Natural Disaster Survey Report 74-1

The Widespread Tornado Outbreak of April 3-4, 1974

A Report to the Administrator

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

Rockville, Md.
December 1974

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U. S. Department of Commerce
Frederick B. Dent, Secretary
National Oceanic and Atmospheric Administration
Robert M. White, Administrator

Foreword

The widespread tornado outbreak of April 3-4, 1974, led to the formation of a National Oceanic and Atmospheric Administration survey team to review the effectiveness of NOAA's tornado warning services. This Natural Disaster Survey Team was formed by the evening of April 4. This report describes the tornado outbreak and presents the findings and recommendations of the survey team.

Edward S. Epstein
Associate Administrator for Environmental Monitoring and Prediction

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Preface

The NOAA Natural Disaster Survey Team that investigated the widespread tornado outbreak of April 3-4, 1974, consisted of Edward S. Epstein, Associate Administrator for Environmental Monitoring and Prediction; Gerald A. Petersen, Director of NOAA's Office of Meteorological and Hydrological Services; Herbert Lieb, Deputy Director of NOAA's Office of Public Affairs; John Davies, of NOAA's Office of Meteorological and Hydrological Services; Vincent Oliver and James Purdom of the National Environmental Satellite Service; and Philip Dales of the National Weather Service's (NWS) Communications Division. Most of the team arrived at Birmingham, Ala., on April 5. By April 12, the team had surveyed damaged areas in Alabama, Tennessee, Kentucky, Indiana, and Ohio. The team was aided in their survey by specialists from the NWS's Southern, Central, and Eastern Regions who visited the disaster scene 6 to 12 hours after the tornadoes and provided briefings on results of their surveys in Georgia, Alabama, Tennessee, Kentucky, Indiana, and Ohio. During the week of April 22, members of the team visited additional sites in Missouri, Illinois,and eastern Tennessee.

The tornado outbreak extended from the afternoon of April 3 through the morning of April 4. At least 127 tornadoes occurred in an area from Chicago southward to the Gulf of Mexico and eastward almost to the Atlantic coast. Several of the tornadoes were among the most severe ever observed. The magnitude of this outbreak tested NOAA's tornado warning system fully.

The survey convinced team members that a remarkable job of warning the public was done. It also revealed the need to assess the effectiveness of the Nation's warning system and to find ways to improve the system further. This report is an attempt in that direction.

The NOAA Natural Disaster Survey Team appreciates the help it received from Federal, State, and local officials, the news media, and the people who granted interviews during times of stress and personal loss. The team also thanks the many NWS employees who helped in the survey after performing so tirelessly during the disaster period.

Executive Summary

In terms of number of tornadoes, length of tracks, total area affected, and damage, the April 3-4, 1974, tornado outbreak was the greatest in recorded history. Several of the 127 tornadoes documented at this writing were among the most severe ever observed.

The storms killed 315* people in 11 States. The American National Red Cross reported 6,142 injured and that 27,590 families suffered losses.

The Defense Civil Preparedness Agency places the property loss at $600 million within the 10 States declared a disaster area by the President. The greatest damage was in the city of Xenia, Ohio; however, some smaller communities—Guin, Ala., and Brandenburg, Ky.—had comparable losses.

The NOAA survey team is convinced that the warnings by the NWS Warning System, the relay of warnings by the news media, and the protective actions taken at the community level saved thousands of lives. But good fortune played a big role. For example, had the Xenia tornado, which destroyed or severely damaged several unoccupied schools, arrived unheralded while the schools were in session, hundreds probably would have died. The Monticello, Ind., tornado passed directly through the business district in the late afternoon, killing two people. However, many stores close Wednesday afternoons, and the downtown area was less busy than usual. It also was evident that the late afternoon and early evening occurrence of many of the tornadoes made visual sightings of the approaching storms possible and contributed to the effectiveness in disseminating the warnings. It is apparent from this event that the capability to deliver timely warnings to all schools, hospitals, and congested areas at any hour of the day must be improved.

For the most part, the NOAA warning system performed remarkably well under the most trying of conditions. Early on Tuesday, April 2, the National Severe Storms Forecast Center (NSSFC) at Kansas City alerted all network radar stations in the National Weather Service Central Region to perform needed radar maintenance. The Regional Warning Coordination Center (RWCC) in Ft. Worth relayed a similar alert to NWS Southern Region stations. The early morning severe thunderstorms outlook for April 3 outlined an area where severe thunderstorms were expected. Most of the tornadoes occurred in this area on April 3. The NSSFC issued a total of 30 watches between 3:50 a.m. CDT on April 3 and 2:00 p.m. CDT on April 4. During almost the same period of time, more than 250 severe thunderstorm and tornado warnings were issued by the National Weather Service Forecast and Services Offices. Most of the tornadoes occurred in or near valid watch areas. Not all occurrences were covered by tornado warnings, but many warnings were received in time for effective actions to be taken.

