Analysis of the Record Mesosnowfall Event of 1997 in Central Mississippi

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31 August 2000 and 20 July 2001

ABSTRACT

Although rare, heavy snowfalls in the southern United States have significant impact and are often associated with distinct surface low pressure systems. However, the central Mississippi record snowfall event of 14 December 1997 displayed mesoscale characteristics and was caused by a rapidly intensifying upper-level system with no surface reflection. Record amounts of unforecast snowfall of up to 8 in. (20.3 cm) occurred. A synoptic and diagnostic analysis of the event determined significant jet streaks, the existence of a middle- and upper-level moisture pool, and a deformation zone with high-level frontogenesis led to the snowfall despite rather unremarkable surface conditions. The system was fully investigated in terms of atmospheric and model diagnostics in an effort to provide clues for an improved forecast. A hindcast simulation of the event using the Pennsylvania State University–National Center for Atmospheric Research fifth-generation Mesoscale Model (MM5) revealed that the use of a mesoscale model in real time may have made a significant difference in forecasts up to 18 h before the event began.

1. Introduction

Although rare, heavy snowfalls in the southern United States have significant impacts and are often associated with distinct surface low pressure systems. In particular, central and southern portions of the Gulf coastal states, though averaging an inch (2.5 cm) or less of snowfall per year, do receive substantial snows—even to the coast (e.g., Mobile, AL, Mar 1993 and others). In central Mississippi the National Weather Service (NWS) Office in Jackson records an average of two snow events (i.e., measurable) per winter season (based on Jackson NWS data, 1999, personal communication) with an average of 1.4 in. (3.6 cm) and a record snowfall event of nearly 12 in. (30.5 cm) in January 1904. Historically, these averages are biased by a number of years in which no measurable snow is reported as compared to the few in which several inches (5–15 cm) fall. Based on a review of existing Jackson NWS records (as little historical information exists), winter in central Mississippi is as likely to bring icing conditions as snowfall given the typically shallow cold air that invades the region.

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Most snowfalls in this region of the country are associated with strong high pressure systems (and typically with arctic outbreaks) or well-developed (or intensifying) surface-low pressure systems. In a preliminary study for Mississippi (Croft and Webb 2000, unpublished manuscript) for the period 1970–99, 66% of all snowfall events were associated with nearby high pressure (of varying intensities) while a surface low center was located in the Gulf of Mexico, 16% with developing or intensifying surface low pressure systems, and approximately 8% with passing frontal zones. Only a small percentage (less than 10%) were not directly associated with these features, including the record mesosnowfall event of 1997, which took place across central Mississippi on 14 December 1997. The economic impact of this event was limited by the fact that it occurred during the weekend (Saturday night through Sunday), had temperatures near 0°C throughout, produced snow that did not collect substantially on roadways, and caused relatively few power outages.

During this event a record snowfall of up to 8 in. (20.3 cm; see Fig. 1) blanketed central Mississippi during the overnight and daylight hours. The event was noteworthy in that it was not forecast to occur, it took place following the prediction of several unrealized snowfall events during the preceding days, the large

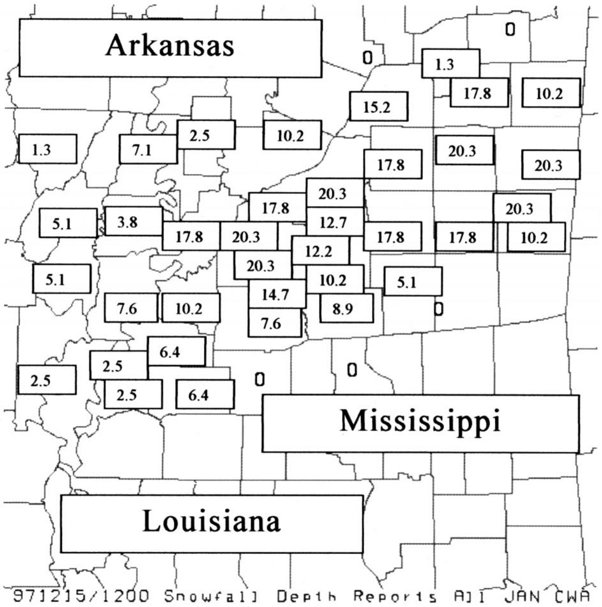

FIG. 1. Snow depths to nearest 1/10th of a cm as reported Monday, 1200 UTC 15 Dec 1997 for central Mississippi.

number of widespread cancellations and closures for that day and the next two days, and the extremely poor performance of the operational models in handling the evolution of an upper-tropospheric system within a data-dense region. Moreover, the event was worthy of further study given its mesoscale characteristics (in time and space; see Fig. 2) and the lack of significant surface features. In an effort to improve upon the prediction of such an event a detailed diagnostic and operational study was performed through a Cooperative Program for Meteorology, Education, and Training (COMET) grant partnership between Jackson State University and the Jackson National Weather Service Forecast Office. This effort included a hindcast of the event using a mesoscale model.

