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OPERATIONAL CONSIDERATIONS OF THE DECEMBER 26, 2004, SNOWSTORM ACROSS HAMPTON ROADS VIRGINIA AND NORTHEAST NORTH CAROLINA

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1. INTRODUCTION

Six to fourteen inches of snow fell from the Virginia Eastern Shore across Hampton Roads and into northeast North Carolina on December 26, 2004 (Fig. 1).

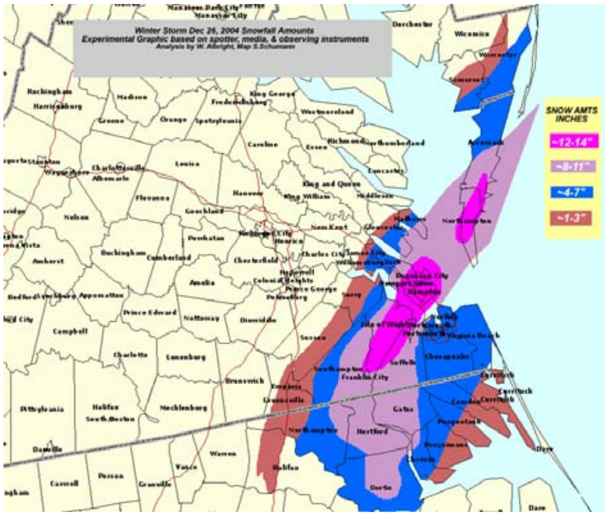

Fig. 1. Snowfall total map of Dec 26, 2004.

Several synoptic and mesoscale features contributed to these enhanced snowfall amounts. Synoptically, the combination of low pressure moving northeast off the mid Atlantic coast and high pressure centered over eastern Canada pushed colder air over the affected area, resulting in snow rather than rain for most of the event. These colder temperatures, combined with strong midlevel frontogenesis helped develop a mesoscale band that contributed to the production of substantial snowfall over the region.

An Albright and Cobb (2004) local study of Mid-Atlantic winter storms showed that there are five predominant patterns that produce four inches or more of snowfall across southeast Virginia and northeast North Carolina. The December 26, 2004 storm is considered a Type E (Offshore) (Fig. 2), more commonly known as an “East Coast Runner”, due to the fact that surface low pressure develops in the Gulf and then deepens as it moves northeast along the East Coast. However, pinpointing where the heaviest snow will occur, and whether mesoscale banding will develop and enhance the snow totals, presents a challenge to forecasters.

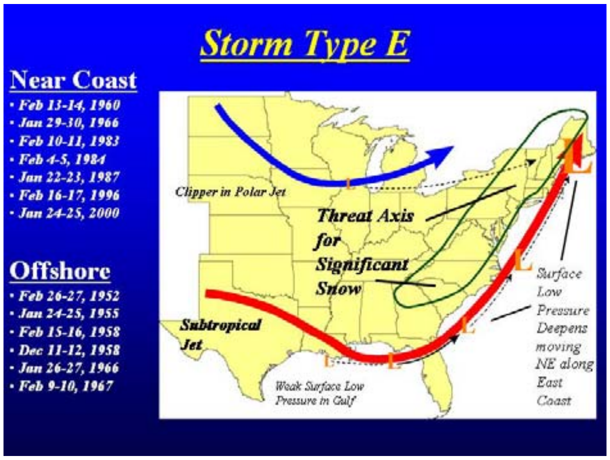

Fig. 2. Red line subtropical jet and Blue line polar jet.

An analysis of the performance of the operational models and their handling of the synoptic and mesoscale features for this storm are examined to evaluate means of improving forecasts in these situations. Model surface temperature forecasts were poor for this event and contributed to an under forecasting of snowfall for the area close to the southern Chesapeake Bay.

