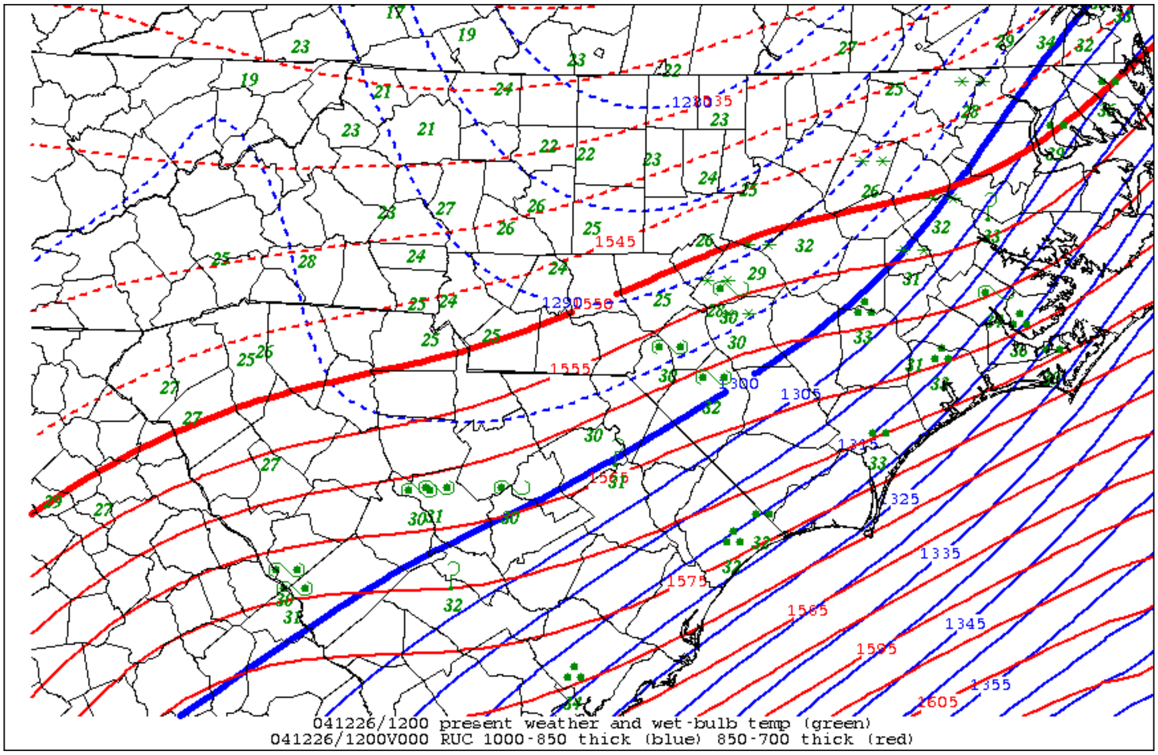

Figure 18. 12/26 12z RUC Analyzed wet-bulb (green), 1000-850mb thickness (blue), 850-700mb thickness (red) ;

