Service Assessment

BLIZZARD

January 6 - 8, 1996

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, MD

December 1996

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PREFACE

January 6-8, 1996, a major "nor'easter" paralyzed the Eastern Seaboard for the better part of a week. Right on the heels of a Federal Government shutdown that furloughed most Federal employees, some of the heaviest snow of the late 20th century blanketed the highly populated urban corridor from Washington, D.C., to Boston, Massachusetts. I believe the facts contained in this report speak for themselves concerning the quality of service that both the National Weather Service (NWS) and all of our partners in the hazards community provided to the public. Many NWS employees were stranded at or near the office for several days, working long hours and sleeping either on-site or at nearby hotels. A few risked their lives to get to work.

Local emergency managers across the affected area commended local NWS offices for timely and accurate warnings, watches, and outlooks. Rigorous continuing coordination between NWS field offices, local emergency managers, and the media months in advance of the event ensured that clear lines of communication were already in place when the storm struck. The final result was that the warning system worked, enabling the public, local decision makers, and all weather sensitive interests to take timely actions to reduce the threats to life and property.

Elbert W. Friday, Jr.

December 1996

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ACRONYMS

AFOS	Automation of Field Operations and Services
ASOS	Automated Surface Observing System
AWIPS	Advanced Weather Interactive Processing System
C	Celsius
CWA	County Warning Area
ECMWF	European Center for Medium Range Weather Forecasting
EMA	Emergency Management Agency
ERH	Eastern Region Headquarters
F	Fahrenheit
FAR	False Alarm Rate
HCH	Hurricane Coordination Hotline
HPC	Hydrometeorological Prediction Center
km	kilometer
kt	knot
mb	millibar
MRF	Medium-Range Forecast
MSLP	Mean Sea Level Pressure
NCEP	National Centers for Environmental Prediction
NEXRAD	Next Generation Weather Radar
NOS	National Ocean Service
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSFO	NEXRAD Weather Service Forecast Office
NWSO	NEXRAD Weather Service Office
PNS	Public Information Statement
POD	Probability of Detection
QPF	Quantitative Precipitation Forecast
RDA	Radar Data Acquisition
UKMET	United Kingdom Meteorological Office
UTC	Coordinated Universal Time
VDOT	Virginia Department of Transportation
WSOM	Weather Service Operations Manual
WSR-88D	Doppler Weather Surveillance Radars
WSW	Winter Storm Watch/Warning/Advisory

SERVICE ASSESSMENT
National Implications

OFFICE OF METEOROLOGY PERSPECTIVE

On January 6-8, 1996, a large portion of the eastern United States was struck by a major winter storm that buried the heavily populated Northeast Corridor under one of the greatest snowfalls of the 20th century. The metropolitan areas of Washington, D.C., Philadelphia, New York City, and Boston were virtually paralyzed as snowfalls of 19 to 31 inches were whipped into 5- to 8-foot snow drifts. In the mountains of western Virginia and West Virginia, 40- to 48-inch snowfalls were common. Hazards associated with the winter storm included blizzard conditions, strong winds, extreme wind chills, and minor to moderate coastal flooding. The storm caused over $500 million in insured losses, contributed to 60 fatalities, and shut down or hampered travel and commerce for 5 days after it ended. The storm was caused by a low pressure system that developed in the Gulf of Mexico on January 6. From there it moved northeastward along the East Coast, leaving a swath of snowfall in excess of 10 inches from eastern Kentucky northeastward across the Mid-Atlantic States into southern and central New England.

NWS warnings and forecasts provided information with the types of lead times that enabled all levels of government, local decision makers, and businesses to make timely life and property decisions both before and during the event. For example, the Virginia Department of Transportation (VDOT) began preparing for the storm *four* days before it hit, while the Governor of Virginia declared a state emergency before the first snow flake fell. Similarly, airlines moved their aircraft from East Coast cities so that they could be brought into service more quickly and not confound airport snow clearance procedures.

On the large scale, forecast services were exceptional. Forecasters at the Hydro-meteorological Prediction Center (HPC), after analyzing guidance from the Environmental Modeling Center Medium-Range Forecast (MRF) model, the United Kingdom Meteorological Office (UKMET) and the European Center for Medium Range Weather Forecasting (ECMWF), provided NWS field offices with an early "heads up" concerning the potential development of a low pressure system in the western Gulf of Mexico. As early as January 1, they noted a systematic bias in the MRF model of too little amplitude and too much progressivity in the southern stream of the upper air flow. Over the next 2 to 3 days, this assessment proved to be accurate as HPC forecasters continued to add value to the numerical guidance.

Given this numerical and HPC guidance, field forecasters throughout Eastern Region began to assess the effects that this storm would have upon their respective areas of responsibility. By January 3, they began to highlight the potential for a winter storm beginning late in the week over the Ohio Valley and spreading east over the weekend. As the event drew closer, output from subsequent numerical model runs continued to agree with that of earlier runs, allowing the offices to convey a more definitive message of the impending storm. Late in the afternoon on Friday, January 5, Winter Storm Watches were issued along the Eastern Seaboard for as far north as the Baltimore/Washington, D.C., area. Early Saturday morning, January 6, the watch area was extended northeastward across the New York City area to extreme southeastern New England. These watches had lead times of 24 to 36 hours.

On the smaller time and space scales, however, there were some inaccuracies in NWS guidance and forecasts. Uncertainties in the storm track, noted in the medium-range guidance from several days earlier, continued with the shorter range guidance that was produced on Friday, January 5, and Saturday, January 6. Relatively small shifts in the storm track often cause large changes in the weather in certain critical areas, and this storm was no exception. As the weekend progressed and the storm began to track further north and west, the numerical and HPC guidance began to shift the forecast of the outer edge of the snow shield further north and west. This placed additional areas under the threat of heavy snow, including much of Ohio, northern Pennsylvania, southern New York, and more of southern and central New England. Forecasters in these areas had to play "catch up" by issuing Winter Storm Warnings with shorter lead times and forecasts with increased snowfall amounts.

In some of these areas of low forecast certainty, forecasters in adjacent offices disagreed on forecast details which were not always sufficiently resolved prior to forecast issuances. With the Modernization and Associated Restructuring of the NWS, the boundaries between the forecast and county warning areas of adjacent NWS offices frequently do not coincide with state boundaries. Therefore, any differences in opinion between forecasters in adjacent offices can result in substantial forecast differences within a single state. This can be confusing to the media as well as state and local emergency planning officials. While the HPC and the NWS field offices along the coast had the advantage of being able to use the Hurricane Coordination Hotline (HCH) to accomplish internal coordination, noncoastal offices did not have this capability and were forced to resort to multiple one-on-one telephone calls with adjacent offices. This not only proved ineffective but most likely contributed to inconsistent forecasts in portions of the Ohio Valley. To facilitate effective internal warning and forecast coordination, conference call capability in <u>all</u> NWS field offices is essential.

Storms of this magnitude are notorious for producing massive multistate power outages, and this one was no exception. Nonetheless, the National Centers for Environmental Prediction (NCEP) and all field offices remained open and functional. Some equipment outages were reported. The most noteworthy included the loss of the Doppler Weather Surveillance Radars (WSR-88D) at Raleigh, North Carolina, and Blacksburg, Virginia, both of which, due to the depth of the snow, could not be accessed for repair until after the storm.

Emergency managers at the state and local levels were contacted immediately after the storm to assess how the NWS met their needs. Nearly all people contacted gave the NWS high marks for its quality of service. Economic and public safety benefits were most strongly realized in those areas where the NWS was already actively engaged in a program of collaboration and education with its customers. The Next Generation Weather Radar (NEXRAD) Weather Service Forecast Office (NWSFO) in Sterling and VDOT provided a model example of this collaborative effort. Post-storm interviews with local media outlets were also quite positive. Cooperation between the NWS and local media outlets was unprecedented with some field offices chalking up more than 100 interviews in a 24-hour period. As a result, the media served as an extension of the NWS warning process, ensuring that critical life- and property-saving information was given the widest possible dissemination.

While nearly all post-storm contacts commented favorably about NWS services, some concerns were noted. One media representative mentioned that the Automated Surface Observing System (ASOS) observations were, at times, misleading to the public because ASOS does not measure snowfall, the wind equipment became inoperative during freezing rain, and freezing precipitation reports often do not reach the public because they are only noted in the remarks section of the observation. One state emergency manager noted that while warnings and watches were issued well in advance of the event, individual forecast packages were later than usual. Since the NWS is expected to come to end state staffing levels before the Advanced Weather Interactive Processing System (AWIPS) reaches maturity, forecast delays could become even longer and more prevalent. Therefore, the Office of Meteorology needs to work with the Regions to define service priorities in relation to dwindling staff resources to ensure that the most vital information is issued as rapidly as possible.

The storm had a major impact on NWS employees and demonstrated the dedication and commitment of our workforce. Field and NCEP personnel worked around-the-clock with little relief. People brought extra food and sleeping bags to their respective offices and remained at these offices or in nearby hotels for 48 hours or longer. Sixteen-hour shifts and three-hour commutes were common. People took extraordinary efforts to get to the office. In some cases, four wheel drive vehicles were used to ferry people to their offices while at least one employee cross-country skied to work. All this occurred during a Federal Government shutdown when most Federal employees were furloughed. Nonetheless, NWS employees continued to serve and ensure public safety around-the-clock without the assurance of paychecks. This conscientious "can do" attitude of NWS employees likely contributed to the amazingly low death toll for an event of this magnitude.

FINDINGS AND RECOMMENDATIONS

Finding 1: This storm underscored the fact that NWS internal forecast coordination still needs improvement. Although Eastern Region offices made considerable efforts to coordinate their warnings and watches, some inconsistencies did exist. Furthermore, though the NCEP and coastal field offices had the availability of the HCH to facilitate coordination, most inland offices were forced to rely on multiple one-on-one telephone calls which proved time-consuming and frustrating.

Recommendation 1: The NWS regions should work with their Warning Coordination Meteorologists to ensure that field forecasters appreciate how their products are perceived by their customers. The NWS regions also must take steps to ensure that adjacent field offices reach a consensus forecast, especially within single state boundaries. The Office of Meteorology must continue to work with the Regions to provide coordination capabilities similar to the HCH to all offices involved in the warning process.

Finding 2: Internal coordination between forecasters in adjacent offices was Enhanced whenever forecasters had previously met face to face.

Recommendation 2: Meteorologists in Charge should arrange for forecasters to regularly visit and attend meetings and workshops at adjacent offices.

Finding 3: Coordination between the Sterling NWSFO, VDOT, and the Virginia Emergency Management Agency was excellent because the Sterling office has expended much time and effort into outreach and customer education activities with state officials.

Recommendation 3: Meteorologists in Charge and Warning Coordination Meteorologists should make it a high priority to maintain and enhance a good working relationship with the emergency management agencies (EMA) in their county warning areas (CWA). NWSFO/NEXRAD Weather Service Office (NWSO) staffs need to know the operational needs and capabilities of EMAs. Field office staffs must also make a point of educating EMAs on NWS operational needs and capabilities. This mutual education, collaboration, and planning enhances public safety, thereby improving the cost/benefit ratio to taxpayers.

Finding 4: The "Blizzard of '96" made travel nearly impossible over the affected area for almost 48 hours. Personnel were unable to leave because their relief could not get to work. Some personnel stayed at the office for over 36 hours.

Recommendation 4: Long-term planning is vital to continuing operations at NWS offices affected by prolonged significant weather events. Long-term planning should include arranging for temporary sleeping quarters at a nearby motel/hotel or campus center. Otherwise, cots should be obtained for personnel to sleep at the office. An office food cache should be available for emergencies, including canned foods that do not require heating.

Finding 5: Winter Weather Outlooks issued under the Automation of Field Operations and Services (AFOS) header Special Weather Statement were issued almost 3 days in advance of the "Blizzard of '96." Many emergency managers gave high praise to this early notice.

Recommendation 5: The Office of Meteorology will work with the Regions to ensure that all offices appreciate the customer's needs for this product and that offices issue them in a consistent manner.

Finding 6: Winter Storm Watch/Warning/Advisory products issued under the AFOS header WSW had a tendency to be too long, limiting their effectiveness to users.

Recommendation 6: WSWs should be as short and to the point as possible. The Office of Meteorology will work with the Regions to develop a streamlined WSW product.

Finding 7: The most frequently requested information during and after the storm was snowfall amounts. However, offices use a variety of AFOS products to disseminate this information, forcing users to search through several products to find the data they want.

Recommendation 7: The same NWS product should be used by all offices to disseminate snowfall amounts. It should be issued as often as possible but at least every 3 hours with a final release to give storm totals. Within Eastern Region, the Public Information Statement (PNS) is now being used for this purpose. The Office of Meteorology should coordinate with the Office of Systems Operations and the Regions to implement a standard product for this purpose.

<u>Finding 8</u>: Many erroneous snowfall reports were reported to our offices, some of which were disseminated to the public.

<u>Recommendation 8</u>: A distinction needs to be made between official NWS observations, made by NWS trained observers, and unofficial observations. The Office of Meteorology will work with the Office of Systems Operations and the Regions to ensure that Data Acquisition Program Managers provide proper snowfall measurement training. The revised NWS Snow Measurement Guidelines, dated October 23, 1996, fulfills this purpose.

<u>Finding 9</u>: Field offices on the predicted edge of the precipitation field were reluctant to issue watches or include counties in existing watches due to the sharp gradients in model guidance fields and the resulting uncertainties in predicted snow amounts.

<u>Recommendation 9</u>: Forecasters must realize that the issuance of a watch does not mean that its event is certain to occur. The Regions should work with their field offices to ensure that they follow the guidelines in Weather Service Operations Manual (WSOM) Chapter C-42, Winter Weather Warnings, section 6.2, which states that "WSFO/NWSFOs should issue a winter storm watch when conditions are favorable for hazardous winter weather conditions, as defined in section 4, but the occurrence is still uncertain."

<u>Finding 10</u>: Several days in advance, the MRF model poorly forecast the digging of a 500-millibar (mb) shortwave into the base of the developing trough over the Mississippi Valley. It subsequently was unable to deepen this feature strongly enough to correctly model the rapid deepening of the surface low pressure center associated with the "Blizzard of '96" along the East Coast on January 7 and 8, 1996. The ECMWF was the most consistent model in forecasting the precursor synoptic-scale conditions that lead to the rapid deepening of the low pressure center associated with the "Blizzard of '96."

<u>Recommendation 10</u>: The Environmental Modeling Center should investigate this bias of the MRF to provide more reliable meteorological forecast guidance during periods of highly amplified ridges and downstream digging jets. Until model changes can be made, attention to this bias should be noted in HPC technical discussion products.

<u>Finding 11</u>: Some of the NWS customers reported that while warnings and watches were issued with sufficient lead time, some individual forecast packages were available later than usual. Since the NWS is expected to come to end state staffing levels before AWIPS reaches maturity, forecast delays could become even longer and more prevalent.

<u>Recommendation 11</u>: The Office of Meteorology needs to work with the Regions to define service priorities in relation to dwindling staff resources to ensure that the most vital information is issued as rapidly as possible.

<u>Finding 12</u>: The WSOM outlines national criteria for the issuance of winter weather and nonconvective warnings, watches, and advisories which are expected to be modified by the regional headquarters to account for climatic variations. Eastern Region offices interpreted the national guidelines differently which led to inconsistent service.

<u>Recommendation 12</u>: Eastern Region Headquarters (ERH) should work with their field offices to develop regional guidelines on the issuance of winter weather and nonconvective warning, watch, and advisory products that would promote consistent product delivery.

<u>Finding 13</u>: NWSFO Brookhaven lost the ability to link to the National Ocean Service (NOS) REALDATA tide information and were forced to turn to ERH for the information. As of November 1996, this problem has been corrected by NWSFO Brookhaven.