This paper examines the processes involved in the formation of mesoscale snowbands in this event using the operational models and WSR-88D data. The North American Mesoscale (NAM), Global Forecast System (GFS), and Rapid Update Cycle (RUC) models are evaluated to diagnose frontogenesis, equivalent potential vorticity (EPV), and potential for conditional symmetric instability (CSI). These parameters are compared with the snowbands depicted by the radar. The poor model surface temperatures will be discussed, along with methods provided to help improve temperature forecasts along marine areas in winter storm situations.

2. OPERATIONAL CONSIDERATIONS OF POOR MODEL SURFACE TEMPERATURES

Surface temperatures are a difficult field to forecast by numerical models for a number of reasons. The NAM uses a land surface model (Ek et al. 2003) which determines a surface energy balance that influences 2 meter temperatures. Lackmann (2002) showed how precipitation can impact the 2 meter temperature

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forecast. These issues combined with the lack of detail even with the 12 km resolution in the NAM along the coastline probably impacted the surface temperature forecasts.

This storm presented a significant challenge as the colder air was advected from the north across the coastal waters. Sea surface temperatures were in the 40s which could warm the boundary layer enough to make it just a rain event for the eastern sections of Hampton Roads. However, model forecast surface temperature errors over the Delmarva and Hampton Roads Virginia areas were as much as 5^{o}C during the heaviest precipitation. Farther west over more inland locations, the model surface temperature forecasts were within 1^{o}C of the observed temperatures.

A primary job of forecasters is to improve upon model guidance. This situation presented quite a dilemma for the forecasters in making the correct adjustments to the model to provide accurate and timely local forecasts and warnings. The NAM model uses a continuous data assimilation and initialization scheme that incorporates short-term forecasts from previous cycles to develop a first guess (Rogers 2001). This implies that the new model run initial conditions should be looked at in greater detail to see if any of the prior poorer forecasts are being carried into the new model run. Also at the time of this event, surface observations were not being utilized within the NAM's data assimilation system. (G. DiMego, personal communication). By knowing these sources of potential model error, improvements can be made to the model output.

All models did an excellent job of initializing surface temperatures until the 12 UTC run on 12/25/04 (Fig. 3).

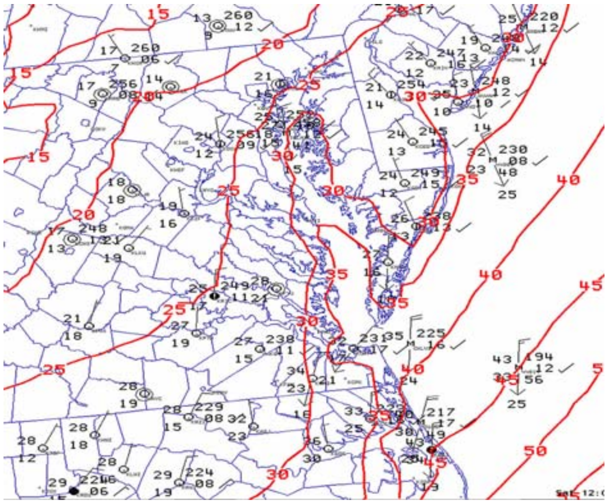

Fig. 3. 12 UTC 12/25/04 NAM model initial surface temperature in solid lines overlayed on surface observations.

This run introduced a 2 to 3^{o}C error in temperature at initialization time over the Delmarva and into southern New Jersey. The 18 UTC NAM (not shown) indicated these errors persisted and even got slightly worse. The surface temperature problems appeared to be mainly confined to the immediate coastal areas, typically within 50 km of the coast. These errors were evident on both the NAM and the GFS. The errors continued in the 00 UTC run on 12/26/04, with short range (6-hour forecasts) showing the error becoming more concentrated along the Delmarva and Hampton Roads as shown in Fig. 4.