Courtesy of National Weather Service – Raleigh

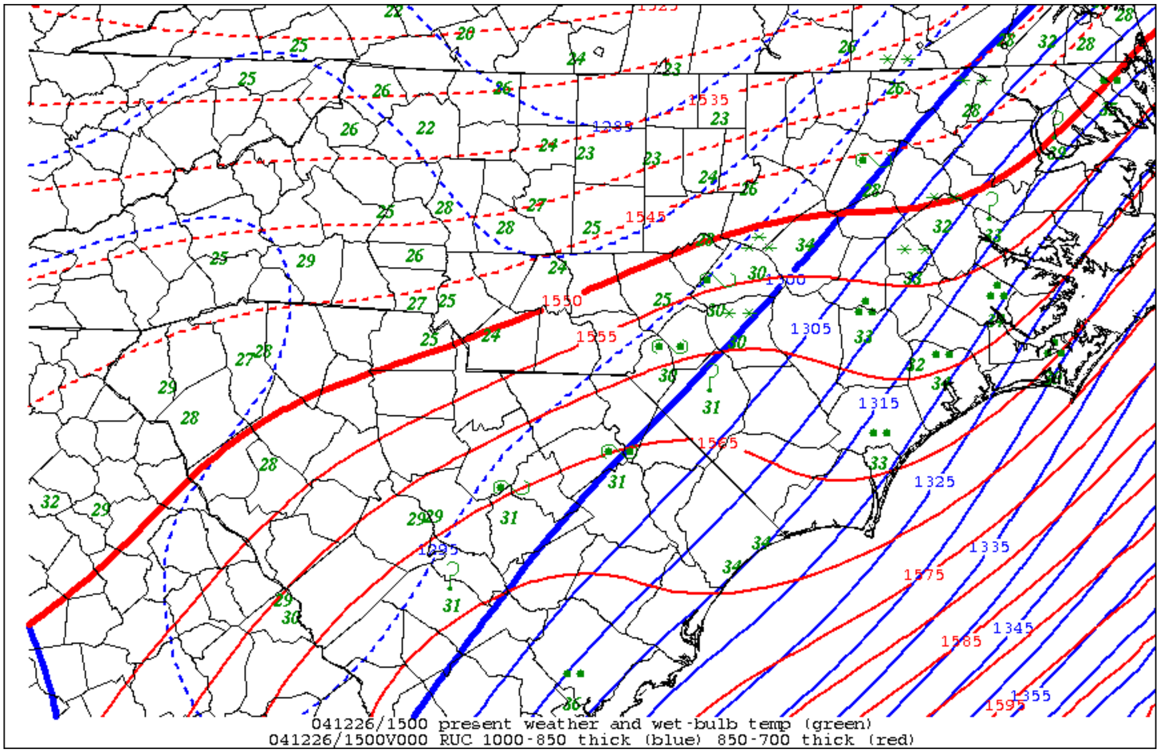

Figure 19. 12/26 15z RUC Analyzed wet-bulb (green), 1000-850mb thickness (blue), 850-700mb thickness (red) ;