SYNOPTIC OVERVIEW

PREPARED BY HYDROMETEOROLOGICAL PREDICTION CENTER

The "Blizzard of '96" was in many ways a textbook example of a Northeast snowstorm. A low pressure system developed in the Gulf of Mexico and then moved northeastward along the East Coast. Correspondingly, widespread high pressure across the northern United States provided cold air for snow. The evolution of the storm was quite complex, with several low pressure centers forming, diminishing, and reforming. However, it still followed the overall pattern of a storm that developed in the Gulf of Mexico and moved northeastward along the Atlantic Seaboard.

Low pressure developed in the Gulf of Mexico early on January 6, 1996, with an inverted low pressure trough extending northward into the Gulf Coast States. As the low pressure system moved east-northeastward in the Gulf of Mexico on January 6, two additional centers of low pressure developed within the inverted trough by midday, one over eastern Mississippi and the other over Tennessee. These three centers were evident at 0600 UTC on January 7 as the surface low/inverted trough continued eastward extending from eastern Tennessee southward into the eastern Gulf of Mexico. By 1200 UTC on January 7, the multiple center structure began to change dramatically as both the eastern Kentucky and northeastern Gulf low pressure centers began to diminish and a surface low over eastern Georgia began to rapidly deepen. At the same time, a new low began to develop just north of Cape Hatteras, North Carolina, along a developing coastal front. In the next 6 to 12 hours, the southern low pressure system would appear to "jump" rapidly northeastward toward the developing low pressure system that remained virtually stationary just east of the North Carolina/Virginia border through 0000 UTC on January 8. By this time, one primary low pressure center predominated and was located just east of Norfolk, Virginia, with a central pressure of 990 mb. As the multiple centers evolved into one center, pressures fell relatively rapidly with the central pressure of the low off Virginia dropping 16 mb in 12 hours. In the following 12 hours, the main surface low drifted very slowly north-northeastward and continued to deepen to 980 mb by 1200 UTC on January 8, the time the cyclone reached its lowest pressure. To complicate matters, a new low pressure system developed farther east over the Atlantic Ocean prior to 1200 UTC on January 8 and moved northeastward in the following 12 hours. It is also possible that other low pressure centers developed over the Atlantic Ocean as the entire system began to propagate more rapidly northeastward over the Atlantic Ocean.

An analysis of the snowfall from the storm is shown in figure 1. In the highly populated Northeast Corridor, which includes the metropolitan areas of Washington, D.C., Philadelphia, New York City, and Boston, snowfall amounts ranged from 19 to 31 inches. Amounts between 40 and 48 inches were reported in western Virginia and the mountains of West Virginia. These amounts were among the highest observed during the late 20th century.

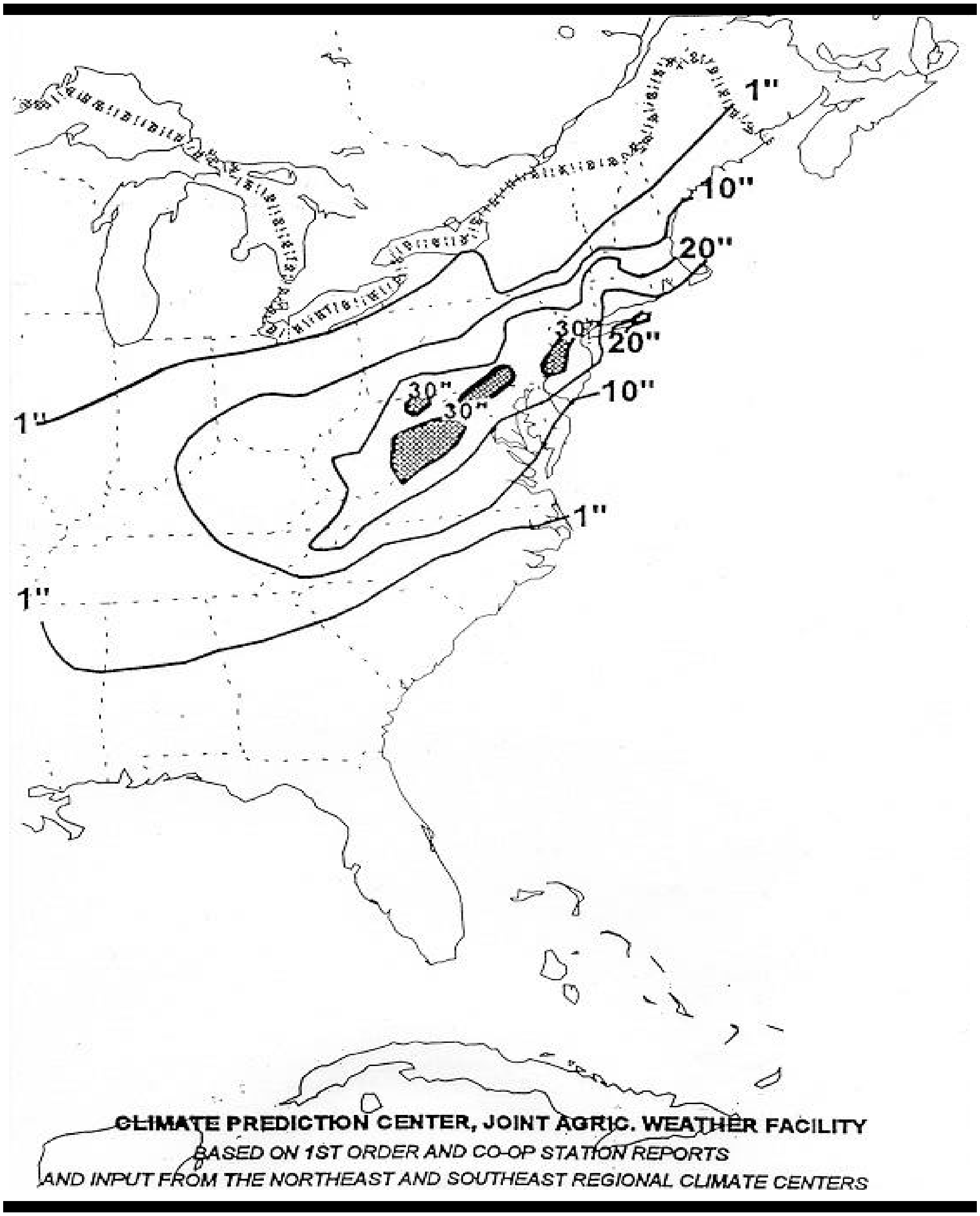


Figure 1. Total snowfall (inches) from the "Blizzard of '96" (January 6-8, 1996).

CHAPTER I

The Event and Its Impact

PREPARED BY EASTERN REGION HEADQUARTERS

Overview

The "Blizzard of '96" was one of the great winter storms of the past few decades, accompanied by all the "classic" signatures associated with a blizzard (i.e., heavy snow, strong winds, along with very cold temperatures and wind chill values).

The diversity and quantity of adverse weather associated with this storm system covered nearly the entire spectrum of NWS warnings, watches, advisories, and statements. Likewise, the entire population of the eastern third of the United States was affected in some way by this storm. This section of the report describes the storm's impact on both the public and NWS offices in those areas most severely affected. While the fine details varied locally, many signatures of the storm's impact were repeated from area to area and office to office.

Table 1 provides a snapshot view, by state, of the *known* direct and indirect storm-related fatalities and **insured** damages associated with the "Blizzard of '96." The majority of deaths were heart attack victims, resulting from shoveling snow. Insured losses totaled $585 million. If non-insured losses are included, the total storm damage approaches $1 billion.

This storm was the most significant event to impact the region since all modernized NWS offices assumed their new CWA responsibilities. The blizzard's impact will be viewed from south to north and from the perspective of this new NWSFO/NWSO structure.

County Warning Area Summaries

NWSFO Columbia, South Carolina, CWA — Heavy snow fell in the mountains and portions of the foothills. Six to twelve inches fell in the mountains and 2 to 6 inches in the foothills. This area also had 1/2 to 1 inch of freezing rain and up to an inch of sleet. The Piedmont had 1 to 3 inches of snow, up to an inch of sleet, and 1/2 to 1 inch of freezing rain. The midlands of South Carolina had an inch or less of snow and around 1/4 inch of freezing rain.

Highways were treacherous across the northwest half of South Carolina. There were several injuries due to weather-related accidents but no known deaths. There was little impact on the Columbia office. Personnel were able to get to and from work with little or no trouble. Staffing levels were adequate.

Table 1

FATALITIES + INSURED DAMAGE ESTIMATES (MILLIONS OF DOLLARS)

STATES	KNOWN FATALITIES	AIA* #
PA	13	100
NY	3	70
VA	18	65
MD	14	60
MA	0	60
NJ	0	55
CT	0	45
NC	6	25
OH	3	15
WV	2	15
DE	0	15
TN	0	15
RI	0	10
VT	0	10
NH	0	10
RI	0	10
SC	1	-
IN	0	5
TOTAL	**60**	**585**

* Derived from statistics provided by the **American Insurance Association (AIA)**. Claims represent **insured** losses primarily from wind and water (non-tidal) damage.

\# **Non-insured** losses on private or public property are not included in this list. "Public" denotes such items as cleanup costs, beach erosion, boardwalk, seawall and pier damage, lighthouse damage, etc. Also not available are specific tourist dollar losses.

\- Damages were below the insurance organization's threshold.

Note: Known fatalities are **directly** and **indirectly** storm related.

- # *NWSO Greenville-Spartanburg, South Carolina, CWA* — The storm produced up to 2 1/2 feet of snow in Mitchell and Avery Counties, located in the northern mountains of North Carolina. Snow amounts decreased to about 1 foot near the North Carolina/South Carolina border in the mountains and foothills, then decreasing to 1 to 2 inches eastward to Charlotte and points south to northeast Georgia.

  Mainly snow fell on the North Carolina mountains and foothills. Various mixtures and changeovers of precipitation occurred in upstate South Carolina, northeast Georgia, and the North Carolina Piedmont counties.

  Two of the NWSO's employees worked 16-hour shifts because two scheduled people could not report due to the storm.

  Three fatalities occurred, all traffic-related deaths—one in upstate South Carolina and two in western North Carolina. Numerous power outages occurred in the CWA.

- # *NWSFO Raleigh, North Carolina, CWA* — Precipitation type and snow amounts were the biggest problems faced in North Carolina. Many areas in North Carolina received a combination of snow, sleet, and freezing rain. For example, Raleigh received around 4 inches of an ice-snow mix, with at least 2 inches having fallen as sleet. The resulting accumulation of densely packed snow and ice was at least equivalent to a 10-inch snow.

  For over a week, driving conditions remained hazardous, and many area schools were closed. The impact of the storm's effects included six deaths from traffic and sledding accidents and millions of dollars spent by local government responding to the storm.

  The NWSFO maintained adequate staffing throughout the event, largely due to the Raleigh staff braving very hazardous driving conditions to get to the workplace.

- # *NWSO Wakefield/NWSO Blacksburg, Virginia, CWAs* — Snow amounts up to 2 feet occurred in several of the counties in the NWSO Wakefield CWA. There were widespread areas with more than 14 inches. Mixed precipitation of snow, sleet, freezing rain, and rain also impacted the CWA.

  During this storm, Roanoke and Lynchburg, Virginia, recorded their all-time high 24-hour snowfalls of 22.5 and 22 inches, respectively. Blacksburg's storm total of 34 inches would probably have been a record if local records were available. Otherwise, snow accumulations ranged from 14 to 40 inches.

  Four fatalities occurred in the NWSO Wakefield CWA—three from heart attacks related to snow shoveling and one attributed to a traffic accident. Some tree/power line damage and associated power outages resulted from freezing rain which fell in a narrow swath from Sussex and Surry Counties into the eastern portions of the middle peninsula and the northern neck of Virginia. Between 1/4 and 1/2 inch of ice accumulated at the NWSO.

In the NWSO Blacksburg CWA, the heavy snow closed airports, schools, businesses, and shopping centers; stranded motorists; derailed an 80-car train; collapsed mobile home roofs; and indirectly resulted in numerous traffic accidents and two fatalities.

Based on the grave NWS forecasts, a State of Emergency was declared in Virginia before the storm began. Virtually all schools, many businesses, and most Federal, state, county, and municipal offices were closed 1 or 2 days. The Richmond airport was also closed for an extended period of time. One building collapsed in Louisa County, Virginia, due to the weight of snow and sleet.

Due to the difficult and, in some cases, impassable roads, some of the NWSO Wakefield employees were at the office up to 32 consecutive hours. For those who were able to make it to the office, the commute averaged 3 hours.

A yeoman effort from all personnel kept NWSO Blacksburg adequately staffed during the storm. Several NWSO employees got their vehicles stuck in the snow enroute. A few had to walk through deep snow and in below zero wind chills to get to their residences. The office's four-wheel drive vehicle was used to transport staff members to and from work. Vehicles of many employees were buried in the NWS parking lot for several days.

NWSFO Washington, D.C. (Sterling, Virginia), CWA — The region was almost entirely shut down for 3 days with only limited movement and transportation of goods for nearly a week. Virginia reported 18 deaths associated with the storm. Three deaths were hypothermia related, and one occurred when a tree fell on a vehicle, killing its occupant. Ten fatalities were from heart attacks while shoveling snow, and four were related to vehicle accidents. Maryland reported 13 deaths due to snow shoveling and one fatality in a metro-rail accident that was weather related.

Almost the entire states of Virginia, Maryland, and West Virginia received over a foot of snow with a large area from the southern Shenandoah Valley of Virginia across Frederick and Hagerstown, Maryland, receiving up to 3 feet. Nearly 2 feet of snow fell along the I-95 corridor from Fredericksburg, Virginia, through Washington, D.C., and Baltimore, Maryland. Even to the south, Richmond, Virginia, saw a foot of snow. Strong winds following the storm caused problems with drifting snow that in many cases reached between 5 and 8 feet. Two additional snow events later that week added to the recovery frustrations.

Three roofs collapsed under the weight of the heavy snow: a nursing home in Clinton, Maryland; a church in Springfield, Virginia; and a school in the District of Columbia. Fortunately, no fatalities resulted from these incidents.

Metro-rail transit was discontinued at all above ground stations and did not resume full operations until late in the week. Area airports suffered a similar fate. The Federal and local governments were closed for a number of days. Stores and regional malls were closed. The economic impact was huge to retailers in the Washington area who were already suffering from lost sales during a long stretch of government furloughs and budget uncertainty.

As was the case at many NWS offices, travel to and from the NWSFO facility became nearly impossible. Office personnel, who had the "fortune" of finding themselves on-shift during the height of the storm, worked 12-hour shifts. During the times of most difficult travel, NWS personnel could not even travel the relatively short distance to a nearby hotel that had been selected because of its close proximity to the office. As was the case at many facilities, the office of the Meteorologist in Charge and the room off the main floor became makeshift dormitories.

***NWSFO Charleston, West Virginia, CWA* —** In Charleston, this storm produced the second highest snowfall from a single storm and the second greatest snow depth. Snowfalls ranged from 10 to 16 inches in southeast Ohio and eastern Kentucky. Across the Ohio River, counties in West Virginia accumulated up to 18 inches of snow. Across the rest of the West Virginia lowlands, 15 to 24 inches occurred. In the coal fields, 18 to 28 inches were measured. The southern mountains and Greenbrier Valley reported 20 to 30 inches, with the northern and central mountains reporting 24 to 48 inches.

Two deaths were recorded in West Virginia. One fatality occurred when a tree fell on a car, and the second was a snow shoveling/heart attack victim in the Charleston area. The Governor of West Virginia declared a State of Emergency in all counties. Power outages, affecting over 20,000 customers, were reported in Buchanan, Dickenson, Lee, Scott, Washington, and Wise Counties in extreme southwest Virginia. In Scott County, 15,000 customers were without telephone service.