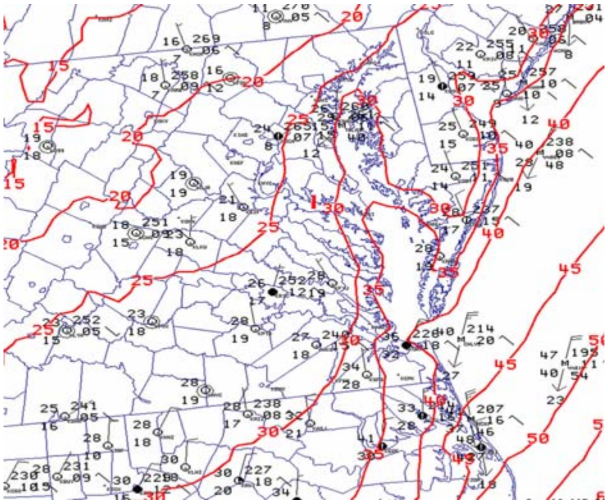

Fig. 4. 00 UTC 12/26/04 NAM 06-h surface temperature forecast for 06 UTC . Solid lines are model surface temperatures overlayed on surface observations.

Fig 5. shows how the 12 UTC on the 26th run of the NAM even had large errors for the surface temperatures in the initialization particularly over the Hampton Roads area. Observations had temperatures between 1 and 2^{o}C while the model forecast was closer to 4 to 7^o C. So,

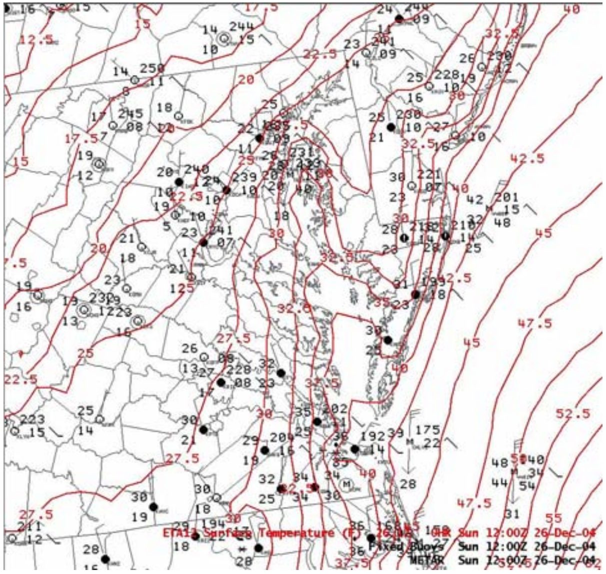

Fig 5. 12 UTC 12/26/04 NAM 00-h surface temperatures for 12 UTC. Solid lines are model surface temperatures overlayed on surface observations

even the shortest range NAM did not produce the proper forecast. These initial conditions at 12z were even worse then the 00 UTC NAM run.

Fig. 6 shows the 00 UTC NAM soundings developed a steeper lapse rate in the lowest layers across coastal areas such as Norfolk during the precipitation. While inland at Wakefield (85 km west of Norfolk), the temperature lapse rate was closer to isothermal which is expected in this type of heavy precipitation situation. It appeared the NAM may have been transferring too much heat from the water into the lowest layers of the atmosphere. By comparing model output with observations in real time, adjustments can be made to improve the surface temperature forecast. Model and observational trends provide insight into how the temperature fields are evolving. In this event, the surface temperatures needed a significant downward adjustment. Also, eliminating the unrealistic steep low level lapse rate in the sounding would significantly reduce the temperatures.

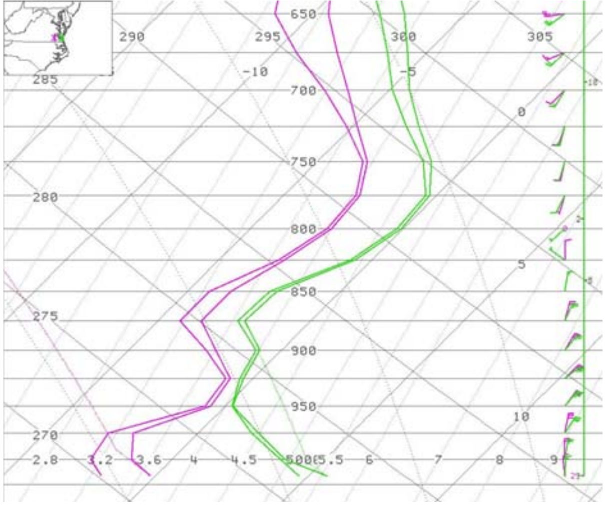

Fig. 6. 00 UTC 12/26/04 NAM model 18-h forecast skew-t for Norfolk in green and Wakefield in violet valid at 18 UTC.