Courtesy of National Weather Service - Raleigh

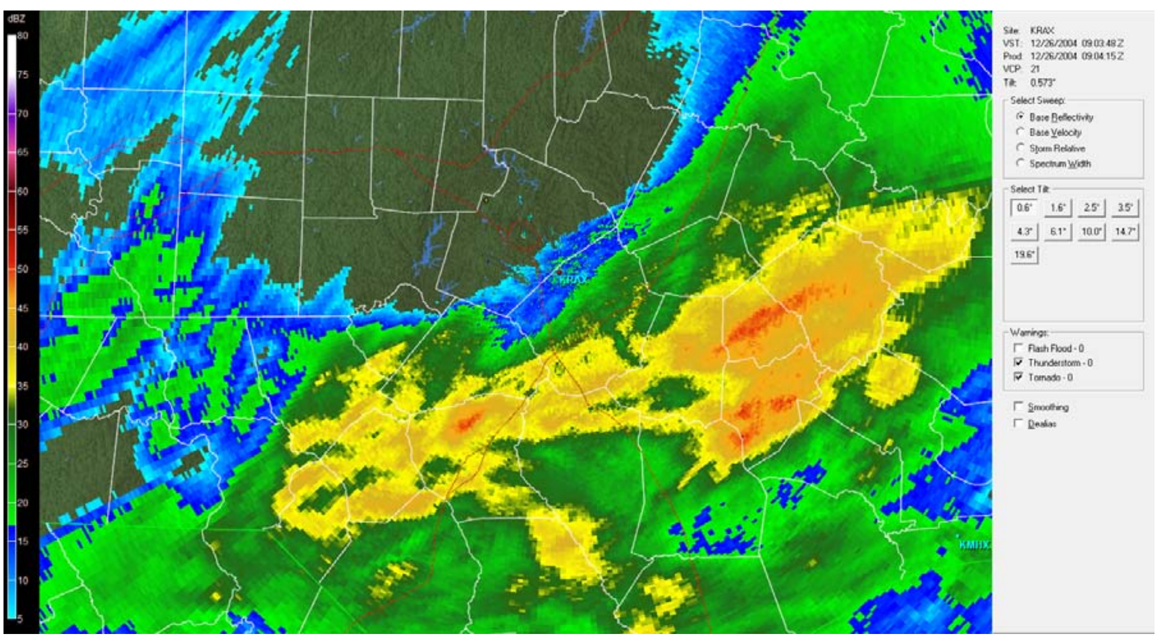

Figure 20. 09z KRAX Level II Radar

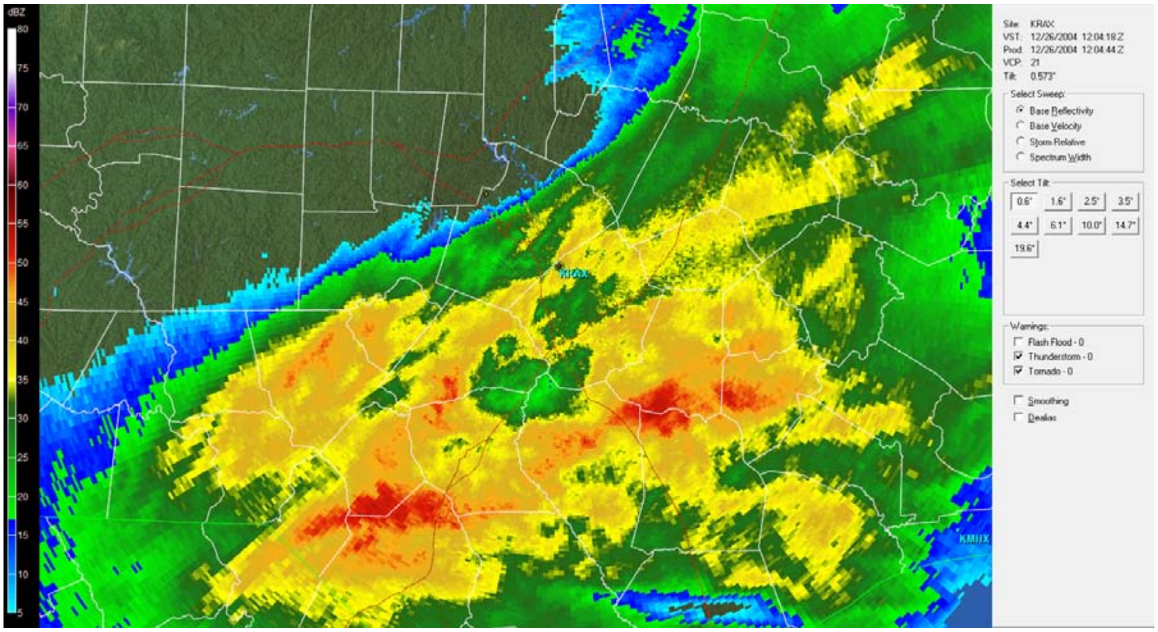

Figure 21. 12z KRAX Level II Radar