***NWSFO Cleveland/NWSO Wilmington, Ohio, CWAs* —** The storm total snowfall for Cincinnati was 14.4 inches, a new single storm and 24-hour record. The storm total for both Dayton and Columbus was 9.8 inches.

Snow emergencies were issued for the entire state except the extreme northwest counties. Thirty Ohio counties closed county roads to all but emergency traffic. The Ohio Governor issued a proclamation of emergency for Preble, Darke, and Belmont Counties to help the Ohio Department of Transportation and the National Guard with snow removal. Many major businesses were closed. Postal deliveries were canceled in some areas on the day following the storm. Some roofs collapsed due to the weight of the snow.

Three people were killed in traffic accidents, two of which were children in the Dayton area. One person died from hypothermia after falling asleep in his car.

There was no major impact to the Cleveland NWSFO. At NWSO Wilmington, extra staff had to be called into the office, and a few employees were unable to get to the office for their scheduled shift(s).

NWSFO Philadelphia (Mount Holly, New Jersey)/NWSFO Pittsburgh/NWSO State College, Pennsylvania, CWAs — A State of Emergency was declared for New Jersey, eastern Pennsylvania, and Delaware. Philadelphia recorded 30.7 inches of snow, its all-time record for an individual storm. Thirty-eight inches were recorded in Glenville, Pennsylvania, located in York County near the Maryland border.

Large metropolitan areas in Pennsylvania, including Harrisburg, Lancaster, and York, east to Philadelphia, were virtually shut down. Many Steeler fans from areas east of Pittsburgh were stranded in the city after the Sunday National Football League playoff game. In Harrisburg, the 22.2-inch storm total was the second highest on record and the highest ever for January. In Wilkes-Barre, 21 inches exceeded the previous 24-hour record of 20.5 inches.

Snowfall totals from the storm were over 30 inches in Franklin County, Pennsylvania, the mountains of West Virginia (Preston and Tucker Counties), and Maryland (Garrett County). A total of 18 to 24 inches fell in south-central Pennsylvania, 18 to 20 inches fell in extreme southwest Pennsylvania and northern West Virginia, and 6 to 14 inches fell in east-central Ohio through west-central and central Pennsylvania. Two inches or less fell in extreme northern Pennsylvania.

The Governor of Pennsylvania declared a snow emergency and closed the roads, except for emergency travel, in 47 of the 67 counties in the state. The Governor of West Virginia placed the entire state under a State of Emergency and called in the National Guard to assist with snow removal.

Thirteen deaths were reported throughout Pennsylvania. Twelve of the 13 deaths were due to heart attacks from shoveling snow. USAir cancelled about half of its regularly scheduled flights at its Pittsburgh hub. Virtually all public, private, and day care schools closed in Pennsylvania, except for extreme northern Pennsylvania which only had 1 to 3 inches of snow. Federal, state, and city offices in Pittsburgh closed. Penn State University was shut down—certainly a rare occurrence.

A roof collapsed in Edison, New Jersey, due to the weight of the snow. Additionally, many of the NWSFO Philadelphia staff worked numerous extra hours due to the inability of some of the staff to reach the office.

Coastal portions of Delaware and New Jersey experienced moderate to locally severe coastal flooding and erosion. The National Guard had to evacuate a number of individuals out of harm's way.

NWSFO New York (Brookhaven), New York, CWA — Heavy snow combined with strong winds caused blizzard conditions for a prolonged period of time, crippling local routine activities. Newark, New Jersey, recorded 28 inches of snow, while in Manhattan's Central Park, almost 21 inches fell—the third highest snowfall total for an individual storm.

In Suffolk County, New York, three men died from heart attacks while shoveling snow. Eighteen people in the tri-state area suffered from "partial" carbon monoxide poisoning (i.e., they fortunately survived) in their stranded cars. As in the Boston CWA, heavy snow caused several roofs to collapse throughout the New York CWA. A State of Emergency was declared for southeastern New York State during the height of the storm.

Minor to moderate coastal flooding and beach erosion occurred along the south and north shores of Long Island. Along the south shore, the 50-year-old Casino bar and restaurant in Davis Park (on Fire Island) was swept into the sea. In addition, three homes in the Fire Island Pines were destroyed, and Gilgo Beach lost 50 to 75 feet of sand. Just after high tide, up to 2 feet of water flooded downtown Ocean Beach where 150 families live. Extensive flooding was also reported in Atlantique, making driving down the main Fire Island thoroughfare virtually impossible.

Local airports were closed for nearly 48 hours. Similar major disruptions were experienced by the area's rail systems. Mail and newspaper deliveries were delayed.

Since roads were impassable from Sunday afternoon through Monday morning, scheduled staff were unable to come in and relieve working staff. Consequently, many of the staff worked extensive extra hours.

NWSFO Albany, New York, CWA — Snowfalls ranged from half an inch at Albany to isolated amounts over 30 inches in Dutchess and Berkshire Counties. Snowfalls ranged from 10 to 20 inches with 6- to 10-foot drifts in Berkshire County, Massachusetts; Litchfield County, Connecticut; and Greene, Columbia, Delaware, Ulster, Sullivan, and Dutchess Counties in New York. States of Emergency were declared in Litchfield, Pittsfield, Berkshire, Dutchess, Columbia, and Ulster Counties.

NWSFO Boston (Taunton), Massachusetts, CWA — The storm produced up to 29 inches of snow, blizzard conditions, and a (relatively minor) 2-foot storm surge along the coast. Over 20 inches of snow fell in Rhode Island, Connecticut, and Plymouth and Bristol Counties in Massachusetts. This swath was a continuation of the heaviest snow band which originated in central Virginia, then crossed eastern Pennsylvania and northeast New Jersey. The snowfall from this storm added to the existing snow cover, giving Boston's Logan Airport 30 inches on the ground. This broke the all-time snow depth record of 29 inches set in February 1978. However, the 18.2 inch total for this storm at Logan was only the seventh heaviest snowfall event—the Blizzard of '78 is this area's benchmark storm.

The storm's main impact was to shut down school systems, airports, and other transportation means for several days. In addition, heavy snow accumulations collapsed roofs in the days following the blizzard.

A number of the NWSFO's staff were put up at a local Holiday Inn to ensure sufficient staffing during the blizzard.

NWSFO Portland (Gray), Maine, CWA — This was "just another storm" as a large portion of the NWSFO's CWA experienced little or no accumulation. In New Hampshire, only the southern third of the state reached warning criteria with no snow in the north. In Maine, the

snow reached warning criteria only in the southwest and coastal zones with no snow in the northern and mountain zones. Scarborough, Maine, received 12 inches; Portland, Maine, 10.2 inches; and Portsmouth, New Hampshire, 12 inches.

CHAPTER II

Warning/Forecast Services and User Response

PREPARED BY EASTERN REGION HEADQUARTERS

Internal Coordination

NWS offices along the Atlantic Seaboard have long benefited from using the HCH as a coordination tool for major East Coast storms. This closed-circuit telephone link allows multiparty internal coordination between NWS offices. The advantages of this system are that it allows forecasters to discuss potential forecast problems and provide a consensus-based, integrated, and seamless forecast to the user community.

The HCH was used to its fullest before and during this event. The first HCH call was initiated on Wednesday morning, January 3. At minimum, two coordination calls per day occurred through the duration of the event, with intermittent briefings done on an as needed basis. Event start times, precipitation types and transition zones, and event magnitudes were all addressed, with additional expertise and feedback available from NCEP.

Unfortunately, at the time of the blizzard, most interior Eastern Region offices were not served by the HCH and needed to accomplish coordination via one-on-one telephone calls. This was not totally effective as certain offices needed to make as many as six initial coordination calls. When discrepancies existed between adjacent offices, additional calls were needed. Consequently, areas of inconsistency were apparent along some forecast boundaries. To help solve this problem, the Federal Emergency Management Agency and the NWS are upgrading the current National Warning System configuration to provide coordination capabilities to all NWS offices. The upgrade is expected to be completed in spring 1997.

State Summaries

South Carolina

Coordination calls were made by the Columbia NWSFO to perimeter NWSOs and NWSFOs before the watch and warnings were issued. The Winter Storm Watch was issued around 2100 UTC, January 5, or 18 hours before the snow began. Snow developed during the morning of January 6 in the upstate area and during the afternoon and evening in the midlands. Winter Storm Warnings and Advisories were issued on the day shift of January 6, with an average lead time of 2 hours for the warnings and 4 hours for the advisories. Statements and Short Term Forecasts were issued during the event to update the general public and emergency officials concerning short-term changes in impending weather conditions. Through an effective collaborative effort between the NWSFO and the South Carolina state police, the NWS was kept well informed of real-time weather and road condition reports through the State Law Enforcement Division network, an automated computer interface. The Columbia NWSFO provided direct calls to the county emergency management officials prior to the event, enabling them to initiate winter storm contingency plans.

 # North Carolina

Two days before the snow and sleet began to fall in North Carolina, the Raleigh NWSFO issued forecasts and statements indicating that a winter storm was expected. As confidence in the various models and guidance improved, the Raleigh office relied upon HPC forecasters to assess the best model for the event and then used local forecast tools to prepare the warnings, watches, and advisories. The Winter Storm Watch had 36 hours lead time, and the Winter Storm Warning had 18 hours lead time. Hours before the onset of the precipitation, the Raleigh NWSFO issued a forecast showing the distribution of the predominant precipitation types across North Carolina. The accuracy of this forecast was praised by the *Raleigh News and Observer*. The public responded, and by Friday, January 5, the shelves of the grocery stores in the Raleigh area were cleared. The Raleigh/Durham International Airport, a USAir hub, used the aforementioned precipitation-type forecast (i.e., freezing rain and sleet for the airport) to properly change the chemicals used for road and runway deicing. Consequently, the airport remained open throughout the storm.

 # Virginia/Maryland

The possibility of a winter storm was noted in the extended forecast and the State Forecast Discussions issued by the Sterling NWSFO on Wednesday, January 3. The first Winter Storm Watch was posted for the southern two-thirds of the forecast area at 2100 UTC, January 5. The first Winter Storm Warning was issued for almost the entire region at 0900 UTC, January 6, as a result of the models having intensified the storm with a track further to the north. The remaining northern tier of Maryland was added to the warning area at 1500 UTC, January 6. Gale Warnings were issued for the coast, and by 2100 UTC, January 6, a Coastal Flood Watch was issued. The afternoon package on January 6 forecast near blizzard conditions within 24 hours and total accumulations of 18 to 24 inches over the metropolitan areas. The Winter Storm Warning was upgraded to a Blizzard Warning in the 0900 UTC, January 7, package for the Baltimore/Washington Metropolitan area and a swath to the northeast. Winter Storm and Blizzard Warnings were downgraded to an advisory the morning of January 8, and the advisory expired at 2100 UTC that same day.

Heavy snow conditions began over southwest Virginia the evening of January 6 and spread northeast across the entire Washington, D.C., forecast area by 0900 UTC, January 7. The lead time on the Winter Storm Watch for the Washington, D.C., area was 36 hours, and the lead time for the Winter Storm Warning was 24 hours. Snowfall totals of over 1 foot were predicted 24 hours in advance of the storm and 1.5 to 2 feet were forecast within 12 hours. The Washington, D.C., NWSFO had a false alarm rate (FAR) of zero and a probability of detection (POD) of

100 percent for its Winter Storm Warnings. All counties under a Winter Storm Watch also verified.

At 1500 UTC, January 7, Storm Warnings were issued for the coastal waters and a Coastal Flood Warning was issued for the coastline. Coastal Flood Warnings were dropped the morning of January 8 due to winds shifting offshore behind the storm.

The most impressive response by an agency using NWS services was given by Mr. Ron Miner of VDOT. VDOT acted upon outlooks issued by the Sterling NWSFO and began gearing up for the event 4 days prior to the storm. VDOT started out by renting 300 additional pieces of snow removal equipment, including graders and sanders. They did such an effective job securing equipment that, when the storm arrived, surrounding districts came to them for assistance. Extra effort was devoted towards repairing VDOT's regular equipment inventory well ahead of time. Temporary staff were hired, and hotel reservations were made for them. Regular VDOT personnel were encouraged to take days off prior to the storm to prearrange for their families' food and shelter needs. Later, they worked the long hours necessary to clear the snow. By adjusting work schedules in this manner, VDOT reduced overtime costs and engendered the good will of its employees.

The Sterling NWSFO and VDOT have been working together closely during the past year to establish clear lines of communication and understand each other's operational needs and capabilities. This mutual education/collaboration process has paid large dividends to the NWS, VDOT, and the citizens of Virginia. It serves as an excellent example for other offices to follow.

George Foresman, Director of Operations for the Virginia Department of Emergency Services, specifically identified the coordination efforts which established clear lines of communication and a good working relationship well in advance of the event. Everyone was aware of each others' expectations:

> **"On a scale of one to ten, I'd rate their performance a 200!"**
>
> **"If anyone ever wants to do a case study on how to do interagency coordination, send them to Virginia."**

The Governor of Virginia declared a State of Emergency on Saturday morning, January 6, before the first snowflake fell. Other governors' offices around the region were also involved intimately in briefings either directly or through their state emergency organizations. Based upon forecasts and coordination calls from the Sterling NWSFO, the Governor of Maryland declared a State of Emergency and opened the state emergency management agency for the entire weekend. After the storm, he presented a Governor's Citation to the Sterling NWSFO in honor of their exemplary service to the citizens of Maryland.

Extensive telephone interviews were given to the media, emergency services, congressional staffs, and the Office of Personnel Management. The Sterling NWSFO conducted over 100 of these briefings within a single 24-hour period. The prompt public response was reflected in a *Washington Post* story that highlighted the shopping frenzy at grocery stores. The Wakefield and Blacksburg, Virginia, NWSOs each logged around 50 briefings within a 24-hour period. Mr. Bill Bratton, Program Manager for WFIR Radio, gave accolades to the new Blacksburg, Virginia, NWSO. He stated that he held frequent 30-second interviews with meteorologists at the station, and they were very helpful in apprising the public of the latest situation.

 # Eastern Pennsylvania/New Jersey/Delaware

The first statement indicating a possible winter storm was issued at 2100 UTC, January 4, as a Winter Storm Outlook. Additional Winter Storm Outlooks were issued on January 5. A Winter Storm Watch was issued with the early morning forecast package at 0900 UTC, January 6, for the portion of the Mount Holly forecast area from the lower Susquehanna and Lehigh Valleys southeastward to include all of New Jersey and Delaware for late January 6 and January 7. The watch lead time was about 24 hours.

The watch was upgraded to a Winter Storm Warning in the 2100 UTC forecast package on January 6, with the warning area extended north to cover the Pocono Mountains. The warning lead time was about 12 hours.

A Blizzard Warning was issued in the early morning on January 7 for southeast Pennsylvania, all of New Jersey, and Delaware. This warning was later changed to a Winter Storm Warning for portions of southern Delaware and extreme southern New Jersey. All warnings were downgraded to advisories for blowing and drifting snow on January 8, but even these were dropped by the 2100 UTC, January 8, forecast package.

A Coastal Flood Watch was issued for the New Jersey and Delaware coasts on the afternoon of January 6 for moderate to severe coastal flooding during the night of January 7 and the morning of January 8. The watch was upgraded to a Coastal Flood Warning early on January 7. Follow-up Coastal Flood Statements were issued through early morning on January 8 when the threat of flooding ended.

For the entire event, the Mount Holly NWSFO logged over 500 telephone briefings to the media, emergency managers, and other state and local officials. The Pennsylvania Emergency Management Agency responded by opening for the entire weekend while the New Jersey and Delaware emergency agencies opened on Sunday. Mr. Peter Jespersen from the New Jersey Office of Emergency Management reported that forecasts and services from the Mount Holly office were accurate and up to date.