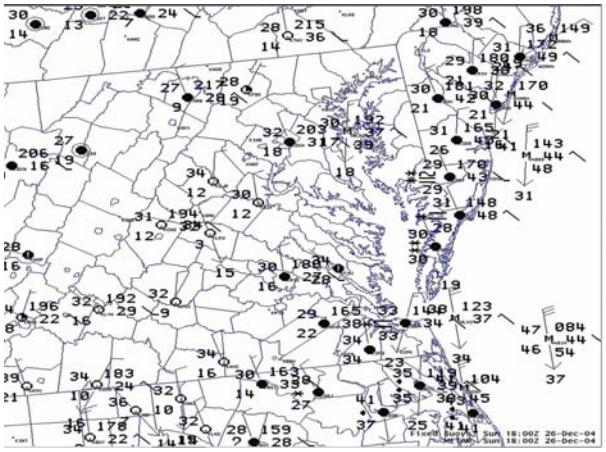

Fig. 7. 18 UTC 12/26/04 surface observations.

Combining these aspects leads to a reduction in surface temperature of 3 to 5°C which would bring temperatures back closer to observations. This reduction kept temperatures near 0°C during the event over the Hampton Roads area. Since temperatures aloft were easily cold enough for snow (all the melting was forecast to occur in the near-surface layer), the chances of significant snowfall were greatly increased. Fig. 7 shows the observed temperatures during the event.

3. A FORECAST STRATEGY FOR RECOGNIZING MESOSCALE BAND FORMATION WITHIN MID ATLANTIC CYCLONES

Anticipating whether and particularly where mesoscale snowbands will form in the vicinity of a mid Atlantic cyclone is very challenging to forecasters. Certain synoptic and mesoscale features are essential for the development of these bands and have been documented in previous studies (Novak et al. 2004a,b). Recognizing the favorable synoptic and mesoscale flow environments in the forecast area is a first step in assessing whether or not band formation could occur in an event one to two days in advance.

The surface analysis at 00 UTC 25 December 2004 indicated cold high pressure essentially extending from eastern Canada south into the Gulf Coast States, with a frontal boundary off the Atlantic coast into the Gulf of Mexico where low pressure was developing. Beginning with the 00 UTC 25 December NAM and GFS model runs, low pressure in the Gulf was forecast to track closer to the southeast and mid Atlantic coast and intensify during December 26. Surface analysis at 12 UTC 26 December 2004 showed a 1002 MB low pressure area just off the Georgia coast. By 21 UTC 26 December, the low had intensified to 995 MB just off the southeast Virginia, northeast North Carolina coast. According to studies of synoptic and mesoscale environments of banded cyclones from Nicosia and Grumm (1999) and Novak et al. (2004b), there is a dynamical link between the process of cyclogenesis, accompanying deformation zones, and associated frontogenesis. Both papers present a conceptual model of banded cyclones depicting the synoptic and mesoscale features. Heaviest precipitation banding will occur to the north and west of the surface low, where deformation and the presence of a temperature gradient contributes to frontogenesis, which provides the mesoscale forcing for banded precipitation (Novak et al. 2004b).