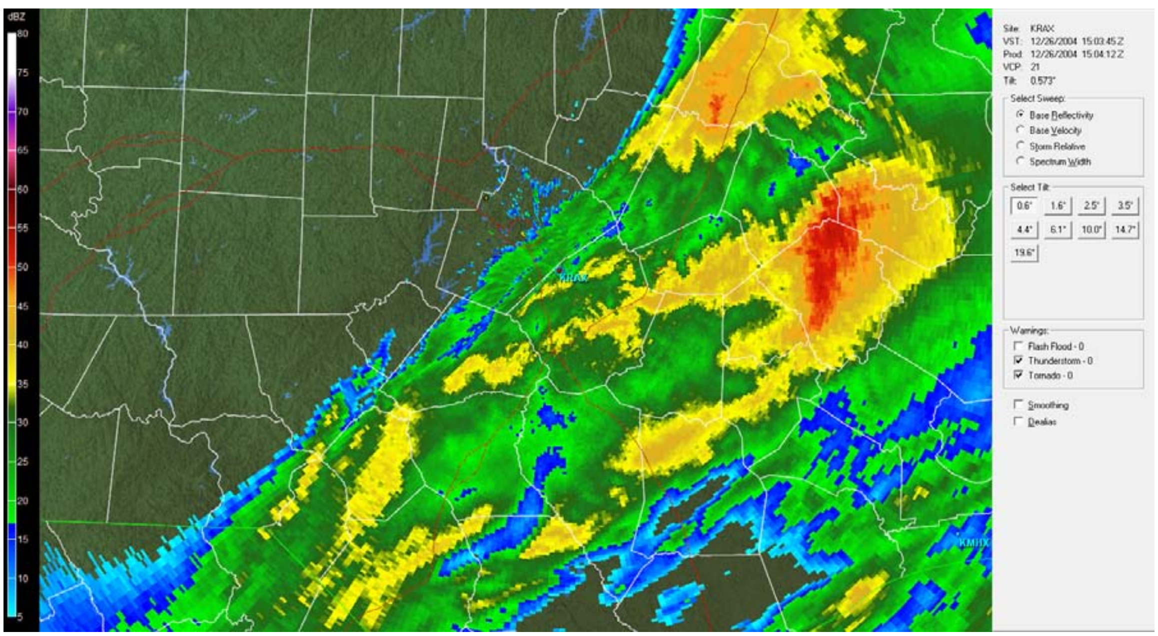

Figure 22. 15z KRAX Level II Radar

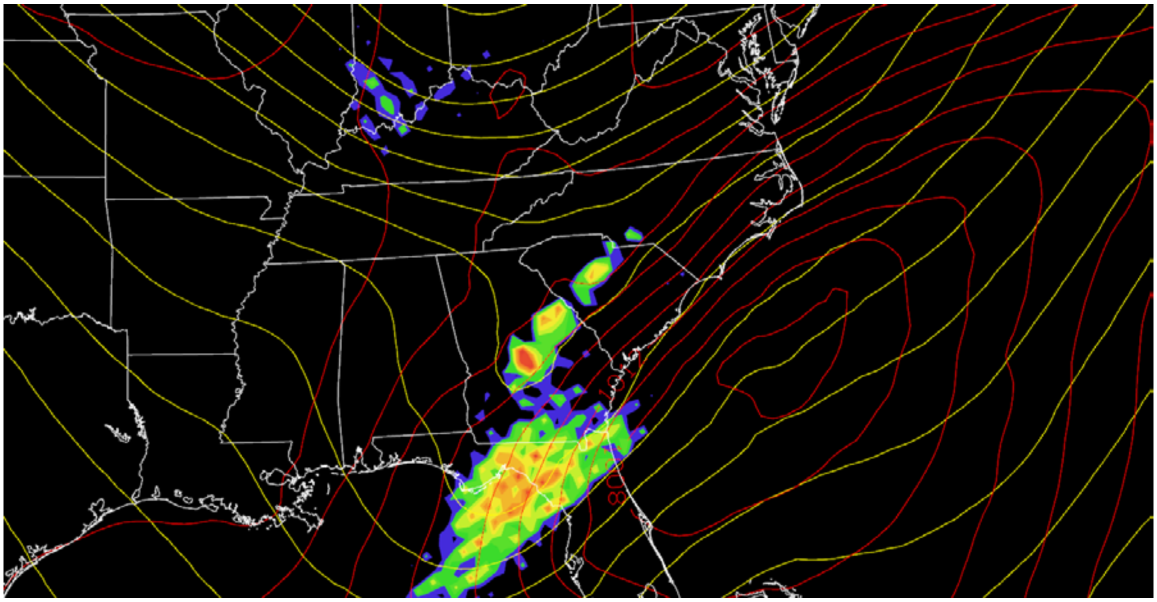

Figure 23. 09z 12z RUC Analyzed 500mb Geopotential Hght., Abs. Vorticity, and MSLP