2. Methods

Model output, satellite imagery, surface and upper air observations, and model diagnostics were collected, produced, and examined for the 24-h period prior to the event. Numerical models included the National Centers for Environmental Predictions Eta Model, Global Spectral Model, and Nested Grid Model with initializations up to 24 h in advance of the start of the event. Initial conditions were examined at various standard levels using the General Meteorological Package (GEMPAK) Analysis and Rendering Program software. Satellite imagery included the 10.7-, 3.9-, and 6.7-μm infrared channels. The 6.7-μm water vapor imagery was analyzed particularly to determine the distribution of moisture and the position of synoptic and mesoscale features

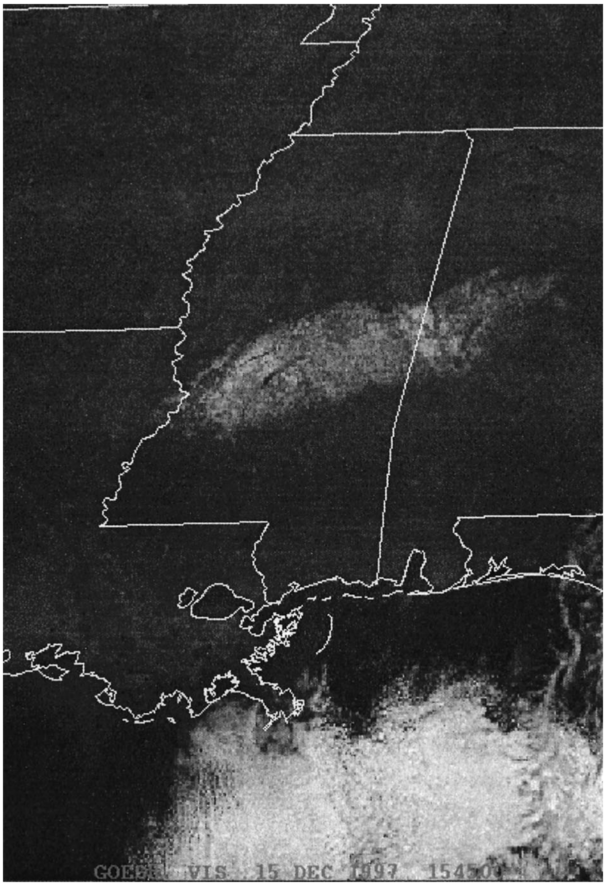

FIG. 2. Visible satellite imagery showing limited extent of snow cover observed Monday, 1545 UTC 15 Dec 1997 for central Mississippi.

in the middle and upper levels of the troposphere prior to and during the snowfall event.

The record mesosnowfall event was examined with regard to precedent conditions, operational constraints, model forecasts, and according to the ‘‘mind-set’’ of the forecasters at the time. These were used to answer the questions: *What did happen? Why did it happen? What would have made the forecaster consider the possibility of snow? Could the event have been forecast?* These questions are relevant to the identification of such events for their operational recognition and prediction.

3. Analysis

The analysis of this event focuses on the synoptic setting in terms of what occurred and the role of the precedent conditions with regard to model guidance and forecaster mind-set prior to the event. A hindcast examination of why the event took place is based on satellite and other operational diagnostics. This approach allows discussion of why the event occurred and provides clues as to how it might have been detected in advance. A postanalysis was also performed through the use of hindcast Pennsylvania State University–National Center for Atmospheric Research fifth-generation Mesoscale Model (MM5) runs based upon initializations prior to the event. This was to determine whether a model with a finer mesoscale resolution (the Eta Model at this time was running at a horizontal resolution of 48 km) and different physics might have made a difference in forecast watch, warning, or advisory issuances.

An initial investigation of the event revealed several features that could have made a difference in operational forecasts. These included jet streak features, a midlevel moisture pool, and a deformation zone as identified through satellite imagery and model diagnostics. The event's mesoscale duration (several hours) and extent (central Mississippi), and the inability of both long- and short-range models to capture it, were also of interest in this regard. In fact, only the late run (0000 UTC 14 Dec 1997 Eta) of the numerical models indicated a snowfall event, but was received and analyzed after the event had already begun (and well past local news and weather coverage via the media). The Saturday, 1500 UTC 13 December 29-km resolution Meso-Eta, although not available in real time during the event (due to communications problems), did indicate precipitation. However, it was in error in terms of amounts being too light and location too far south and east as the precipitation was forecast to occur over southeast Mississippi.

a. Synoptic setting—What did happen?

Surface data, satellite imagery (infrared and visible), and model output (particularly initial conditions) for the period 13–14 December 1997 were examined. The surface pattern (Fig. 3a) for 13 December was unremarkable and indicated the state was covered by a cool (temperatures were seasonable with daytime highs near 10°C and lows near 0°C) continental subpolar air mass with minimal moisture (dewpoints near 0°C). Snow began falling by 0600 UTC on 14 December in northeast Louisiana and west-central Mississippi and spread east before sunrise. Snowfall intensity peaked during the early and midmorning hours and ended during the late afternoon.