The potential for a significant snowfall somewhere across southeast Virginia and northeast North Carolina became evident according to the model runs starting on 12 UTC 25 December. Both the NAM and GFS models were consistent through the 12 UTC 26 December runs of indicating intensifying low pressure moving northeast just off the southeast and mid Atlantic coast. This corresponds well to the conceptual model presented by (Nicosia and Grumm 1999). In addition, the models showed impressive vertical motion (700 mb omega) coinciding with significant QPF amounts north and west of the surface low, with the NAM also consistently depicting strong midlevel (700 mb) frontogenesis from eastern North Carolina across southeast Virginia and into the Virginia and lower Maryland eastern shore during December 26. The NAM model runs from 12 UTC 25 December through 12 UTC 26 December indicated a consistent overlapping of deep moisture, impressive vertical motion, and strong midlevel (700 mb) frontogenesis close to the area where the mesoscale snowbands would form and produce the higher snow amounts.

An 18 UTC 26 December RUC analysis cross section across southeast Virginia indicated strong midlevel (700-750 mb) frontogenesis was present (Fig. 8). A thermally direct ageostrophic vertical circulation associated with the frontogenesis is evident. Temperature profiles supported snow in this area.

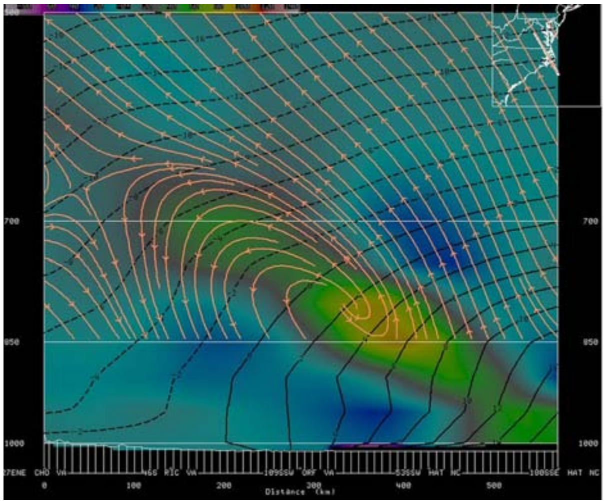

Fig. 8. 18 UTC RUC analyses. Cross section of midlevel frontogenesis (depicted by shaded green area), ageostrophic vertical circulation (depicted by contoured orange), and temperature profile (depicted by contoured black).

Fig 9 shows a cross section of the 6 hour forecast of the 12 UTC 26 December NAM model, depicting strong midlevel frontogenesis and the presence of weak moist symmetric stability (Moore 2005). The best frontogenesis where the heavy snow occurred was between 700 and 750 mb, coinciding with an enhanced area of weak moist symmetric stability. Fig. 10 shows an 18 UTC 26 December RUC analysis cross section that verified the earlier model run of depicting the best location of mesoscale banding.

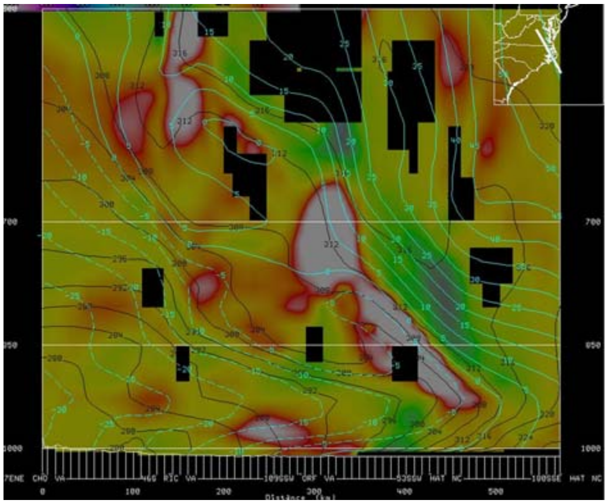

Fig. 9. 12 UTC NAM 6 hour forecast at 18 UTC. Cross section of midlevel frontogenesis (depicted by shaded red/white area), geopotential momentum surface (depicted by green contours), and Theta-E (depicted by solid black).