Western Pennsylvania/West Virginia/Ohio

NWSFO Pittsburgh issued a Winter Storm Watch with the 2100 UTC, January 6, forecast package. The watch included 24 of the 53 counties in the forecast area. Later that evening, warnings were posted for parts of West Virginia and Maryland. By the morning of January 7, Winter Storm Warnings were expanded to cover 37 counties, and Winter Weather Advisories were issued for the remainder of the 53 counties. Warnings continued through January 7, with snowfall forecast amounts gradually increasing throughout the forecast cycles. By late evening on January 7, storm total forecasts of 24-40 inches were issued for the mountains of West Virginia and Maryland. At the same time, warnings were downgraded to advisories for three counties in northern Pennsylvania. All warnings and advisories expired in the early morning on January 8. In addition to the warnings and watches, numerous Short Term Forecasts and Special Weather Statements were also issued. NWSFO Pittsburgh reported an average watch lead time of 20 hours and an average warning lead time of 5.5 hours.

The Charleston, West Virginia, NWSFO first highlighted the potential for heavy snows in West Virginia as early as Wednesday afternoon, January 3. They issued a Winter Storm Watch at 2100 UTC on January 5 for central and southern West Virginia. By January 6, all watches were upgraded to warnings and expanded to include the entire state. At 1500 UTC, January 6, Winter Storm Warnings were dropped for a few counties across southeastern Ohio but were later reissued on January 7.

Mr. Tony Cavalier, lead meteorologist for WSAZ-TV3 (Huntington/Charleston, West Virginia), noted a little waffling on storm total accumulations but was complimentary on warning services overall. He also acknowledged the difficulty in pinpointing totals when forecasting such "prodigious amounts." As important, he noted, was the expertise displayed in anticipating and dispelling flooding fears immediately after the blizzard when the region stayed below critical melting temperatures. Approximately 2 weeks later, many portions of this region were impacted by near-record flooding that resulted, in large part, from the melting of this major snowfall.

The Cleveland, Ohio, NWSFO issued the first Winter Storm Watch at 2100 UTC, January 5, for 15 counties over extreme southern Ohio, covering Cincinnati to Portsmouth but south of Columbus and Dayton. On January 6, a Winter Storm Warning was issued for those counties in the watch area, and a Snow Advisory was issued for areas a little further north, including Dayton and Columbus.

On the morning of January 7, many of the areas in the Snow Advisory were upgraded to a Winter Storm Warning. Unscheduled updates were done at 1730 UTC, January 7. During the event, NWSFO Cleveland had to continue increasing snowfall amounts and moving the warnings and advisories northward. In Ohio, the forecasts in some counties suffered from insufficient internal coordination between adjacent forecast offices. Storm track uncertainty resulted in differences in opinion between adjacent offices. Nonetheless, NWSO Wilmington, Ohio, issued frequent Short Term Forecasts and statements to keep the public informed during this difficult and rapidly changing situation.

New York

The major effects from this storm were felt mainly across southeast sections of the Empire State. This area included all of the New York City Metropolitan area as well as portions of the Albany area of responsibility.

For the New York City area, a Winter Storm Watch was posted the morning of January 6 and then extended to interior sections of southeast New York and Connecticut in the afternoon. The watch included the following information:

- NEAR BLIZZARD CONDITIONS ARE EXPECTED TO DEVELOP AROUND THE REGION SUNDAY NIGHT INTO MONDAY MORNING.

- WE ARE CURRENTLY LOOKING AT THE POTENTIAL FOR A FOOT OR MORE OF SNOW THROUGHOUT THE WATCH AREA.

By 0220 UTC, January 7, a Heavy Snow Warning was issued for the afternoon hours of January 7 into January 8. At 0900 UTC, January 7, the Heavy Snow Warning was changed to a Blizzard Warning valid for coastal areas in the morning and for interior areas in the afternoon. The lead times for the Winter Storm Watch and Heavy Snow Warning were 36 and 18 hours, respectively.

A Coastal Flood Warning was issued at 0900 UTC, January 7, for coastal areas. Numerous Short Term Forecasts and other statements were issued.

The Brookhaven NWSFO reported around 50 briefings per day to the media and state and local emergency management officials. On Sunday, January 7, the emergency managers opened the Long Island office, and at 9 a.m., the governor held a press conference. Mr. Joe Costagna of the New York City Department of Emergency Management said the event was well advertised and that plowing equipment and National Guardsmen were brought in ahead of the storm. (It should be noted that the New York City Department of Sanitation does routine snow removal, and they contract with multiple private weather vendors in addition to using NWS warnings and forecasts to make such decisions.) United Airlines took extraordinary actions to modify flights at the New York City area airports in preparation for the snow.

As early as Thursday morning, January 4, the Albany NWSFO briefed the governor of New York concerning the possibility of a major snow storm. The Albany service area ultimately experienced a wide range of conditions with the effects of the storm confined to areas south and east of the city. In total, eight Winter Storm Watches and nine Winter Storm Warnings were issued. All counties affected had watches or warnings issued, with 4 to 10 hours lead time for the watches and 2 to 5 hours lead time for the warnings. Since this service area was on the outer edge of the precipitation shield and the storm track remained uncertain, forecasts initially underestimated the total snowfall. As the storm track became more certain by the 0900 UTC, January 8, forecast package, storm total snow forecasts were increased accordingly. A total of 20 Short Term Forecasts were issued. Snowfall relationships with WSR-88D data were used to estimate snowfall rates and specify snow depths which varied considerably across relatively short distances.

Peter Ahnert, Meteorologist in Charge at NWSO Binghamton, New York, reported that his office responded to 50 media inquiries during the storm even though only half of his territory was affected by the storm.

Southern New England

Southern New England was also on the northern fringes of this event. All available model guidance indicated a sharp gradient of the Quantitative Precipitation Forecast (QPF) and relative humidity fields. Due to model interpretation and the uncertainty of the guidance, warning and watch lead times were somewhat reduced for a large section of the CWA. Nonetheless, NWSFO Taunton issued numerous statements to update the situation. A Winter Storm Watch was issued Saturday morning at 0900 UTC, January 6, for the possibility of heavy snow for Cape Cod, the Islands, and south coastal Rhode Island. At 0900 UTC, January 7, a second period Winter Storm Warning was issued for the entire Taunton CWA except for Franklin and Hampshire Counties in Massachusetts and Cheshire and Hillsborough Counties in New Hampshire. At that time, these counties were covered with a Winter Storm Watch. In the January 7 afternoon forecast package, all of the Taunton CWA was placed under a Winter Storm Warning. By 0200 UTC, January 8, southeast coastal Massachusetts, including the city of Boston, and south coastal Rhode Island were upgraded to a Blizzard Warning.

As model guidance shifted the snow northward across Massachusetts with time, the Boston forecasters had to catch up to the event and issue warnings instead of watches. Post-storm reviews by the Taunton office noted that the areal extent of the watch should have been increased according to the conservative Eastern Region policy of issuing watches when the probability of the event occurring is at least 30 but less than 70 percent.

Like many notable winter storms, portions of the southern New England coastline were threatened with storm surge flooding. A Coastal Flood Watch was issued early on the morning of January 7 and upgraded to a Coastal Flood Warning that afternoon. The tide of concern was the afternoon high tide of January 8. Just before high tide, the wind became northerly and parallel to the immediate coast, lessening the threat for coastal flooding. Consequently, the impact was relatively minor with some flooding of shore roads, a few of which were closed for a short time.

The NWSFO in Taunton continued coordinating with external users in southern New England even though the storm was initially forecast to head out to sea south and east of the area. As the storm track changed, this constant contact proved beneficial because emergency managers were kept briefed and well informed. After additional coordination calls, the Massachusetts Emergency Management Agency opened on Sunday and the mayor of Boston ordered the removal of existing snow on city streets prior to the onset of the storm.

Mead Herrick, Director of the New Hampshire Emergency Management Agency, was satisfied with the level of service provided by NWS offices but stressed that this was not of the same magnitude that it was farther south. For this area of the country, this was a winter storm and not a blizzard. He felt the coordinating office was well in tune with this, and the forecast products and coordination were in keeping with the event.

Maine

Maine was spared the brunt of the storm's effects. Maine forecasters believed that the storm would pass south of the area and out to sea. Despite numerical guidance, southwest and coastal portions of the forecast area attained warning criteria. To these forecasters, the "Blizzard of '96" was pretty much "just another storm." Although no watches were issued, 15 warnings were disseminated, 14 of which verified with an average lead time of 16.5 hours. One county had marginal warning conditions without a warning being issued.

CHAPTER III

Equipment Performance

PREPARED BY EASTERN REGION HEADQUARTERS

Radar Outages

The WSR-88Ds at Raleigh, North Carolina, and Blacksburg, Virginia, became inoperative on Sunday afternoon, January 7, 1996.

At Blacksburg, a relay switch that transfers power from commercial to emergency sources got stuck halfway between connections so neither commercial nor emergency power was supplied to the site. Subsequent to this event, the Operational Support Facility developed a modification to the switch as the problem was being replicated elsewhere.

Raleigh experienced a wideband communications failure between the Radar Data Acquisition (RDA) unit and the office Principal User Processor. This was caused by a faulty VME card at the RDA which needed to be reset. The faulty card was likely the result of power fluctuations at the RDA.

Both of the above outages required trips to the respective RDAs which could not be accomplished until after the storm due to the excessive snow amounts. At Blacksburg, the trip was made especially difficult as the jeep repeatedly got stuck in the snow. Nevertheless, both radars were operational again by Tuesday, January 9.

The only other incidence with radars in Eastern Region occurred at Charleston, West Virginia, where the archive level II became inoperative during the storm.

NOAA Weather Radio (NWR)

The NWR program in Eastern Region performed admirably during the event. With one of the worst storms of the late twentieth century sweeping the East Coast with blizzard conditions, practically all of the NWRs stayed on the air providing critical life- and property-saving information to the public, elected officials, emergency managers, and local decision makers. The only known exceptions were the Kingston, New York, transmitter which went off the air for part of the day on Saturday, January 6, and the Wakefield console which experienced some tape deck breakages.

Tide Data

The only source of lost tide data occurred at Brookhaven, New York, where the local system failed to provide a link to the NOS REALDATA tide information. This resulted in a loss of tide data from the Battery in lower Manhattan Island and at two locations on Long Island sound. The Brookhaven staff was forced to call ERH personnel whose equipment was successful in connecting to the NOS REALDATA service. As of November 1996, this problem has been corrected by NWSFO Brookhaven.

Surface Observing Equipment

Given the extreme nature of the storm, there were few reported problems with ASOS. Those that were noted comprised concerns that have been endemic with the system since it has been fielded. The Richmond, Virginia, ASOS reported moderate rain with an air temperature of 21°F. In the remarks section, the observation noted that precipitation was frozen but that the type was unknown. At one of the ASOS test sites in the Washington, D.C., management area, the system reported fog instead of snow. The Greenville-Spartanburg, South Carolina, ASOS wind equipment failed when the anemometer iced up. One post-storm media contact complained that the ASOS observations were, at times, misleading to the public. He based these remarks on the facts that freezing precipitation is noted only in the remarks section which does not always reach the public, and that ASOS does not report snow amounts. Finally, the wind equipment at Elizabeth City, North Carolina, failed.

Pathfinder

Overall, the Pathfinder systems operated well, although at the Pittsburgh, Pennsylvania, office, the staff needed to occasionally sweep snow off the antenna to guard against data loss.

CHAPTER IV

Forecaster Guidance

PREPARED BY THE
HYDROMETEOROLOGICAL PREDICTION CENTER

Medium-Range (3-5 Day) Forecasts and Guidance

The operational numerical models from the NCEP, ECMWF, and UKMET were forecasting different meteorological scenarios across the United States for the period January 6 through 9, 1996. NWS meteorologists at NCEP's HPC used their expertise in numerical model guidance interpretation to provide excellent forecast guidance to the NWSFOs, the private sector meteorological community, and the general public in the days preceding and during the "Blizzard of '96." This guidance began with discussions of model differences during the medium-range forecast period (Days 3 through 5) and continued into the short-range forecast period (Days 0 through 2).

The first indications of the potential for a major eastern U.S. snowstorm appeared in the medium-range forecasts issued by the HPC forecasters on January 1. The forecasts from the medium-range numerical models (MRF, ECMWF, and UKMET) that day verifying at 1200 UTC, Saturday, January 6, were indicating very different solutions with respect to the 500 mb flow across North America. The MRF was forecasting westerly 500 mb flow moving through the mean ridge position situated along approximately 120°W, with this flow then progressing east-southeastward into a weak mean 500 mb trough forecast across the eastern half of the United States (figure 2a). The ECMWF and UKMET models, however, were indicating less westerly flow moving through the mean ridge position along the west coast and subsequently had much more amplified upper ridges over this region (figures 2b and 2c). This more amplified upper ridge allowed for the ECMWF and UKMET to indicate the potential for a jet to dig southeastward into the base of an amplifying trough over the central portion of the United States on Saturday, January 6. This trough continued to amplify over the next 2 days and led to the development of the "Blizzard of '96." The verifying 500 mb analysis at 1200 UTC, January 6, meteorological analysis appendix (Appendix A, figure A-3), revealed that this upper ridge along the west coast remained much more amplified than forecast by the operational MRF. Medium-range HPC forecasters correctly recognized the potential for a more highly amplified west coast upper ridge, stating in the Extended Forecast Discussion on January 1, 1996:

> ***"THE MRF APPEARS TO BE BRINGING FAST 500 MB WESTERLIES AND LOWER SURFACE PRESSURE INTO WESTERN CANADA MUCH TOO QUICKLY...I WOULD NOT BE SURPRISED TO SEE THE UPPER TROUGH SHARPEN UP OVER NEW MEXICO FRI..SUPPORTING SURFACE WAVE DEVELOPMENT IN THE WESTERN GULF OF MEXICO ON THE OLD POLAR FRONT."***

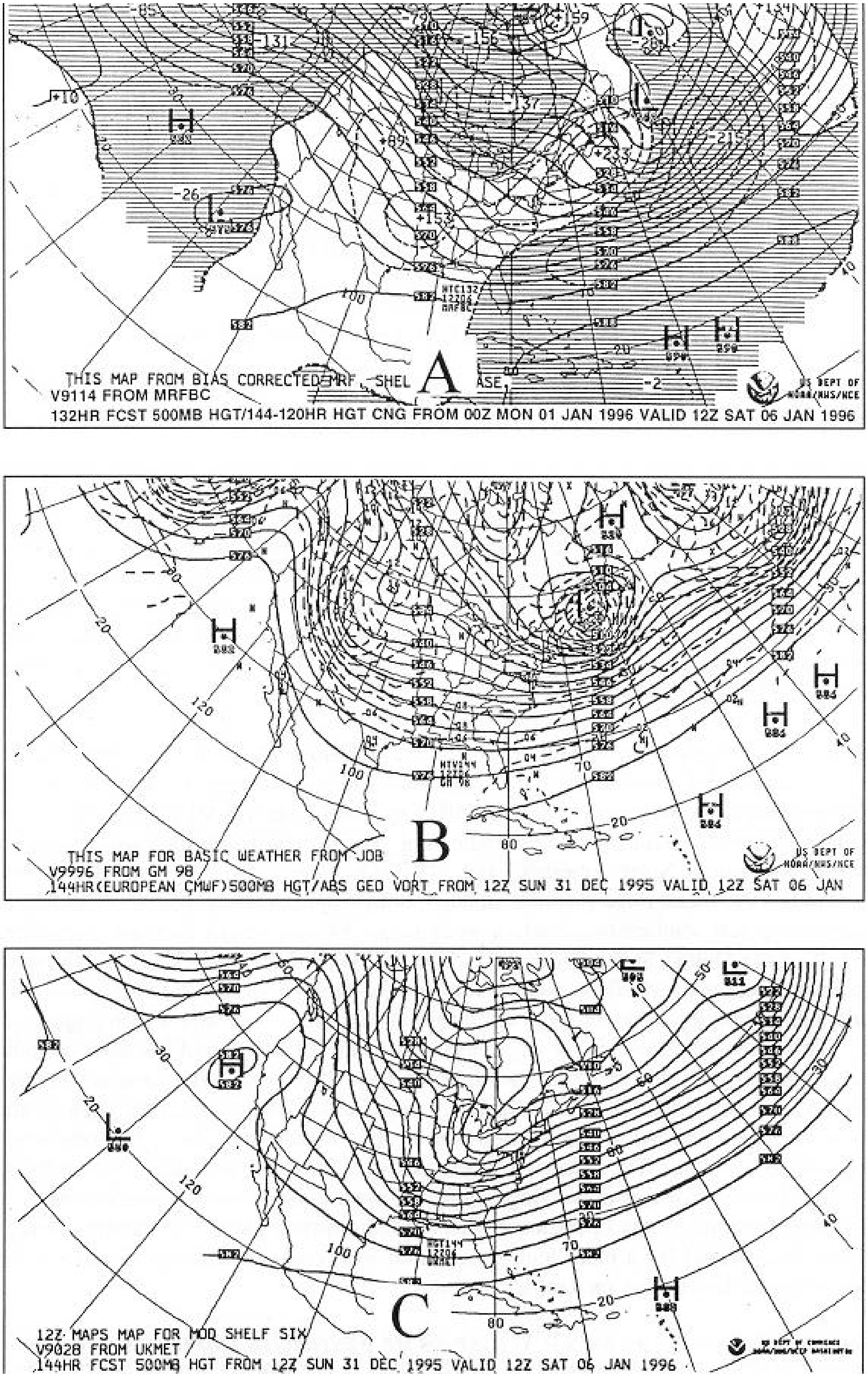


Figure 2. The Day 5 500 mb forecasts valid 1200 UTC, Saturday, January 6, from the (a) MRF, (b) ECMWF, and (c) UKMET.