In the upper air (Fig. 3b) a positive-tilt trough, producing only weak shear vorticity, was moving southeastward from the central plains states with little surface reflection. Deep, but weak, layer cold air advection was occurring across the southeastern region of the United States. There was no quasigeostrophic forcing in place or in development and static stability was uniform across the southeast United States. This synoptic pattern is relatively common during the winter season for the study area and is not typically associated with heavy snow in Mississippi. As no amplification of this pattern was forecast by the operational models, no major event was anticipated. In reality, the verifying pattern from 14 December indicated that while the surface pattern remained relatively quiescent (Fig. 4a), the upper air pattern (Fig. 4b) consisted of a deep closed system moving along the Gulf coast, much stronger than model guidance had predicted (Gerard et al. 1998).

b. Diagnostics—Why did it happen?

Model output from the 1200 UTC 13 December (Saturday) Eta were reviewed and indicated no fall of precipitation for the event period. Interestingly, medium-range model forecasts from the preceding week had indicated several minor snowfall events that never materialized or simply ''moved'' forward in time with each model run only to ''disappear'' as verification time approached. The Saturday evening model run (0000 UTC 14 Dec) did indicate an event but was received as the event began and well after the time necessary for an effective watch to warning, or advisory, sequence. By 1200 UTC 14 December a well-developed mid- and upper-level low was present over southeast Louisiana with heights more than 100 m lower than indicated by earlier model predictions.

An extensive review of operational model performance preceding and during the event (Gerard et al. 1998) indicated large forecast errors in heights (as much as 160 m), amplification (weakening), moisture fields (underdone and decreasing), and location of the upper trough system by all of the short- and medium-range operational models. A retrospective of ''lessons learned'' in that technical review indicated that an analysis of isentropic potential vorticity (IPV) fields may have helped forecasters diagnose these errors. The IPV indicated a potential for the upper-level system to be stronger and to intensify. However, even with this information the mass fields (which had not been well forecast by the models) revealed little available moisture and uniform static stability. Typically this would produce only clouds and the threat of flurries or snow showers in a cold advection environment.

Satellite imagery (water vapor channel) prior to the event indicated significant jet streaks in Mexico and Canada, a midlevel moisture pool over Alabama and Georgia, and a deformation zone moving across Missouri and ultimately into Arkansas (Fig. 5). These features were compared to the initialized model fields (in particular the 1200 UTC Eta for 13 Dec) and found to be in existence, but much weaker. In addition, the jet streak features disappeared within the first 12-h forecast period, and the moisture pool began to dry up, but the deformation zone remained an obvious feature. In contrast, the late run (0000 UTC 14 Dec) maintained the existence of both jet streaks.

The observed jet streak features provided a favorable zone for lift and amplification of the mid- and upper-level system that resulted in snowfall across the region, despite limited moisture. This lift was focused within the vicinity of the deformation zone and coincident with increased, although temporary, frontogenetical forcing