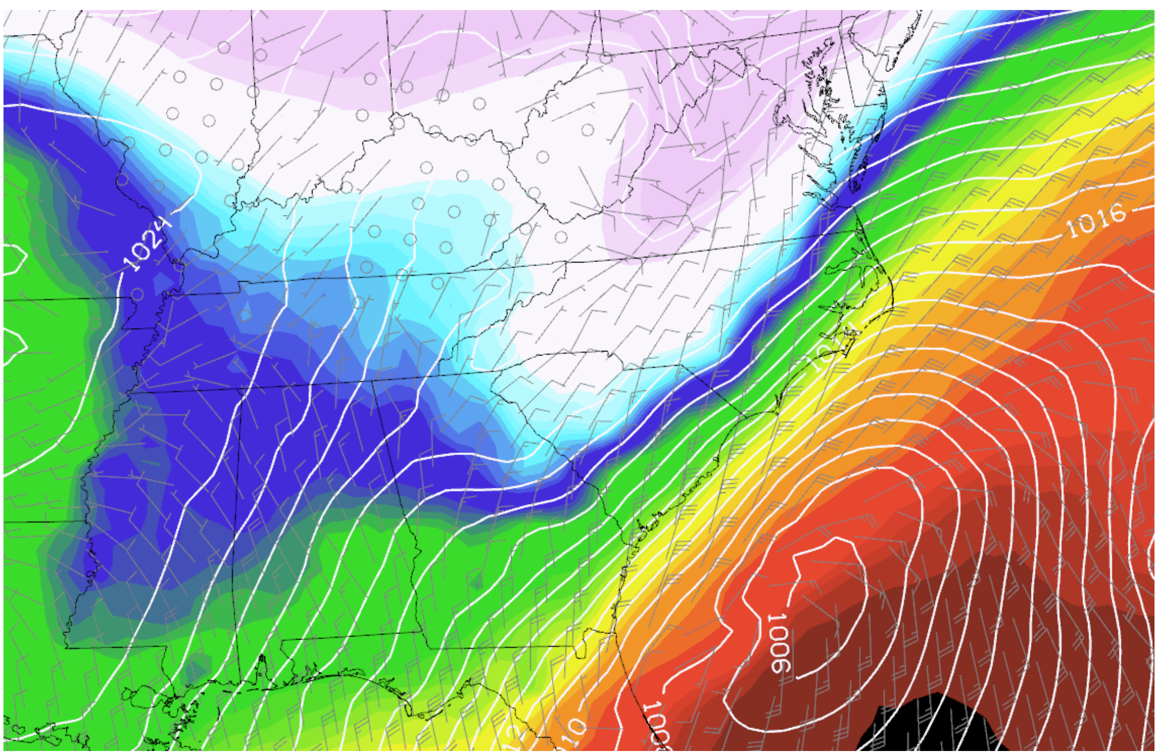

Figure 24. 09z NARR Analyzed MSLP, 1000-850mb thickness (1300m blue), and 1000mb wind