Comparison of figure 3b with the observed surface analysis for 1200 UTC, January 6 (Appendix A, figure A-1), revealed that HPC forecasters were correct in forecasting stronger wave development in the Gulf of Mexico, which continued to deepen over the next 2 days into the "Blizzard of '96."

Major model differences continued during the next several days leading to large discrepancies between the MRF, ECMWF, and UKMET models with the development of the East Coast blizzard. HPC medium-range forecasters continued to correctly identify characteristic biases in the MRF model which were too progressive and too weak with the developing 500 mb trough across the Ohio Valley and Mid-Atlantic region. The extended forecast discussion from January 2 continued to emphasize that the MRF solution was probably too weak and progressive, stating:

> ***"...CONTINUITY LEADS US TOWARD A MORE AMPLIFIED AND SLOWER EVOLUTION OF GULF COAST AND SOUTHEASTERN CYCLOGENESIS....IF THIS SCENARIO WORKS OUT THERE SHOULD BE SIGNIFICANT SURFACE CYCLOGENESIS ALONG AN INVERTED TROUGH/COASTAL WARM FRONT OFF THE SOUTHEASTERN NC/NORTHEASTERN SC COAST MON JANUARY 8, 1996."***

The first indication that this developing low would rapidly intensify along the East Coast occurred with the medium-range model guidance from January 3. Similar to the previous day's runs, there were major differences between the MRF and the ECMWF. HPC forecasters have noted that the MRF has characteristically displayed poor skill in resolving shortwaves moving through the base of mean troughs, with the MRF often too weak and undefined with the shortwaves. The Hemispheric Map Discussion narrative from January 3 emphasized this crucial model forecast difference and stated the potential for this low to become a "bomb" off the East Coast, stating:

> ***"THERE ARE SOME SIGNIFICANT DIFFERENCES WITH THE MODELS RESOLUTION OF THE SOUTHERN PORTION OF THE TROUGH THAT MOVES THROUGH THE ROCKIES BY SATURDAY JANUARY 6 (DAY 3) AND INTO THE PLAINS ON SUN JANUARY 7 (DAY 4). THE ECMWF IS SHOWING THE MOST DEFINITION TO THIS SOUTHERN PORTION OF THE TROUGH AND SUBSEQUENTLY HAS A 1010 MB LOW MOVING FROM THE NORTHERN GA/AL BORDER ON SUN JANUARY 7 (DAY 4) AND BOMBING OFF THE MID-ATLANTIC COAST (984 MB) BY MON JANUARY 8 (DAY 5). THE MRF IS MUCH MORE FRAGMENTED AND POSITIVELY TILTED WITH THIS TROUGH AND SUBSEQUENTLY HAS ONLY A WEAK 1014 MB WAVE SHEARING OFF THE SOUTHEASTERN COAST ON SUN JANUARY 7 (DAY 4). THE RESOLUTION OF SHORT WAVES IN THE BASE OF TROUGHS IS AN AREA THE MRF OFTEN DOES A POOR JOB WITH....WE ARE TRENDING MORE TOWARD THE ECMWF."***

The Day 4 and 5 sea-level pressure and 500 mb forecasts from the MRF, ECMWF, and UKMET valid 1200 UTC, January 7 and 8, respectively, are shown in figures 4 and 5.

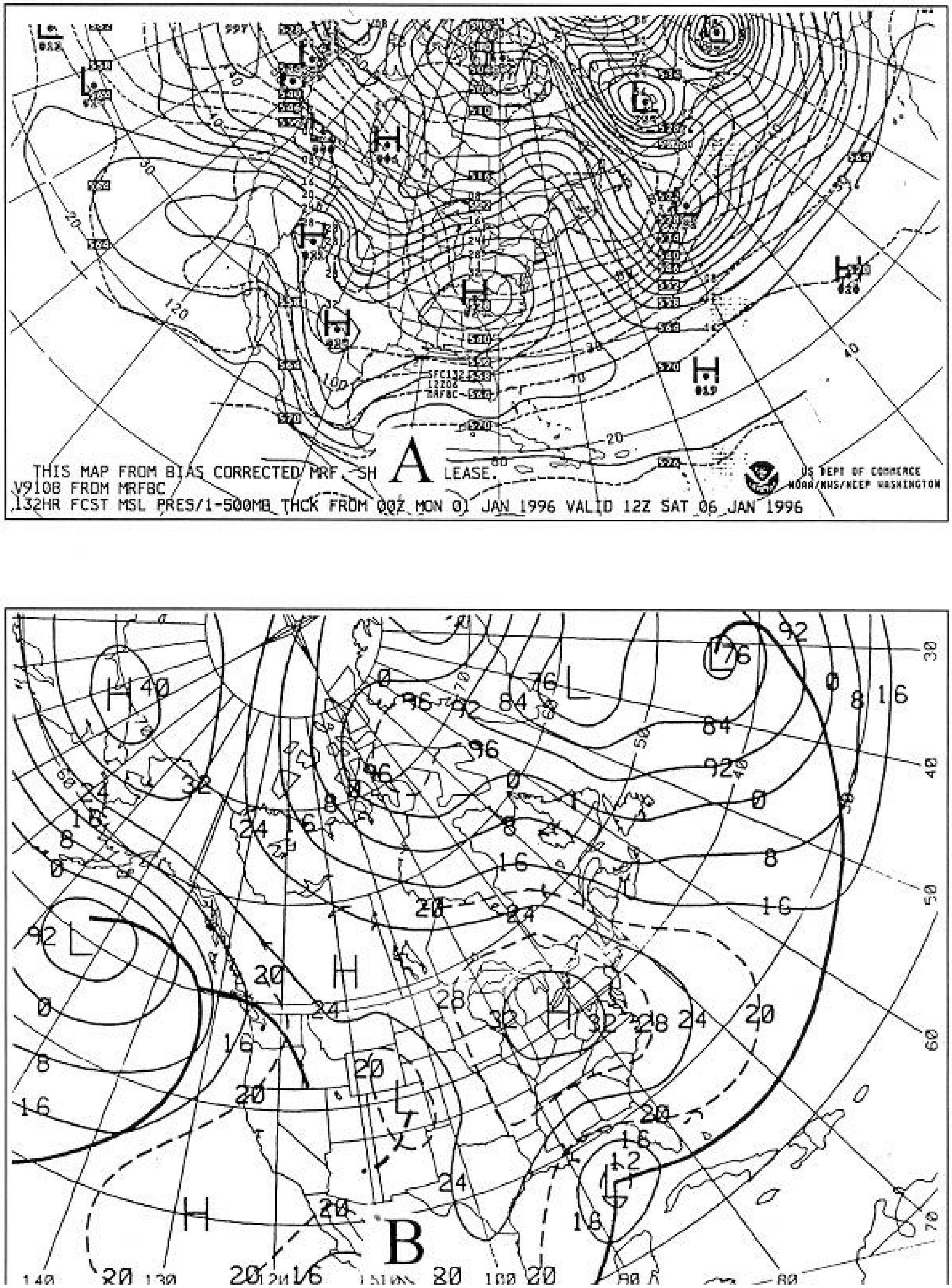


Figure 3. (a) The Day 5 MRF mean sea level pressure (MSLP) forecast valid 1200 UTC, Saturday, January 6, and (b) the HPC Day 5 manual MSLP forecast valid 1200 UTC, Saturday, January 6.

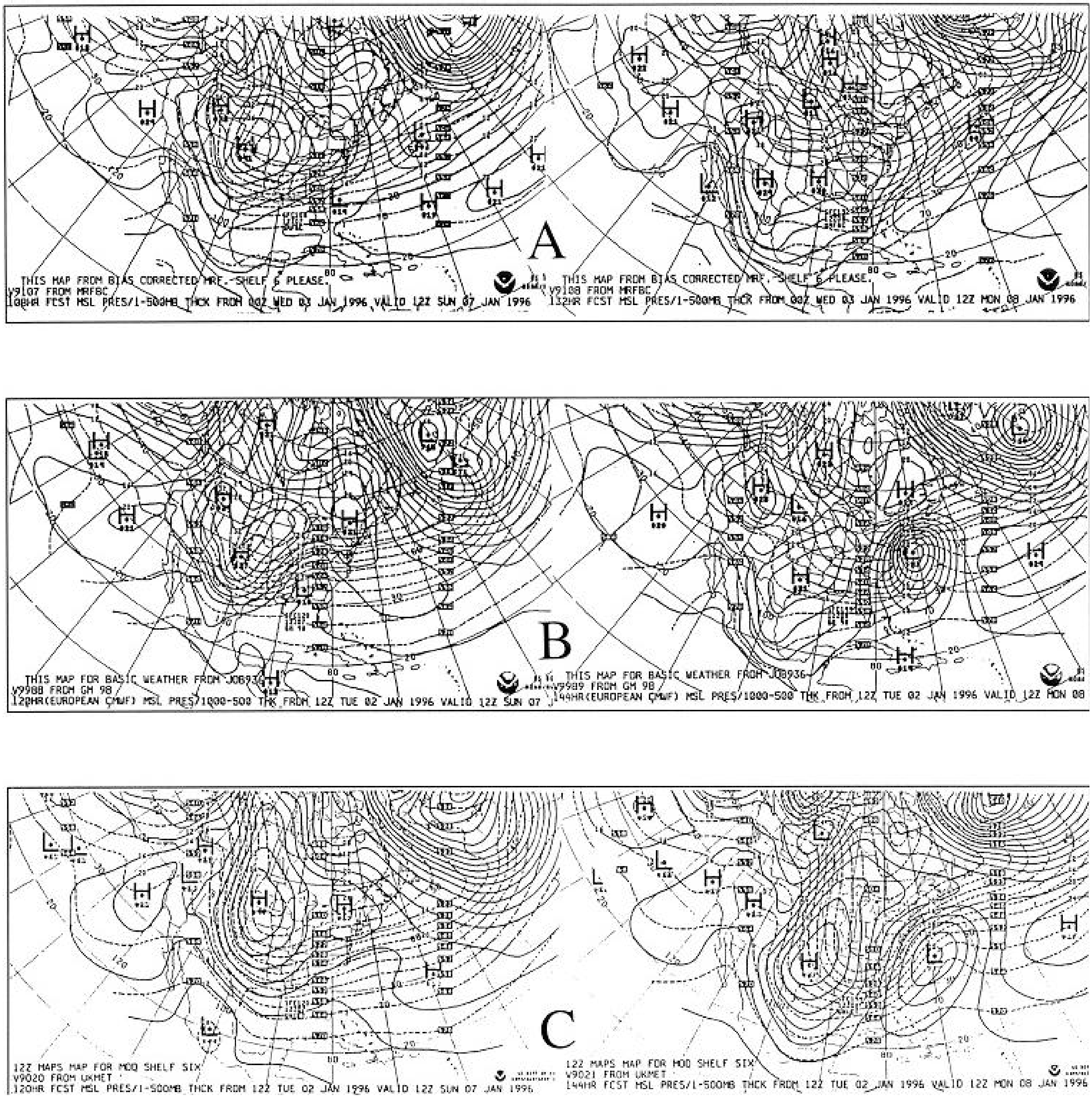


Figure 4. MSLP forecasts for Day 3 (left) valid 1200 UTC, January 7, and Day 4 (right) valid 1200 UTC, January 8, from the (a) MRF, (b) ECMWF, and (c) UKMET.