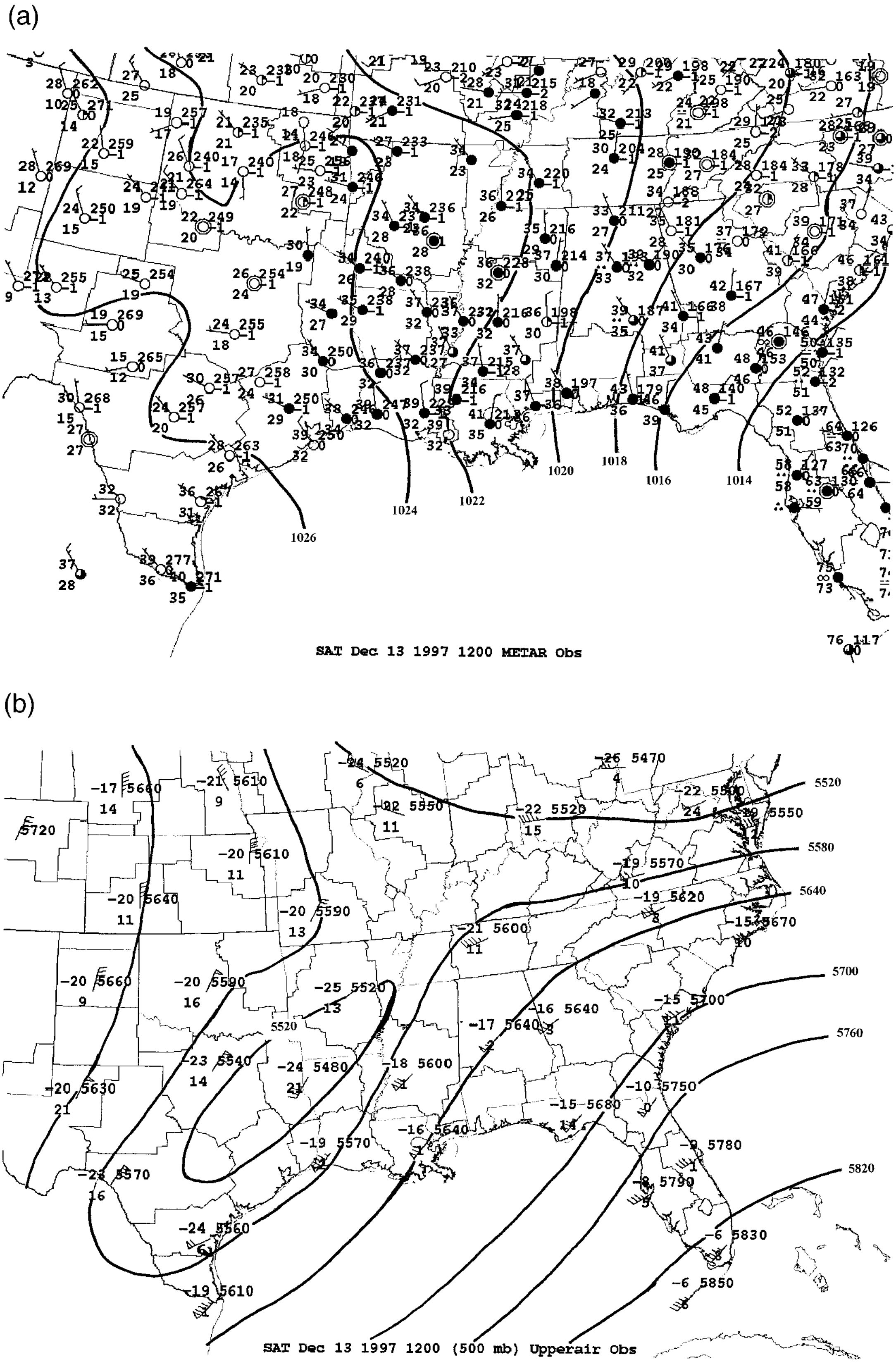

FIG. 3. (a) Surface synoptic station plots including isobars, and (b) 500-mb station plots and contours for the south-central United States observed Saturday, 1200 UTC 13 Dec 1997.

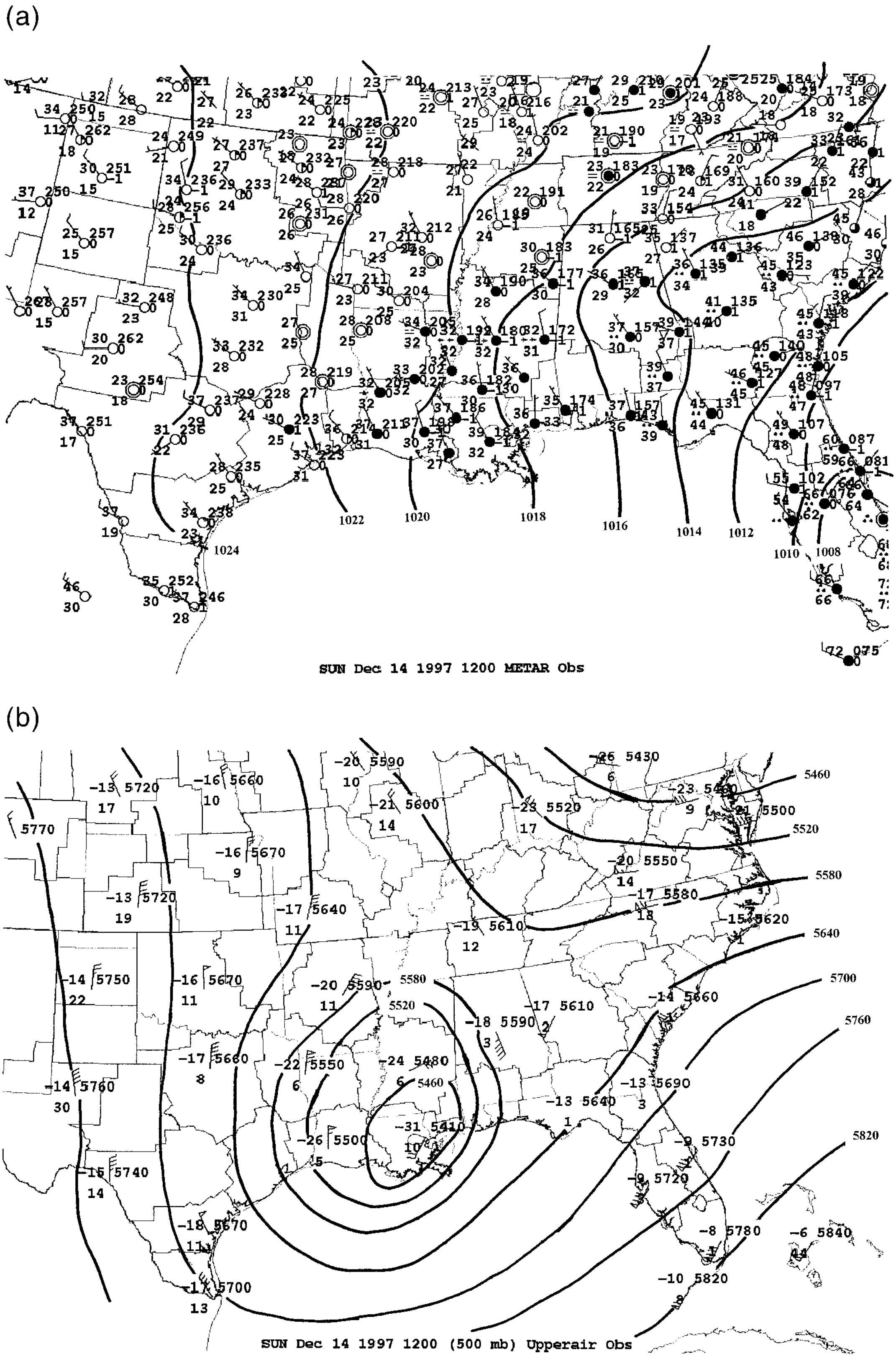

FIG. 4. Same as in Fig. 3 but observed Sunday, 1200 UTC 14 Dec 1997.