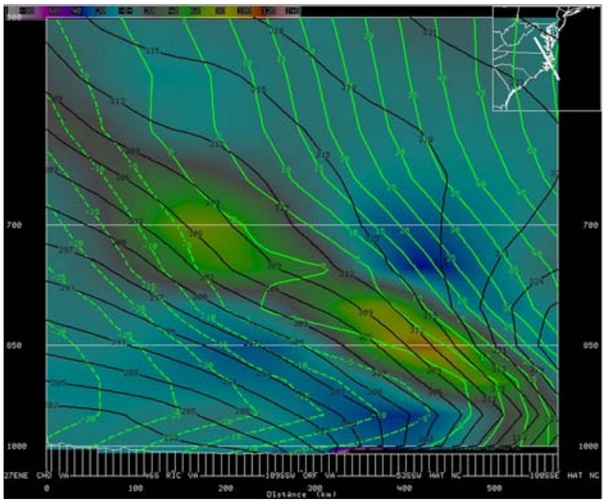

Fig. 10. 18 UTC RUC analyses. Cross section of midlevel frontogenesis (depicted by shaded green area), geopotential momentum surface (depicted by green contours), and Theta-E (depicted by solid black).

Precipitation spread northward into northeast North Carolina just before daybreak December 26. At 10 UTC 26 December, NWS Doppler radar 0.5^o base reflectivity detected higher reflectivities north and west of the

Fig. 11a. WSR-88D radar mosaic 0.5° base reflectivity and surface observation 10 UTC 26 December 2004.

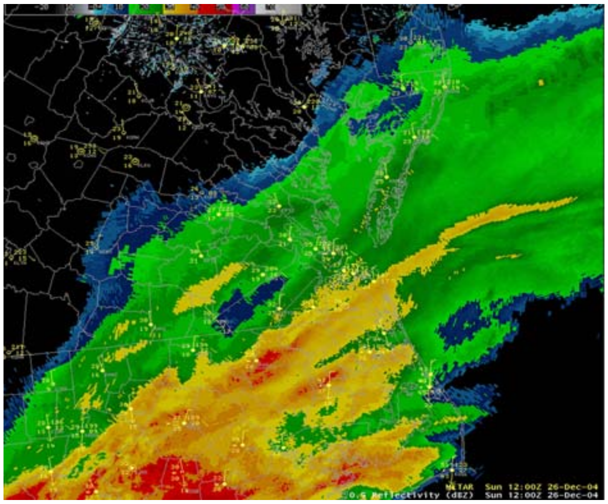

Fig. 11b. WSR-88D radar mosaic 0.5° base reflectivity and surface observations 12 UTC 26 December 2004.

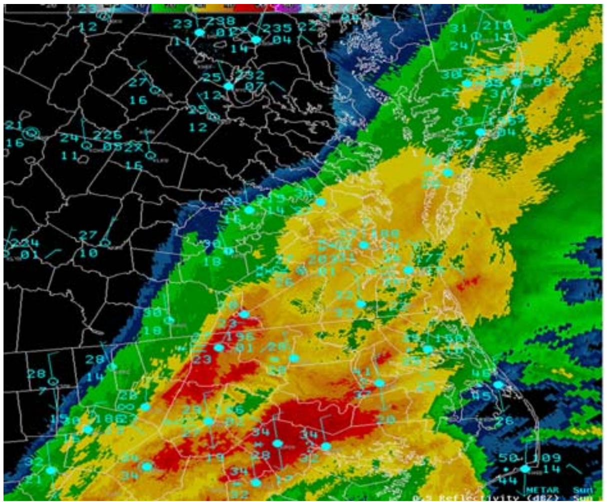

Fig. 11c. WSR-88D radar mosaic 0.5^{o} base reflectivity and surface observations 15 UTC 26 December 2004.

Fig. 11d. WSR-88D radar mosaic 0.5^{o} base reflectivity and surface observations 18 UTC 26 December 2004.