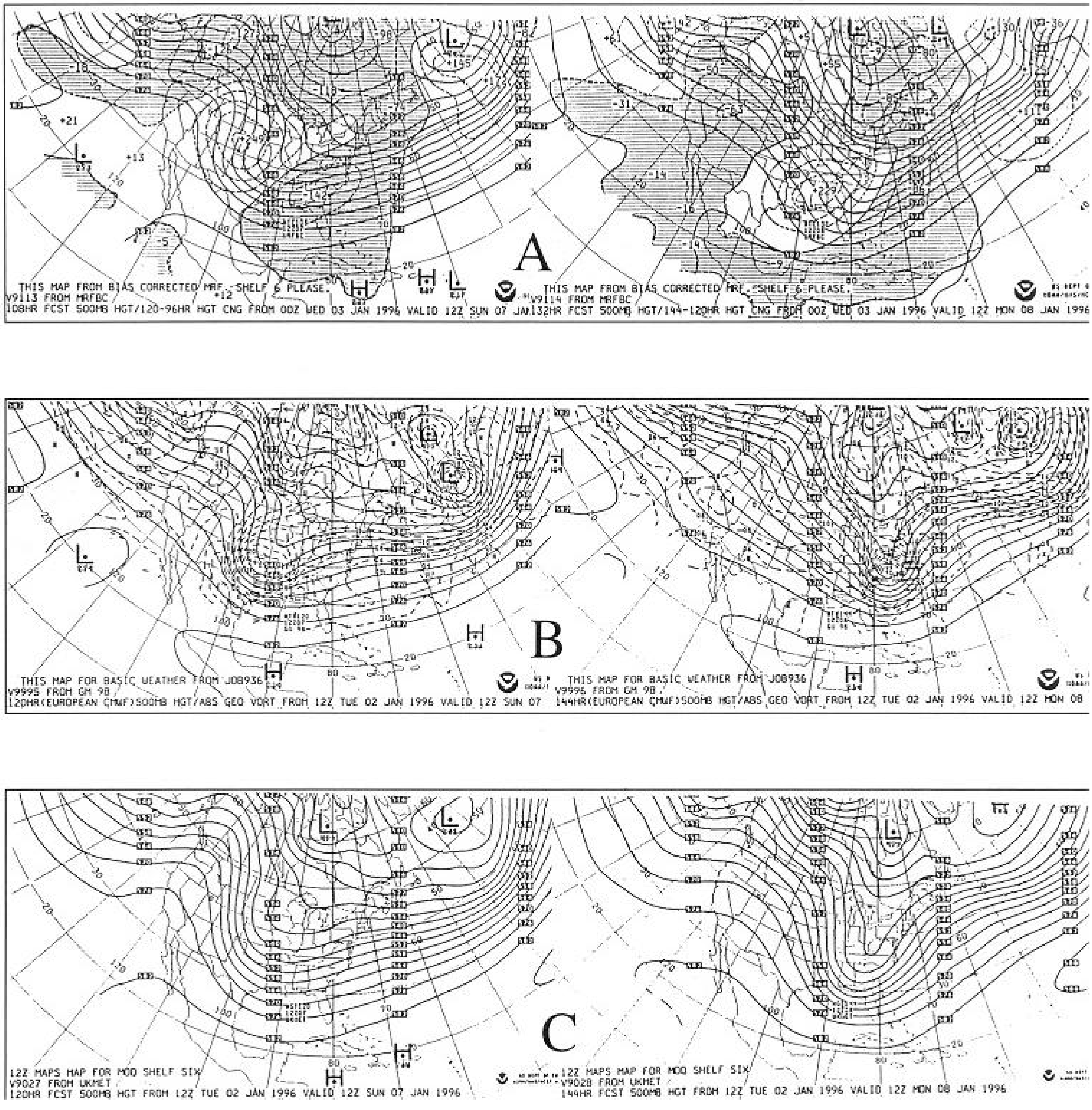


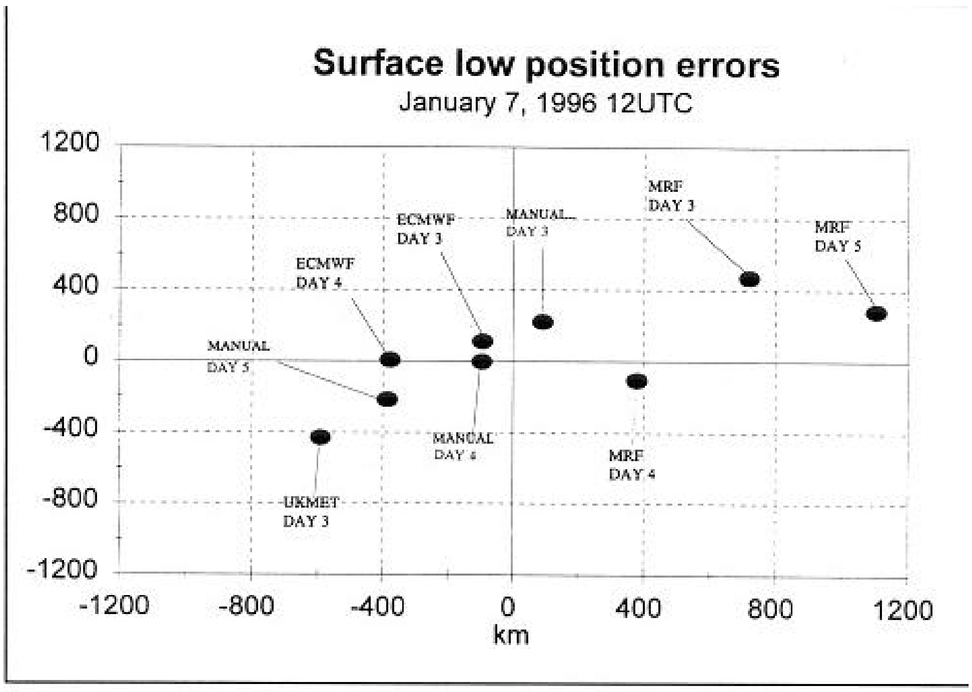
Figure 5. 500 mb forecasts for Day 3 (left) valid 1200 UTC, January 7, and for Day 4 (right) valid 1200 UTC, January 8, from the (a) MRF, (b) ECMWF, and (c) UKMET.

This same problem with the definition of shortwaves in the base of the mean trough continued in the medium-range guidance from January 4. Once again, the HPC forecasters made significant changes to the MRF forecasts for Saturday, January 6 (Day 3), and Sunday, January 7 (Day 4). On both days, the HPC medium-range manual prognosis correctly trended toward a stronger low. This was especially evident on the forecast valid Monday morning, January 8, in which HPC predicted a 992 mb low off the Mid-Atlantic coast, while the operational MRF had a 1012 mb low, with its center farther to the south and much more sheared.

A summary of the forecast positions of the surface low at 1200 UTC, January 7 and 8, is shown in figure 6. In these figures, the verifying positions of the low are located in the middle of the diagrams at the intersections of the 0 kilometer (km) lines. The forecast positions of the low on January 7 and 8 for Days 3 through 5 in the MRF, ECMWF, and UKMET are indicated with the labeled markers. The proximity of these markers to the center indicates the magnitude and direction of the forecast error of these models. Examination of figure 6 reveals that substantial improvement was made on both January 7 and 8 to the forecast position of the sea-level low pressure center. Some of the best improvements to the MRF occurred with the Day 5 forecasts on both of these days. Distance errors of approximately 400 km occurred for the HPC Day 5 forecast surface low position verifying at 1200 UTC, January 7, compared to errors of over 1100 km for the corresponding operational MRF forecast. Similar errors occurred for the Day 5 surface low position forecast verifying at 1200 UTC, January 8, with errors of approximately 500 and 1600 km for the HPC and MRF forecasts, respectively.

Quantitative Precipitation Forecasts

With several days of consistent medium-range guidance from HPC emphasizing the potential for a major snowstorm along the East Coast, the questions that remained to be answered with subsequent numerical model runs from NCEP concentrated on details of the track of the storm and the precipitation types and amounts. Coordination calls among the lead HPC forecaster and the affected East Coast field offices began at 2 a.m. on January 6 and continued through the afternoon on January 8. In addition to the formal coordination calls, HPC lead forecasters contacted some NWSFOs as early as January 5 to emphasize the potential strength of this developing storm and encourage their forecasters to predict a big event. The two products that provided the most critical forecast guidance to the Federal and private meteorological community and to the general public during the 2 days preceding the "Blizzard of '96" were the 12-hour heavy snow forecasts that are issued every 6 hours and cover the period 6 through 30 hours and the 24-hour QPFs for the Day 1, Day 2, and update periods. The combined Day 1 and Day 2 forecasts cover the next 48 hours, while the update is a revision of the preceding Day 2 forecast, taking into consideration later data and model guidance. The 24-hour QPFs issued at 5 a.m., Saturday, January 6, for the 24-hour periods ending 1200 UTC, January 7 (Day 1), and 1200 UTC, January 8 (Day 2), are shown in figure 7. These forecasts indicated the areas where the HPC QPF forecasters believed the heaviest precipitation would fall, with the dashed line showing the delineation between



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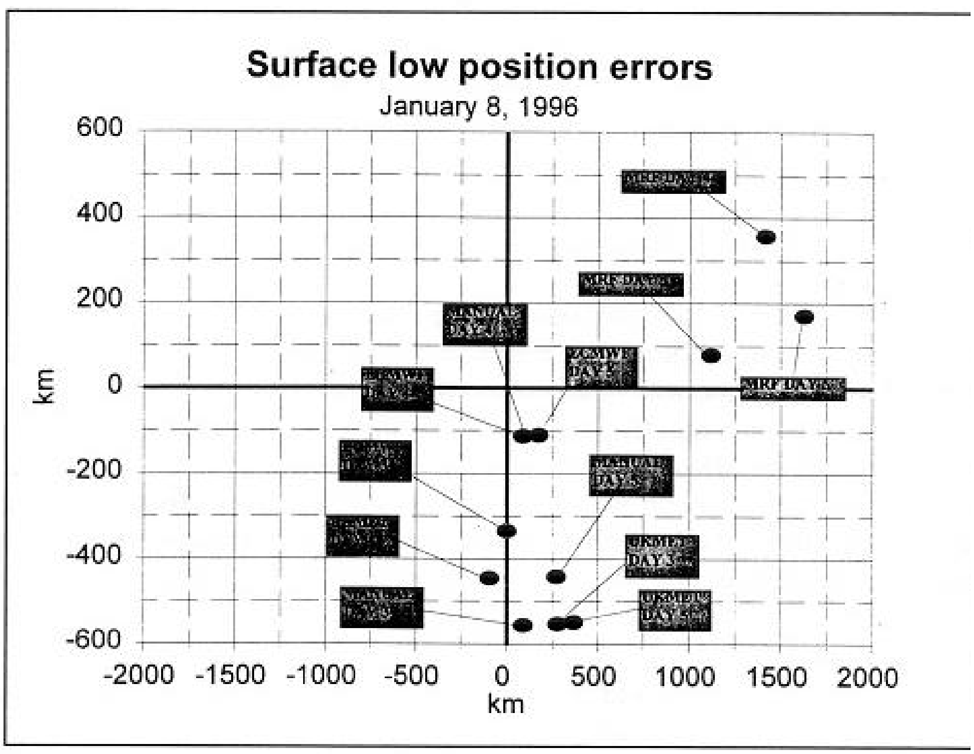

B

Figure 6. The Day 3, 4, and 5 surface low forecast positions from the MRF, ECMWF, UKMET, and HPC Manual prog valid (a) 1200 UTC, January 7, and (b) 1200 UTC, January 8.

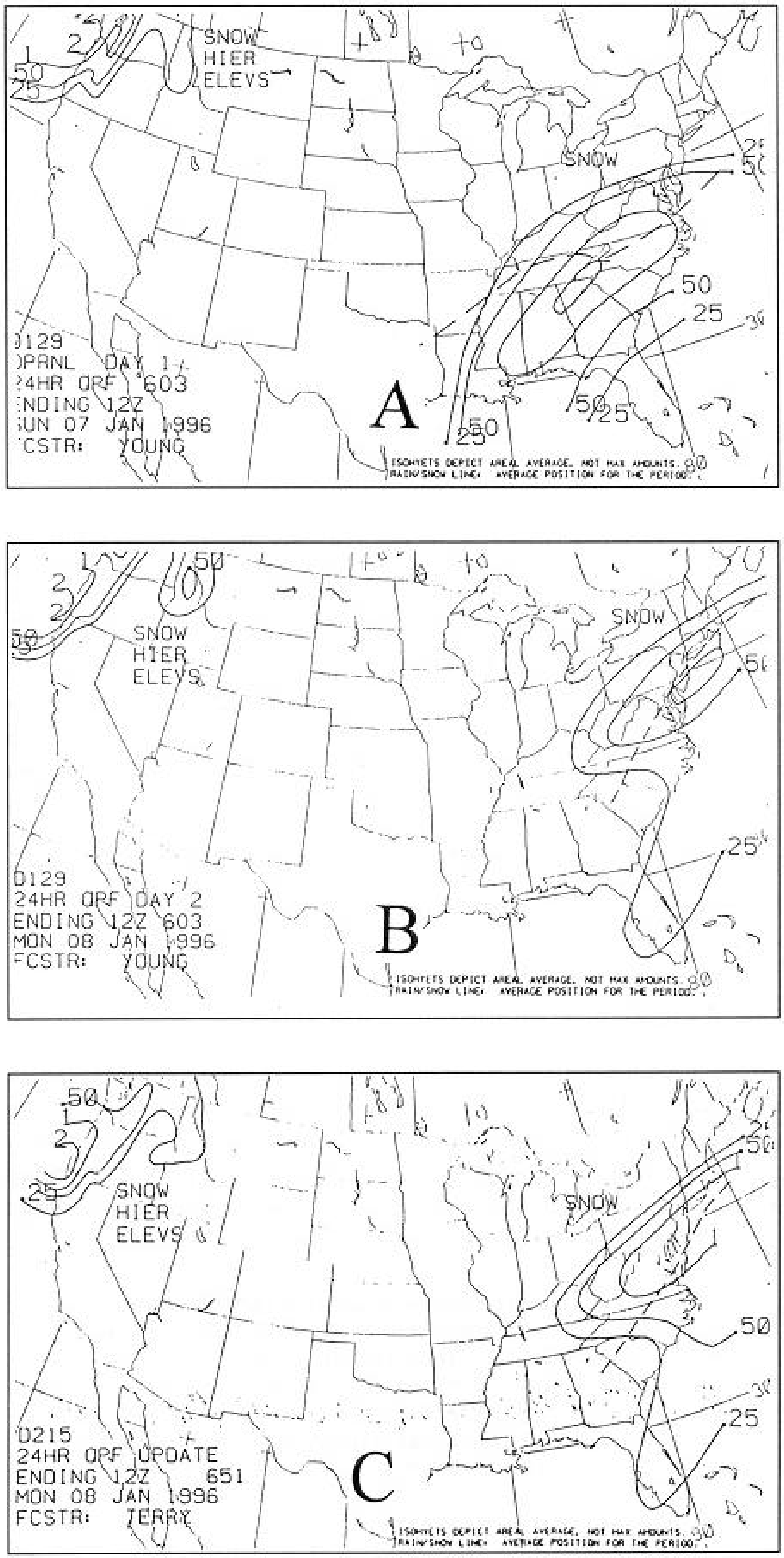

Figure 7. HPC 24-hour QPF for (a) Day 1 (24 hours ending 1200 UTC, Sunday, January 7); (b) Day 2 (24 hours ending 1200 UTC, Monday, January 8); and (c) Update to Day 2 (24 hours ending 1200 UTC, January 8

precipitation that would be predominantly snow versus rain. Figure 7 reveals that a large area of precipitation to the north of the rain/snow line in excess of .5 and 1 inch of liquid equivalent was forecast for both of these days. A large region from West Virginia through Virginia, Maryland, eastern Pennsylvania, and across southern New England was forecast to receive well over an inch of liquid equivalent precipitation for the 2-day period. The maximum amount for these days was forecast for areas of central Virginia, where in excess of 2 inches of liquid equivalent precipitation was forecast during the 2-day period. These HPC forecasts represented a marked improvement over the numerical model guidance.

While these forecasts provided a 24-hour picture of the heavy precipitation threat, the 12-hour heavy snow forecasts issued by the HPC QPF forecasters pinpointed spatially and temporally where the heaviest snow was expected. A series of 12-hour HPC heavy snow forecasts along with the verifying analyses of snowfall are shown in figure 8. Beginning with the 12-hour period ending 1200 UTC, January 7, and ending 1200 UTC, January 8, HPC QPF forecasters provided excellent guidance to both the Federal and private sector meteorological communities and the general public for areas expected to receive snowfall in excess of 4, 8, and 12 inches during the 12-hour periods. Note the excellent agreement between the forecast and observed 8-inch isopleth in figure 8a, the 8- and 12-inch isopleths in figure 8b, and the 8- and 12-inch isopleths in figure 8e. Figures 8a, 8c, 8d, and 8e revealed the heavy snow forecasts were occasionally not extended far enough to the west over the Appalachians and Ohio Valley. Figures 8b and 8c also revealed a bias of being too slow to push the heavy snow to the northeast. While some of these snow forecasts may have been too slow, the 12-hour outlook heavy snow forecasts, which covered the following 12-hour time periods, did forecast heavy snowfall across locations farther to the northeast.