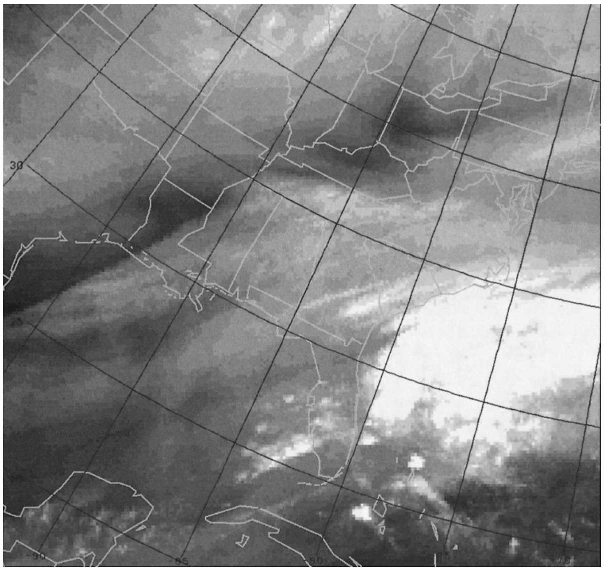

FIG. 5. Water vapor satellite imagery as event began, observed Saturday, 2315 UTC 13 Dec 1997.

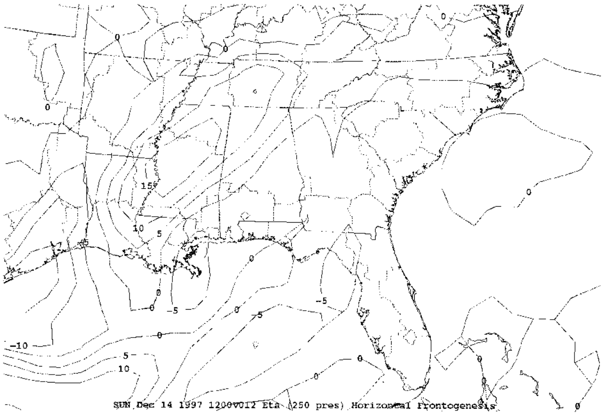

FIG. 6. Observed horizontal frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$] at the 250-mb level based on Sunday, 1200 UTC 14 Dec 1997 Eta initialization.

(Fig. 6). The vertical motion pattern associated with these features gave preferred lift in the mid- and upper levels (based on the 1200 UTC 14 Dec initialization). The deformation and frontogenesis were most obvious above 700 mb, particularly from 500 mb upward, with the best signal being the 250-mb frontogenesis.

The model review, in conjunction with hindcast of satellite observations, illustrates the conundrum forecasters are faced with when all numerical guidance is in good agreement but wrong. Hence it is critical that forecasters closely examine all observational data in conjunction with numerical model data to make a sound meteorological judgment as to the accuracy of the initialization and the early hours of the forecast guidance. However, the integration of such observational evidence into a numeric forecast, particularly if counter to model guidance, is extremely difficult in practice and is clearly not objective or numeric. Similarly, operational comparison of model guidance is inexact without explicit knowledge of the initialization and parameterization errors of each model. These are operationally difficult to assess (e.g., use of ensembles, error diagnostics) and are not correctable in a true numeric sense operationally.

The moisture pool (refer again to Fig. 5) located to the east was initialized by the late run (0000 UTC Dec 14) with 3–4 g kg^{-1} in the 700–500-mb level in the presence of upward motion. The combination of the moisture pool with an induced frontogenetic circulation, and focusing in the vicinity of the deformation zone, allowed for isentropic upglide of the moisture over Mississippi. Weak static stability was observed near and in the vicinity of strong frontogenetic forcing (Figs. 7a,b), both before and during the event, centered over Mississippi. Analyses indicated that the area where the deformation zone developed was the least stable of the region. Thus decreased static stability through the layer allowed an enhanced response to the strong frontogenetical forcing.

This resulted in strong upward vertical motion and saturation in a relatively narrow west to east band in spite of limited moisture. A conceptual model interpretation of this would consider how isentropic lift along the deformation zone allowed the saturation process to occur and the moisture to be ''wrung out'' along a frontogenetic area over central Mississippi. This moisture would thus be available for immediate and sudden transport in a conveyor-belt fashion (Carlson 1980), similar to that of found within an extratropical cyclone's circulatory system. Thus in mesoscale time and space a surprise snowfall could quickly develop with little advance warning.

c. Mesoscale model diagnostics

In an attempt to capture the event in a forecast (hindcast) mode, and in terms of its mesoscale features, the MM5 (version 3.2) was applied. The model initialization datasets (1200 UTC 13 Dec and 0000 UTC 14 Dec) were obtained from the COMET archive. The MM5 model domain consisted of a triple nest grid centered over Jackson, Mississippi (Fig. 8 showing model grid/domain) with an outer domain of 27 km, and inner grids of 9 and 3 km. The model was run for a nonhydrostatic atmosphere. Accumulation of precipitation in the two inner grids was explicit.