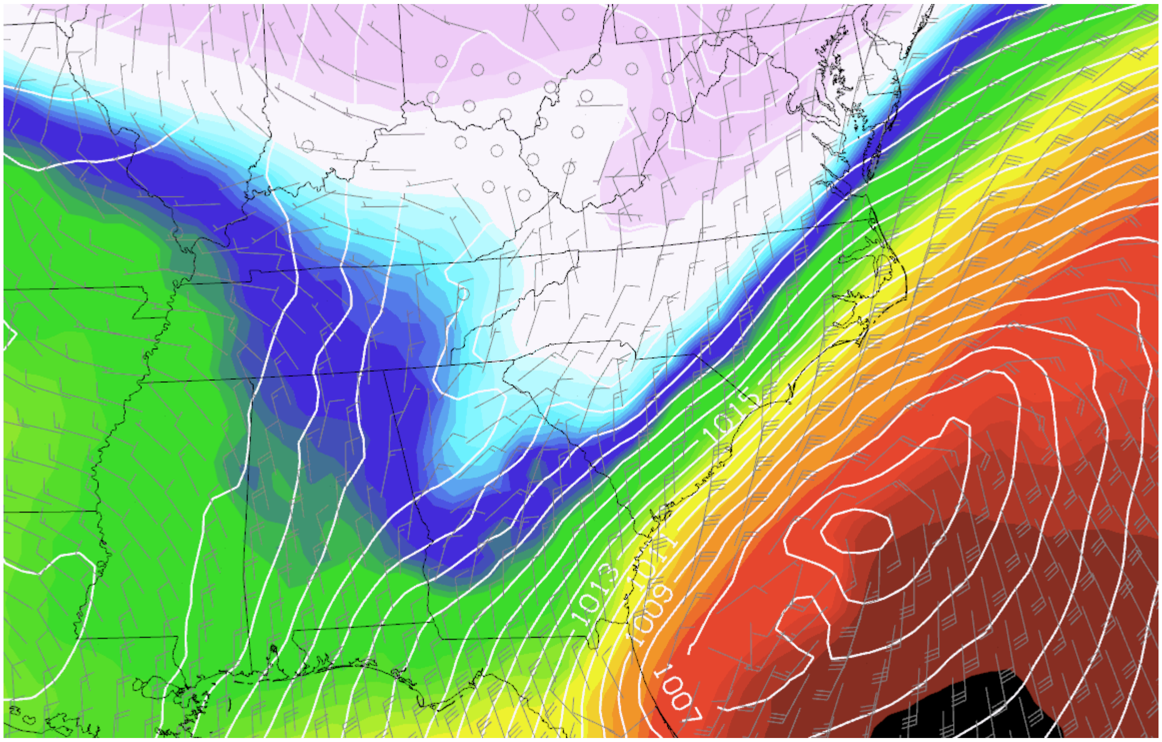

Figure 25. 12z NARR Analyzed MSLP, 1000-850mb thickness (1300m blue), and 1000mb wind

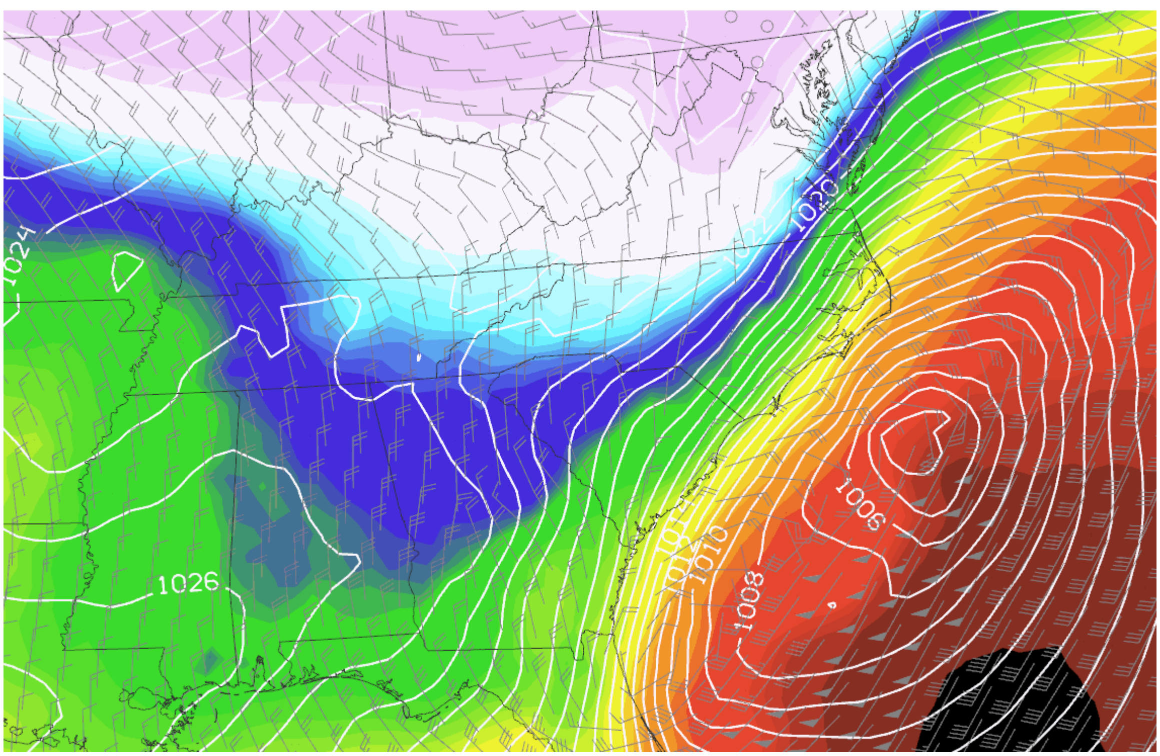

Figure 26. 15z NARR Analyzed MSLP, 1000-850mb thickness (1300m blue), and 1000mb wind