Short-Range Narratives

Along with graphical 24-hour precipitation and 12-hour heavy snow forecasts, the HPC meteorologists also provided narratives explaining these forecasts. While model differences were not as dramatic as during the medium-range period, significant differences between the ETA, NGM, and AVN models continued during the short-range period (48 hours). An example of significant meteorological differences still facing forecasters is illustrated in the QPF discussion issued early Saturday morning, January 6, which stated:

> ***"THERE ARE SOME SIGNIFICANT DIFFERENCES IN THE LOWER LEVELS. IN GENERAL WE PREFER THE ETA MODEL...THE NGM APPEARS TO BE UP TO ITS TYPICAL BIAS OF HAVING THE SURFACE LOW WRAPPED TOO FAR BACK TOWARDS THE UPPER LOW...AND THE LATEST AVN STILL LOOKS TOO PROGRESSIVE AND RATHER FLAT AT THE SURFACE. THE ECMWF HAS HANDLED THIS STORM PRETTY WELL FOR SEVERAL DAYS AND IT CONTINUES TO BE MUCH SLOWER AND MORE AMPLIFIED THAN THE AVN. THEREFORE.. THE ETA APPEARS TO BE THE MODEL OF CHOICE WITH SUPPORT FROM THE LATEST ECMWF."***

Subsequent runs of the ETA, NGM, and AVN showed better agreement which allowed forecasters to concentrate more on the magnitude of the upcoming event. The NCEP

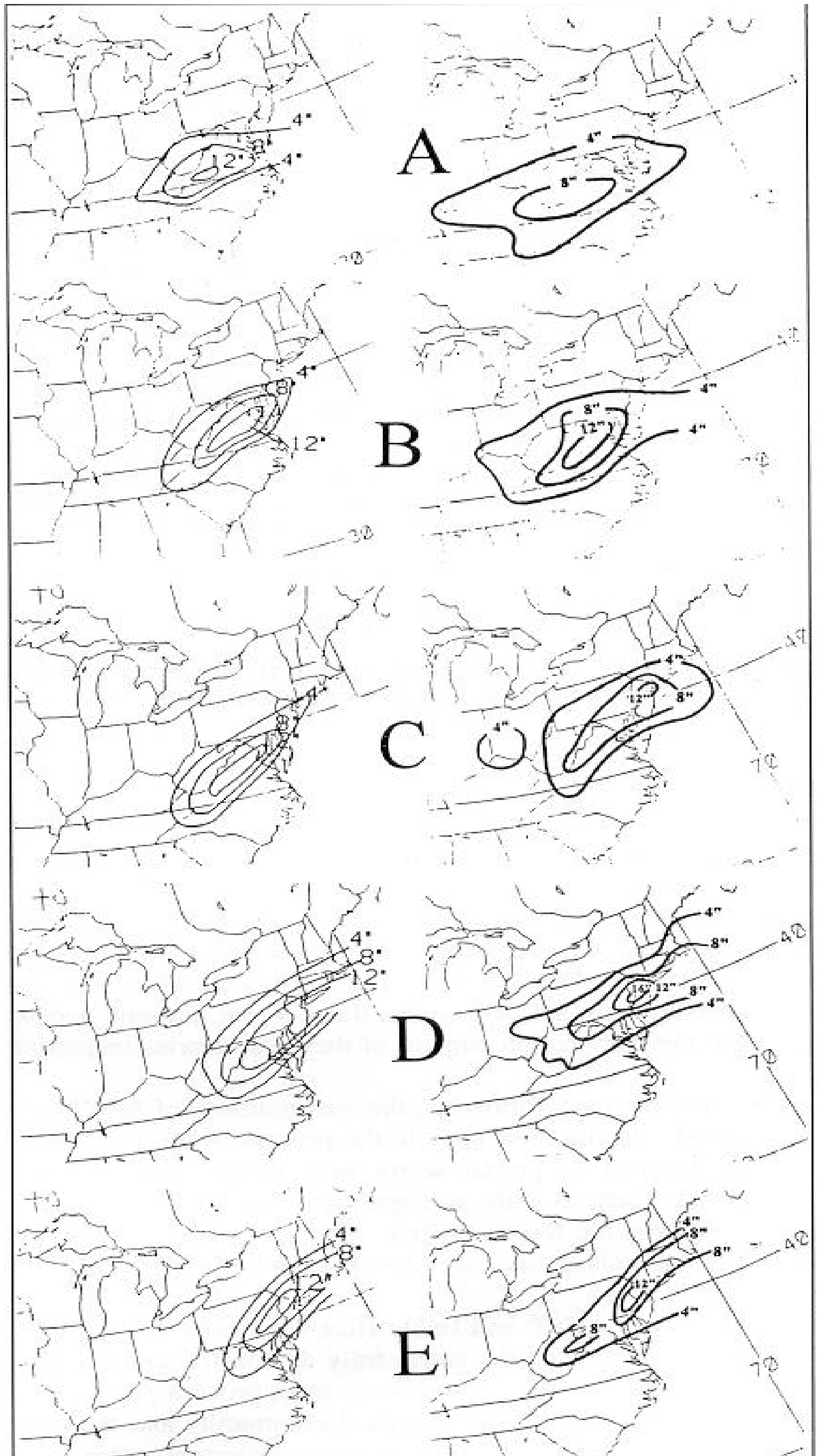

Figure 8. The HPC 12-hour heavy snow forecasts (left) and observed 12-hour heavy snow amounts (right) for the periods (a) 0000-1200 UTC, January 7; (b) 0600-1800 UTC , January 7; © 1200 UTC, January 7-0000 UTC, January 8; (d) 1800 UTC, January 7-0600 UTC, January 8; and (e) 0000-1200 UTC, January8.

Prognostic Discussion issued in the early afternoon of Saturday, January 6, illustrates this, stating:

> ***"THE MRF APPEARS TO BE BRINGING FAST 500 MB WESTERLIES AND LOWER SURFACE PRESSURE INTO WESTERN CANADA MUCH TOO QUICKLY...I WOULD NOT BE SURPRISED TO SEE THE UPPER TROUGH SHARPEN UP OVER NEW MEXICO FRI..SUPPORTING SURFACE WAVE DEVELOPMENT IN THE WESTERN GULF OF MEXICO ON THE OLD POLAR FRONT."***

The HPC forecasters also described the impact this storm was expected to have on the reopening of the Federal Government. The above HPC discussion also stated:

> ***"WHILE POLITICAL LEADERS HAVE DECIDED TO RE-OPEN THE FEDERAL GOVERNMENT IN D.C. THIS WEEK, MOTHER NATURE WILL LIKELY VETO THIS WITH A CRIPPLING SNOW STORM FROM WV/WESTERN VIRGINIA, NORTHEASTWARD THROUGH THE METRO AREAS FROM D.C. TO BOSTON."***

Other references to the magnitude of this storm included:

> ***"INCREDIBLE, RECORD BREAKING..HISTORICAL SNOWS STILL LIKELY FOR PORTIONS OF THE MID ATLANTIC STATES BEFORE THE EVENT FINALLY ENDS MON."***

Media and Personnel Issues

During the "Blizzard of '96," there were numerous media requests for information. NCEP meteorologists provided ten on-camera interviews for both national and local television and nearly 100 radio interviews for local and national stations. Many of the interviews for both television and radio where conducted live. HPC meteorologists issued a total of ten storm summaries prior to and during the storm. The storm summaries were directed to the media as a means of keeping them advised on the storm's past, present, and future status. As the storm progressed, the information content of these summaries increased dramatically.

During the blizzard and the days following, the vast majority of NCEP operational personnel reported for work, risking their lives in the process, when the remainder of the Federal Government and most of the private sector were closed. Most personnel brought extra food and clothing with them to work anticipating being stranded at their offices. Several personnel spent days at the forecast office, sleeping in back offices or at hotels adjacent to the office. Some walked several miles through the deep snow to report for duty.

The forecasts and actions of NCEP and field office employees from 5 days preceding the "Blizzard of '96" to the days following the storm fully demonstrated the team effort of the NWS. This teamwork ensured that the end-to-end forecast process provided consistent meteorological information to both the meteorological community and the general public. This enabled public and private sector personnel to make important, often life or death decisions in both a timely and correct fashion.

CONCLUSION

The East Coast blizzard of January 6-8, 1996, goes down in history as one of the "great ones" of the century. This paralyzing winter storm, packed with strong winds, very heavy blowing and drifting snows, extreme wind chills, and minor to moderate coastal flooding, brought most private and government activity to a halt for the better part of a week. Some of the heaviest snowfall amounts of the late 20th century blanketed the urban corridor from Washington, D.C., to Boston.

Devastating as this storm was, the warning process worked and the public was well prepared. While most of the Federal Government was furloughed for budget reasons, the forecast staff of the NWS literally worked around the clock, providing accurate and timely information to local media outlets and emergency managers. Almost a week prior to the event, the forecasters at the HPC in Camp Springs, Maryland, began to note that certain biases were occurring in the medium-range (3 to 5 day) numerical prediction models and advised NWS and private meteorologists of these biases in routine forecast discussions. Local NWS forecasters throughout Eastern Region, adding their own regional expertise, began issuing outlooks as early as January 3. Winter Storm Watches and Warnings followed, with respective lead times of up to 48 and 24 hours.

As important as all of this meteorological expertise is to the forecast process, it still doesn't tell the whole story. Just as critical to getting the message to the public are clear lines of communication from the NWS to the local emergency managers and the media. Long prior to the event, local NWS offices built and tested these lines of communication in the event of a storm. The final test of the dissemination system is always the severe weather event itself—how quickly did the public get the word? Post-storm interviews with emergency managers up and down the Eastern Seaboard indicate that the NWS not only met but far exceeded expectations.

APPENDIX A

Meteorological Analysis

PREPARED BY THE
HYDROMETEOROLOGICAL PREDICTION CENTER

Surface Analyses

A 12 hourly depiction of the surface evolution of the storm is seen in figure A-1. At 1200 UTC, January 6 (Saturday morning), the surface chart showed a 1012 mb surface low in the central Gulf of Mexico. This weak cyclone was producing an expanding area of rain in Louisiana, Mississippi, Alabama, Georgia, and Tennessee and some light snows into Kentucky, Missouri, and Oklahoma. An inverted pressure trough extended from the Gulf coast northeastward toward eastern Tennessee, Kentucky, and West Virginia. Embedded within the inverted trough was a developing stationary front over the Gulf States. The front separated temperatures in the 20s and 30s (^{o} Fahrenheit [F]) in Texas northeastward to Kentucky from temperatures in the 50s and approaching 60^{o}F in Louisiana and coastal Mississippi, Alabama, and northwestern Florida. Along this boundary, particularly to its north, moderate to heavy rains developed. The beginning of a coastal trough/front developed off the Florida and southeastern U.S. coast as cold air off the East Coast was modified over the Gulf Stream. Farther north, high pressure covered much of the northern United States and southern Canada, with a 1043 mb center over North Dakota and a 1038 mb center over southern Ontario. A core of extremely cold air had passed across New England the previous night, bringing the lowest temperatures of the season, below 0^{o}F, across virtually the entire region, except the immediate coastline of Massachusetts, Rhode Island, and Connecticut.

By the evening, 0000 UTC, January 7, precipitation was spreading rapidly northeastward into the Ohio Valley and the Mid-Atlantic States. Heavy thunderstorms were observed over the Gulf of Mexico, while moderate to heavy rains had spread across portions of the southeastern United States at 0000 UTC, January 7. Meanwhile, moderate to heavy snow had spread northeastward into much of the lower Ohio Valley, eastern Kentucky, West Virginia, Virginia, and western North Carolina. The precipitation shield was expanding as the surface low in the Gulf of Mexico moved east-northeastward, deepening slowly to 1008 mb. The inverted trough to the north of the front had sharpened, with a 1012 mb surface low pressure center over eastern Tennessee and the hint of another low pressure center over eastern Alabama. The coastal trough off the Southeast United States had evolved into a distinct coastal front, separating cold air associated with high pressure anchored north of New York and dammed up to the east of the Appalachians from the milder easterly and southeasterly flow off the Atlantic.

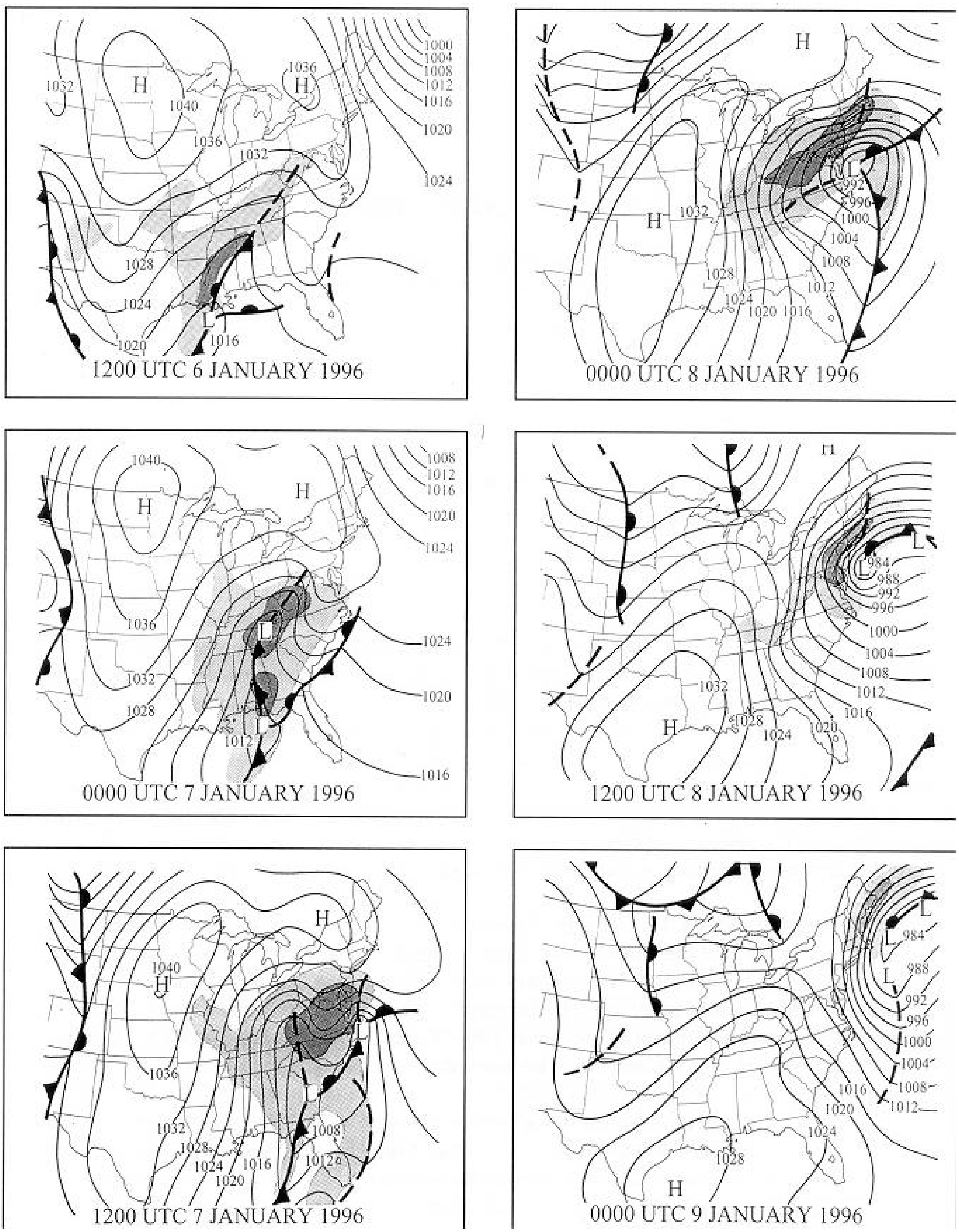

Figure A-1. 12-hour evolution of surface analyses, isobars in mb.