Limited atmospheric model diagnostics were produced and focused on vertical velocity, quantitative precipitation, and frontogenesis. Plan-view cross-section analyses and forecasts were also made (not shown) and analyzed. The intent was to determine whether a mesoscale model, based on the same initial data, might have provided forecasters with information that may have led them to consider the occurrence of a snowfall event. Of primary interest in the modeling was the gen-

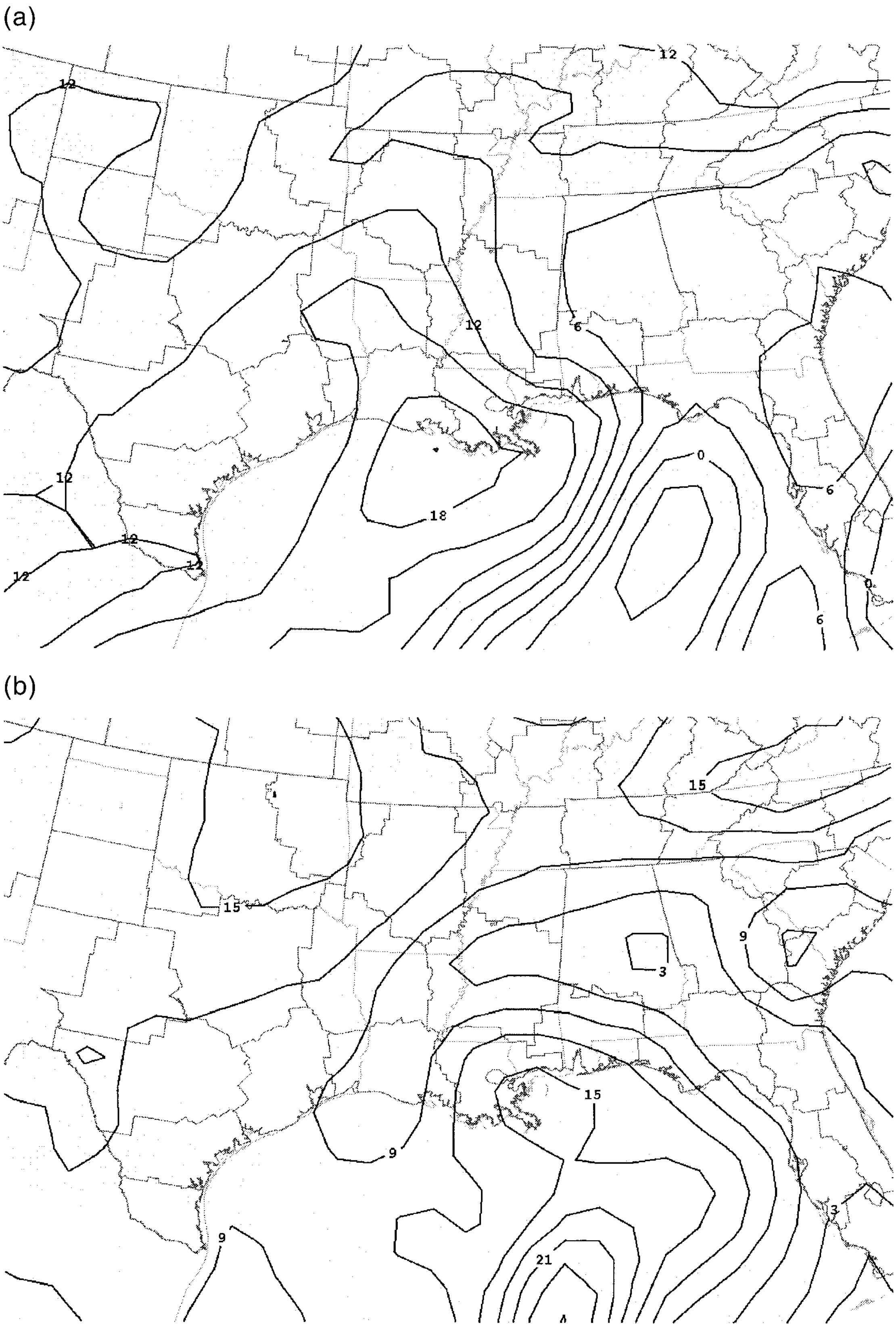

FIG. 7. Static stability (layer difference of equivalent potential temperature in K) for the 750–500-mb layer for model initializations at (a) 0000 UTC 14 Dec 1997 and (b) 1200 UTC 14 Dec 1997.