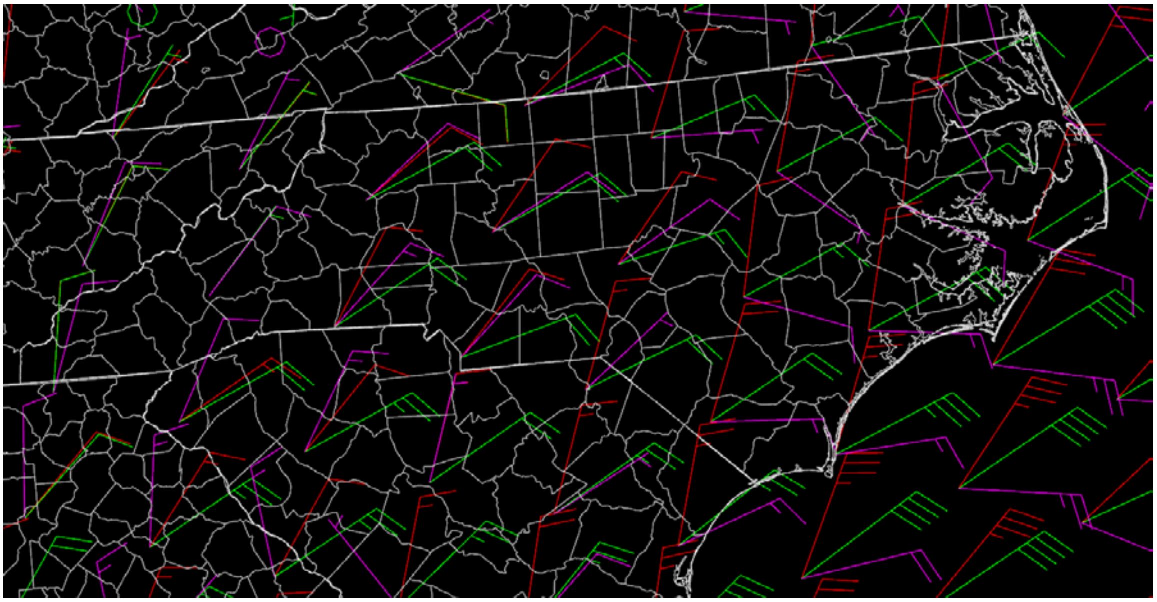

Figure 27. 09z NARR Analyzed Wind 1000mb (red), 925mb (green), 850mb (magenta)