Overnight, the precipitation area continued to expand rapidly northeastward into all of the Mid-Atlantic States as moderate to heavy snows developed over much of Virginia, West Virginia, Maryland, and Delaware. By 1200 UTC, January 7, Sunday morning, as much as a foot of new snow had fallen across western North Carolina, southwestern Virginia, and West Virginia, while snow changed to ice pellets, freezing rain, and rain across central and eastern North Carolina and southeastern Virginia. The low pressure centers over the Gulf of Mexico and southeastern United States had now merged into one center and moved to a position near Augusta, Georgia, and continued to deepen slowly to 1004 mb. A new low pressure center with a central pressure of 1006 mb formed along the coastal front just east of the Virginia/North Carolina border. The cell of high pressure over North Dakota began to slip southward while the other high pressure center remained anchored north of New York, feeding cold air into much of the Mid-Atlantic States. Within the region experiencing the heavy snowfall, temperatures were only in the teens and lower 20s (^{o}F), accompanied by increasing north-northeasterly winds.

During Sunday, January 7, the heavy snows spread northeastward into Pennsylvania, New Jersey, southeastern New York, and southern New England, where temperatures were primarily in the teens (^{o}F) with winds approaching gale force, creating blizzard or near-blizzard conditions. Snow continued throughout much of the lower Ohio Valley into the Mid-Atlantic States, where snow mixed with or changed to ice pellets as far north as Washington, D.C., to the eastern shores of Maryland, Delaware, and extreme southern New Jersey. Late on January 7, Sunday evening, the heavy snows were falling at rates of 1-4 inches per hour from Pennsylvania northeastward into southern New England. Snowfall amounts approached and exceeded 20 inches in much of eastern West Virginia, western and northern Virginia, Maryland, and southeastern Pennsylvania. By 0000 UTC, January 8, the surface low over the Southeast United States had progressed northeastward and merged with the low pressure center east of southeast Virginia and had deepened fairly rapidly to 990 mb, a drop of 14 to 16 mb during the past 12 hours. The high pressure cell north of New York remained fairly stationary, but its central pressure was beginning to decrease, while the other anticyclone dropped southward and was centered over Oklahoma.

On Sunday night into Monday morning, January 7-8, the snows continued over much of the Mid-Atlantic States and southern New England as the surface low, with a central pressure of 980 mb at 1200 UTC, January 8, moved slowly northeastward east of the Virginia coastline. While some of the snowfall rates had diminished over portions of Virginia and Maryland late Saturday afternoon, NEXRAD imagery confirmed that the storm's "backlash" was developing over the area by evening. Moderate to heavy snows in eastern Kentucky, southern Ohio, and West Virginia redeveloped to the east over northern Virginia, Maryland, and Delaware as 6 to 12 inches of new snow affected portions of the region. Farther north, snow continued from New Jersey and Pennsylvania northeastward into southern New England; by morning, 20 to 36 inches were common from West Virginia to northern Virginia, Maryland, northern Delaware, eastern Pennsylvania, central and northern New Jersey, southeastern New York, and southwestern Connecticut. Heavy snows had now moved across much of southern New England, and temperatures in the teens to near 20^{o}F with gusty winds continued the blizzard to near-blizzard conditions.

On Monday, January 8, the storm center finally began to move northeastward and appeared to redevelop into several centers over the Atlantic Ocean. Gradually, snows ended across the Mid-Atlantic States into New York, while snows continued through much of eastern New England. By the evening of January 8, the storm pulled away, and most snows had ended across eastern New England.

850 mb Analyses

At the 850-mb level (figure A-2), a core of -25º Celsius (C) temperatures moved east of Maine at 1200 UTC, January 6. Associated with this core were the coldest surface temperatures of the season to date. Although the core exited the Northeast prior to the snowstorm, 850 mb temperatures remained at -10ºC or colder from Washington, D.C., northward early on January 6. As the surface low was developing across the Gulf of Mexico, the system had considerable tilt to the north in the vertical with the 850 mb low developing over the Tennessee Valley on January 6 before moving east-northeastward toward the Virginia coast. Between 1200 UTC, January 6, and 1200 UTC, January 7, the 850 mb low intensified as it crossed the state of Tennessee. The temperature gradients also intensified as the low moved eastward, and a strong south-to-southeasterly jet developed east of the center at 0000 and 1200 UTC, January 7, commensurate with the development of moderate to heavy rains and snows from the Southeast to the Mid-Atlantic States. By 0000 UTC, January 8, a strong easterly jet was located to the north of the 850 mb low center over Virginia, as heavy snows affected a wide portion of the Mid-Atlantic States and southern New England. Note that the 850 mb low continued to deepen throughout the period. However, this low did not deepen as rapidly as some of the cases described in Kocin and Uccellini (1990) and was consistent with only a moderate amount of deepening of the surface low pressure center. The characteristic S-shaped pattern to the isotherms developed as the 850 mb low deepened, and the 0ºC isotherm was located near the 850 mb low center throughout its evolution until 1200 UTC, January 8, when the cyclone nearly stalled off the Mid-Atlantic coast. At this time, the increasingly cold-core nature of the 850 mb low became apparent. The heaviest snows were associated with 850 mb temperatures between -2ºF and -10ºF (colder than the usual temperatures associated with the maximum snowfall area). The 850 mb low moved slowly east-northeastward and by 1200 UTC, January 8, was accompanied by a 50- to 60-knot (kt) easterly jet to its north and a 50-kt northerly jet to its west, where snow continued to fall.

Upper-level Analyses

The period prior to the "Blizzard of '96" was marked by a persistent blocking pattern dominated by an upper-level ridge over Greenland (figure A-3). As a result, cold air was deflected south of Greenland over eastern Canada throughout much of the early part of the winter, and this period appeared to be no exception. The precyclogenetic period was marked by the movement of an intense vortex at 500 mb over eastern Canada which was followed by a persistent northwesterly flow aloft over eastern Canada and southwesterly flow over the eastern half of the United States. This configuration produced a highly confluent flow over

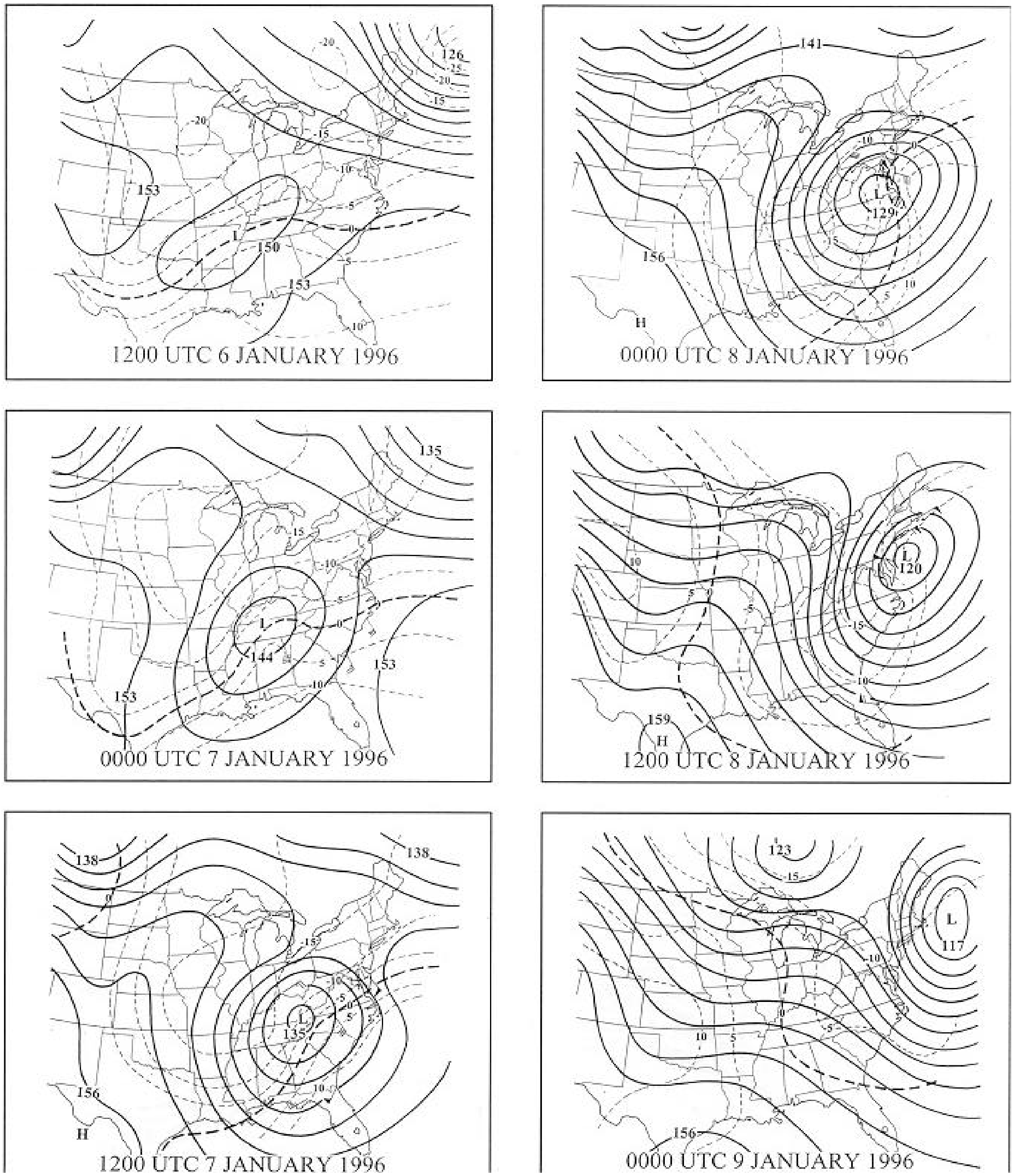

Figure A-2. 12-hour evolution of 850 mb analyses, geopotential height contours in mb, isotherms in ^{o}C, and wind barbs in knots.

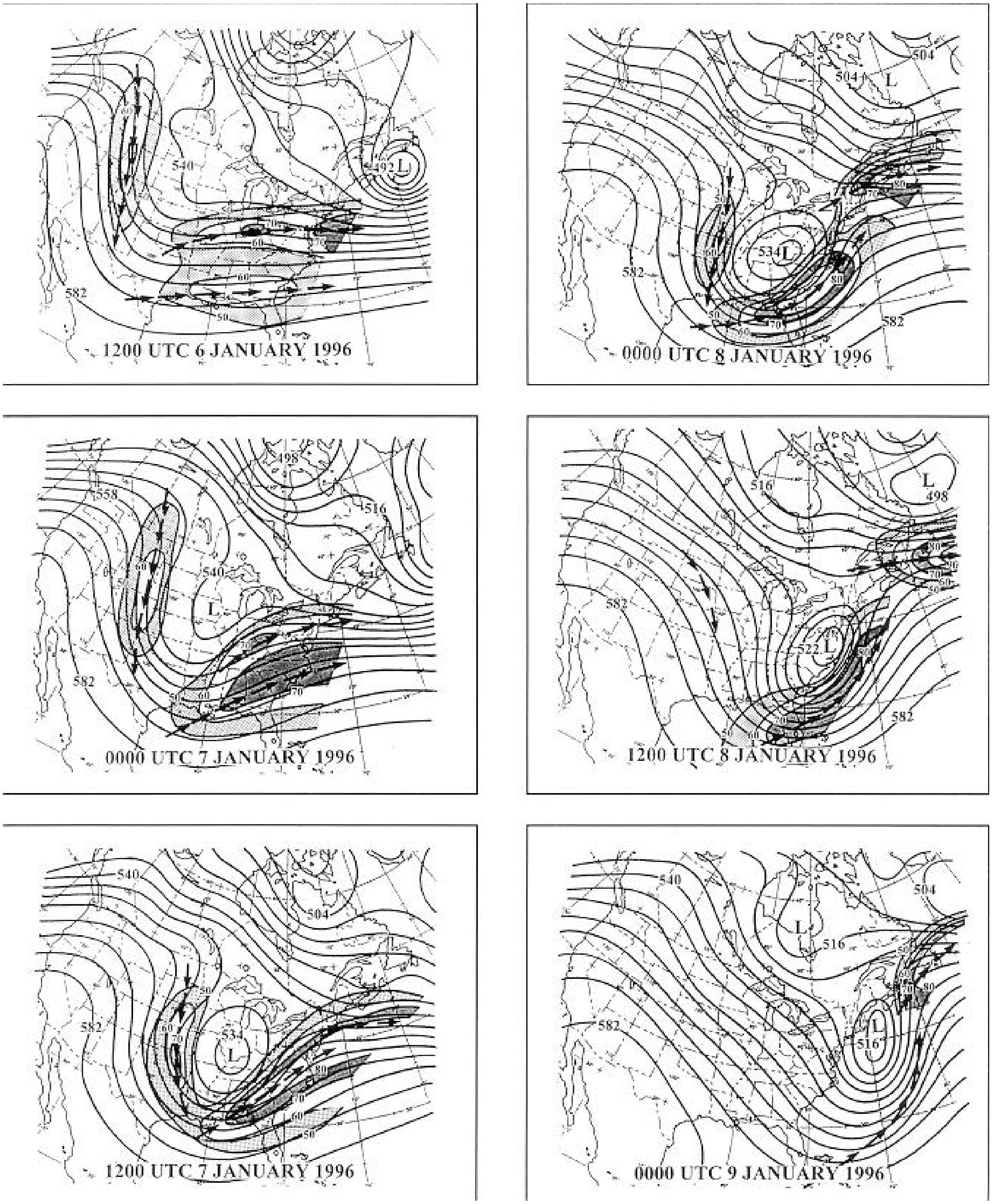

Figure A-3. 12-hour evolution of 500 mb analyses, geopotential height contours in mb, and isotachs in ms^{-1}.

the eastern United States that favored a large area of cold high pressure near the U.S./Canadian border. Since the cold-core low south of Newfoundland was mobile, the confluent pattern was allowed to lift northward, allowing heights to rise across the eastern United States. While some of the early medium-range model simulations appeared to indicate that the confluent field could act to suppress any shortwave trough that might pass within it, the upper trough that ultimately led to the blizzard was ***not*** suppressed and maintained its amplitude, resulting in a storm of considerable intensity.

The shortwave trough that spawned the storm was located at 1200 UTC, January 6, over the central United States, with a 70 ms^{-1} jet plunging southward upstream of the trough axis. In the following 24 hours, the trough would amplify southward and develop a closed center by 1200 UTC, January 7, accompanied by the southward progression of the jet streak to the west of the center and an amplification of the upper-level winds downstream of the trough axis. A substantial amplification of the upper jet was observed between 1200 UTC, January 6, and 1200 UTC, January 7, as heights rose east of the trough axis but remained low over eastern Canada. Wind speeds increased to over 80 ms^{-1} over the East Coast by 1200 UTC, January 7. This increase in the upper-level winds was associated with the expanding precipitation area over the eastern United States. By 0000 UTC, January 8, a coupled jet pattern was clearly seen over eastern North America, with an 80 ms^{-1} jet south of Newfoundland and a separate 80 ms^{-1} jet east of the trough axis along the Southeast United States coast. The area of moderate to heavy snow was found between the two jets, within the entrance region of the northern jet and the exit region of the southern jet. The 500 mb vortex associated with the upper trough that spawned the storm expanded and by 1200 UTC, January 8, moved slowly toward the East Coast where it began to change shape from a broad, rounded orientation to a north-south orientation. At 0000 UTC, January 8, the surface and 850 mb low centers were well east of the 500 mb center. However, by 1200 UTC, January 8, the 500 mb trough appeared to be catching up with the surface low pressure system, an indication that the storm was becoming more vertical or occluded. Colder temperatures surrounding the 850 mb low at this time were another indication of occlusion. Strongest winds were completely to the east of the upper center, indicating that the center was lifting east-northeastward. By 0000 UTC, January 9, the upper trough continued to swing east, and the 500 mb low deepened. By this time, the upper low was becoming increasingly characterized by multiple vorticity maxima (note the increasing north-south alignment of the upper center), and the surface cyclone had split into several separate centers.