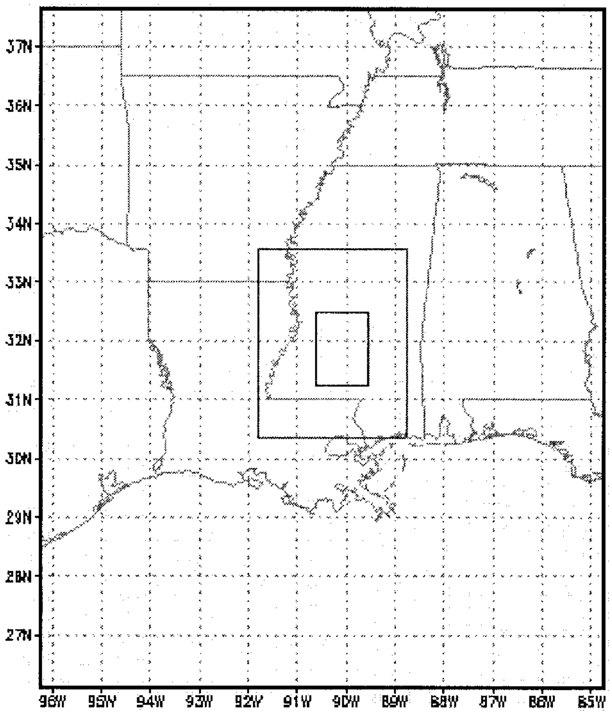

FIG. 8. Model domains used for the MM5 initializations based on 1200 UTC 13 Dec and 0000 UTC 14 Dec datasets.

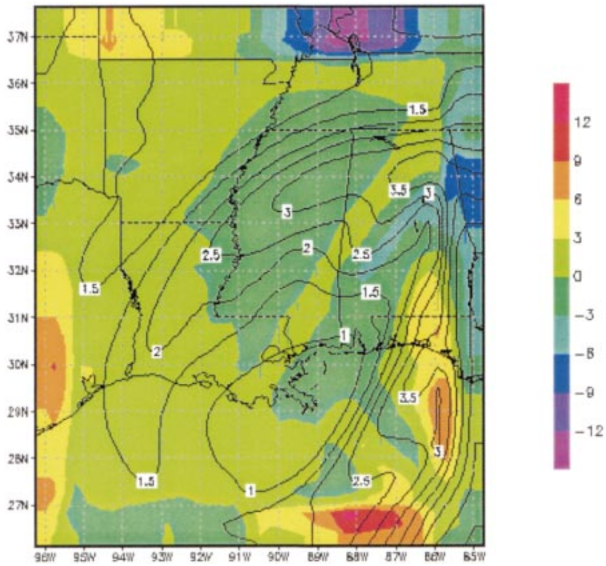

FIG. 9. Vertical velocity (mb s^{-1}, chloropleths) and water vapor content (g kg^{-1}, isopleths) at 700 mb from MM5 24-h forecast valid 1200 UTC 14 Dec, based on 1200 UTC 13 Dec initialization.

eration of precipitation, particularly based on the 1200 UTC 13 December initial data, prior to the time of the event. The MM5 runs were clearly superior in the strength of the upper air system and in capturing the precipitation processes that the operational models had not.

Analysis based on the 1200 UTC 13 December model initialization produced a pattern of vertical velocities and water vapor at 700 mb (Fig. 9), and accumulated precipitation (Fig. 10), which was strikingly similar to that observed (see Figs. 1 and 2). Although the observed amounts were higher, the MM5 run indicated an event that the 1200 UTC 13 December Eta did not. In addition, the MM5 high-level frontogenesis compared favorably with that observed (i.e., based on the initial analysis of the 1200 UTC 14 Dec Eta). This result, in combination with the cross section of vertical motion (Fig. 11), supports the suggested conceptual model and the significance of mesoscale processes in this event.

4. Results

The present investigation examined what happened and why the record snowfall event occurred (and why it was mesoscale in nature), and whether forecasters could have suspected or predicted the event in advance. Preliminary analyses revealed the significance of satellite imagery (and animation) in identifying the salient features while also illustrating the impact of missing and/or delayed data and models in operations.

With the aid of model diagnostics, it was clear that the observed jet streaks had significant interaction with the deformation zone approaching Mississippi and likely created the high-level frontogenesis. These features combined to aid and enhance the midlevel circulation that acted to bring a moisture pool westward with time. This moisture was lifted isentropically over Alabama and Mississippi and maximized the precipitation processes in the vicinity of the deformation zone.

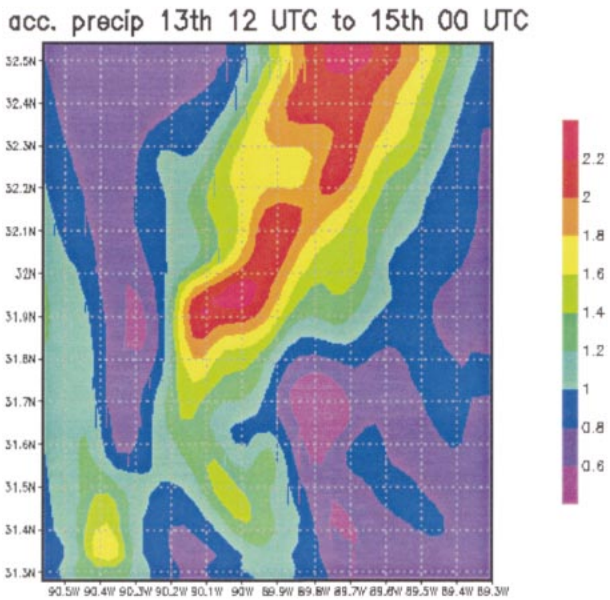

FIG. 10. Quantitative precipitation MM5 36-h forecast valid 0000 UTC 15 Dec, based on 1200 UTC 13 Dec initialization (amounts are in mm).