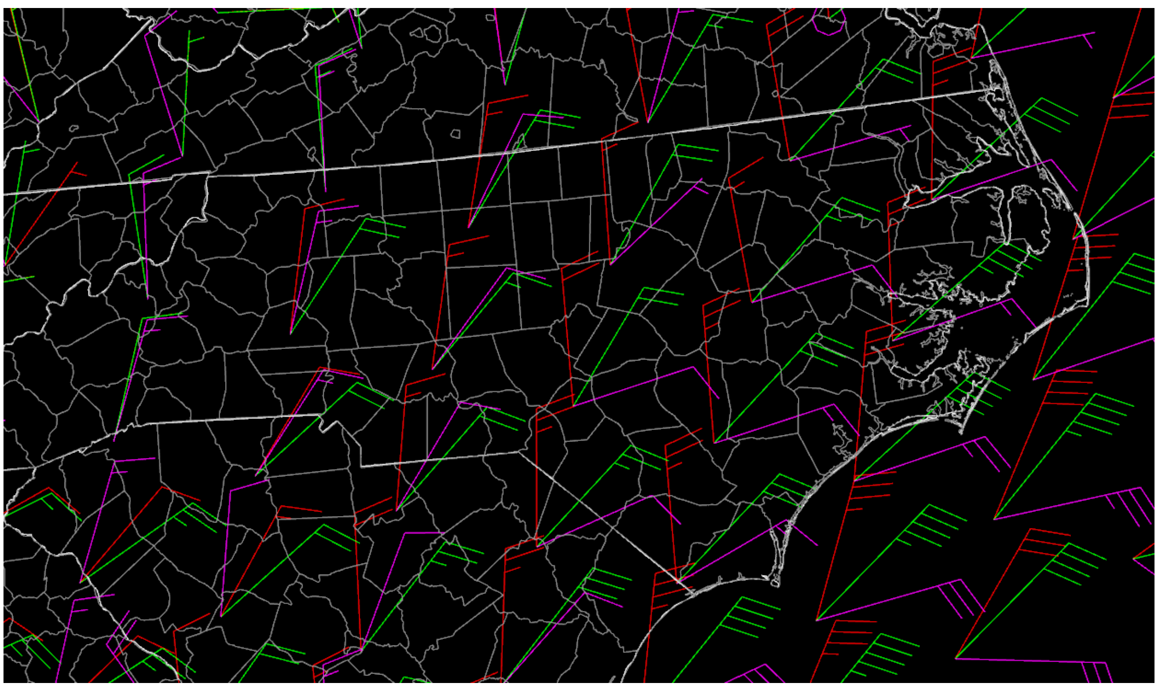

Figure 28. 12z NARR Analyzed Wind 1000mb (red), 925mb (green), 850mb (magenta)

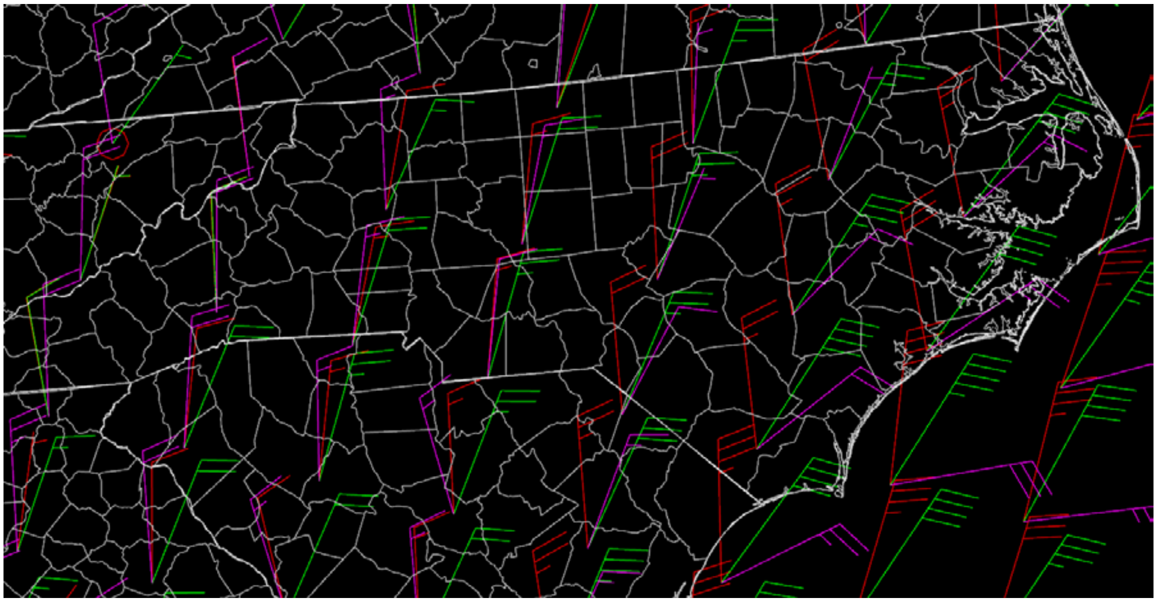

Figure 29. 15z NARR Analyzed Wind 1000mb (red), 925mb (green), 850mb (magenta)