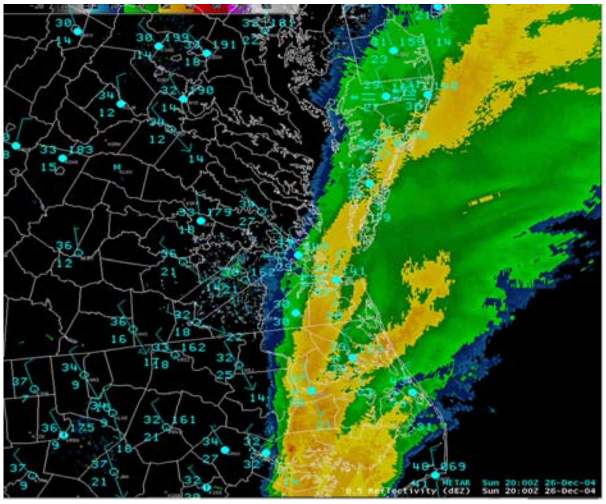

Fig. 11e. WSR-88D radar mosaic 0.5° base reflectivity and surface observations 20 UTC 26 December 2004.

intensifying surface low, extending from just north of the Albemarle Sound southwest into central North Carolina (Fig. 11a). The position of these higher reflectivities, which ranged from 30 dBZ to as high as 50 dBZ, in relation to the surface low, was an indication of developing mesoscale banding. By 12 UTC, the band of higher reflectivities had spread up into extreme southeast Virginia, with surface observations at PHF (Newport News) and ORF (Norfolk) reporting snow falling and a temperature of 36^{o}F (Fiq. 11b). This banding continued over the same area from 15 to 20 UTC. NWS Doppler radar depicted this band evolution, tracking a single narrow mesoscale snowband that set up and gradually shifted east across southeast Virginia and northeast North Carolina (Fig. 11c,d,e). This single band was most pronounced on radar between 18 and 20 UTC with moderate to heavy snow reported at several surface observation sites during this time. This band matched up well with the area of higher snow totals. The snowband then shifted offshore around 22 UTC, as the low pressure area continued to move northeast up the coast. This mesoscale snowband produced snowfall rates of 1-2 inches per hour across portions of southeast Virginia and northeast North Carolina.

High pressure over eastern Canada helped to provide a persistent north surface wind throughout this event. This northerly flow advected dewpoints in the lower to mid teens across central Virginia and North Carolina. Dewpoints ranging from the upper 20s to mid 30s were prevalent from the Lower Maryland Eastern Shore across southeast Virginia and into northeast North Carolina. The 18 UTC RUC analysis cross section (Fig. 8) also illustrates the subsidence region associated with the frontogenetical circulation, which coincided well with the area of much drier dewpoints and sharp precipitation cut off of the mesoscale snowbands indicated by NWS Doppler radar.

4. SUMMARY

Surface temperature forecast in the winter are difficult along coastal sections particularly over the mid Atlantic where even slight onshore flow can make a major change in temperatures. This study showed that by examining model initialized and short range temperature forecasts, and watching how the trend verifies, forecasters can make adjustments to improve the surface temperature forecast. Also, examining model soundings and identifying unrealistic lapse rates can also help improve surface temperatures. In this case, these techniques were applied to improve surface temperatures by 3 to 5^{o}C.

Another aspect of this study dealt with how to anticipate mesoscale snowband formation during certain winter synoptic patterns in the mid Atlantic region. Important focus was placed on consistency of the short-range model forecasts 24 to 36 hours prior to the event to recognize favorable synoptic and mesoscale flow environments for potential band formation across the forecast area. The analysis of the December 26, 2004 snowstorm across southeast Virginia and northeast North Carolina was consistent with previous studies of important mechanisms needed for mesoscale band formation. Mesoscale snowbands developed on the north and west side of the intensifying cyclone, where deformation and strong midlevel (700-750 mb) frontogenesis were present, as shown by the RUC model analysis. Doppler radar tracking of higher reflectivities correlated very well with the bands and enhanced snowfall totals. A thorough understanding of conceptual model theory, strengths and weaknesses of short-range numerical models, and application of observational tools, will help improve operational forecasts of these mesoscale bands.

5. ACKNOWLEDGMENTS

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