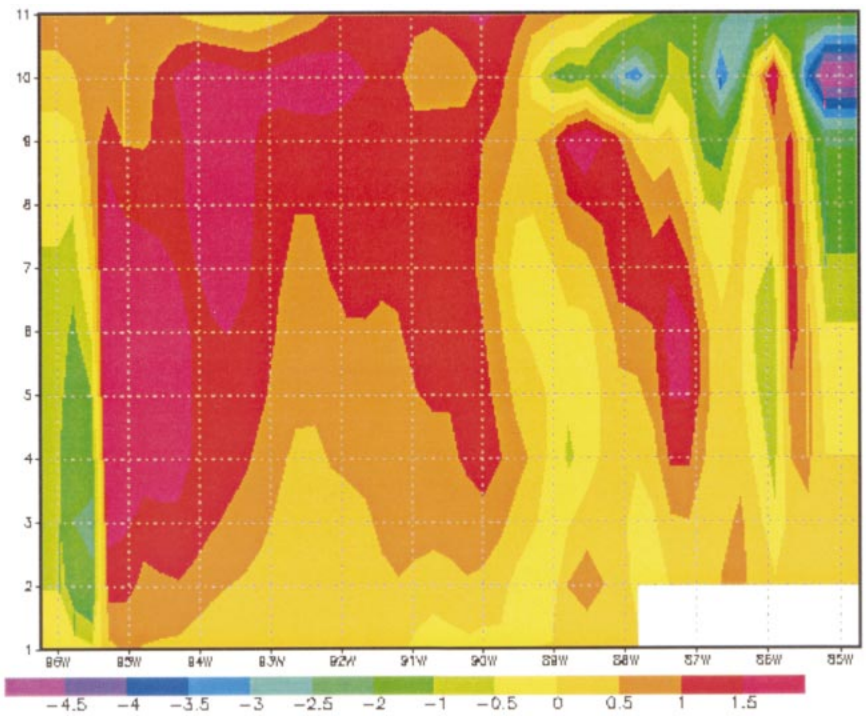

FIG. 11. MM5 24-h forecast cross section (from 85° through 96°W) of vertical velocities (mb s^{-1}) at approximately 33°N, valid 1200 UTC 14 Dec, based on 1200 UTC 13 Dec 1997 initialization (Jackson, MS, is located at approximately 32°N, 90°W).

The diagnosis, although useful, does not completely answer the question of whether forecasters could have—or would have—made a different forecast. Therefore MM5 simulations were conducted to determine whether a mesoscale model (in hindcast) could capture the event and thus provide forecast guidance leading to an improved prediction.

Model results, although not precise, did indicate the occurrence of a snowfall event with mesoscale characteristics. Even though total model precipitation estimates were much lower than observed, they would have likely led a forecaster to consider the possibility of snow regardless of amount and areal extent. Indeed, the existence of a frontogenetic area along a deformation zone (as shown in available and earlier model runs) could also have alerted the forecaster to consider the possibility of precipitation, even if these weakened with model forecast time.

5. Conclusions

Clearly not all major snowfall events occur under easily recognized synoptic or mesoscale settings. In fact, the significance of thinking ''outside the box'' in winter weather forecasting while monitoring short-term conditions is critical. This approach is very similar to that used in the convective season: models routinely miss or misforecast convection. However, operational meteorologists are attuned to this fact and take appropriate and alternative approaches to diagnosing the atmosphere for convection. Although winter weather is typically dominated by dynamic quasigeostrophic systems within data-dense regions, and should be well predicted by numerical models, it would seem logical that specific mesoscale forecast methods must be developed.

It is the authors' opinion that this type of event occurs in many places and at many times across the United States and thus is amenable to a conceptual model approach. The results also indicate the need for refined means of mesoscale analysis for ''winter atmospheres'' and a greater consideration of the above boundary layer processes. Further diagnostic investigations are needed to fully understand and comprehend the dynamics involved in these ''surprise'' events and the resulting moisture and precipitation distributions. The utility of mesoscale models will be paramount to this effort.

Acknowledgments. This project was funded and performed under the COMET Partners Projects UCAR Subaward S99-13029. COMET is sponsored by the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation, its subagencies, or UCAR.

The authors also acknowledge partial support provided by the Army High Performance Computing Research Center at Jackson State University for mesoscale modeling (University Minnesota Army Research Grant R5156038401), the Department of Defense High Performance Visualization Center Initiative at Jackson State University (N62306-99-D-B004), and the ORISE student support program.

Our appreciation to the Jackson National Weather Service staff for their assistance and first-hand accounts of the event and to students Shundra Stewart and Michelle Webb for their help in snowfall event information gathering.

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