NWS personnel and the news media had difficulties in keeping current because of the numerous watches and warnings, some of which overlapped, and because the tornadoes moved at speeds up to 50 to 60 miles per hour.

The value of network and local warning radars during this outbreak cannot be emphasized enough. A large percentage of the timely warnings were based on radar observations. The need for emergency power, especially at all radar sites, was vividly

This count, from the NOAA Environmental Data Service publication "Storm Data," is for deaths attributed directly to storms. Other sources, for example the Red Cross, also include tornado-associated casualties, such as deaths from heart attacks.

demonstrated. The WSR-57 radar at Covington, Ky., was out of action 3 hours; however, most of the worst tornadoes had already occurred by this time, and some backup was available from Air Force and Federal Aviation Administration (FAA) radars. The Huntsville, Ala., local warning radar was able to operate continuously only because emergency power was available and power surges caused by the storms were damped out. Power was not lost at Louisville, but many surges made the radar inoperative from time to time; only exceptional performance by the electronic technician, who changed parts and recalibrated at frequent intervals, kept the radar performance at a reasonable level. In addition, the Lexington Weather Service Office was without power from 7:38 p.m. CDT on April 3 to 2:44 a.m. CDT on April 4. This included the period when storms were active in the Lexington area.

Satellite information available at the Satellite Field Service Stations (SFSSs) in Kansas City and Suitland was used to good advantage in identifying areas of potentially severe and ongoing severe weather. The Kansas City SFSS staff closely coordinated its efforts with those of NSSFC and RWCC, while both SFSSs communicated directly with field offices. Satellite information contributed to the effectivenes of the warning system during the outbreak. For the future, operational GOES systems and higher quality satellite imagery promise substantial improvements in warning capabilities.

The most important element in disseminating watches and warnings was the active participation by television and radio stations. Most stations did not hesitate to interrupt normal programming with warnings as they were received. There were many examples of radio and TV stations performing almost heroically.

The relationship between time of day of tornado occurrence and radio and TV listening and viewing habits of the public is a very important factor in the warning process. When listening and viewing audiences are at the lowest (afternoon hours), reliance on positive alerts such as sirens becomes even more important.

As another part of the dissemination problem, those radio stations with hours of operation limited to a schedule (e.g., sunrise to sunset) should be made aware of the fact in emergencies they are permitted by FCC rules to continue on the air. In addition, the Emergency Broadcast System (EBS) needs attention to take advantage of its potential role.

The value of NOAA Weather Radio (VHF-FM) was apparent in many instances during the massive outbreak. It is the team's view that this capability, along with tone-alert receivers in all schools, hospitals, factories, and local government facilities is an invaluable tool in providing rapid and effective warning. Again, emergency backup power is essential in all offices possessing this capability and at the transmitters.

The question of "watch" and "warning" terminology was repeatedly raised in the States with low tornado incidence. However, in the small rural community of Guin, Ala., everybody interviewed was aware of the different meanings of the two terms.

Public response is the most uncertain variable in the complex chain reaching from issuance of warnings to effective action. Larger cities having active Civil Defense efforts appeared much better prepared than rural towns. Also, sirens were used effectively in some instances, and not at all in others.

Throughout the survey the NOAA team was impressed by the importance of disaster or emergency preparedness. In Alabama people took decisive action by getting into basements, storm cellars, or inner parts of houses. They opened windows and doors and called neighbors. At other locations, in less tornado-prone areas, some people knew what actions to take but many did not. The school system in Xenia had a disaster plan, but had never conducted a tornado drill. Mobile homes are especially vulnerable to storms, yet few owners of such homes had taken advantage of tie-downs or had shelters available for such emergencies. Deficiencies in preparedness added to the number of casualties on April 3-4.

The team's findings and recommendations are detailed in Chapter 1. Backup material is presented in the chapters that follow.

Chapter I

Findings and Recommendations

The survey team is able to draw a number of conclusions based on its many months of effort, including inspection of disaster sites, interviews with the public and the press, discussions with NWS personnel and law enforcement and civil defense authorities, and the review of pertinent events before and during the April 3–4 outbreak of tornadoes. The total warning system, which includes not only components of NOAA, but also spotter networks, radio and television stations, and civil defense and law enforcement agencies, was generally effective. The system did not always operate perfectly or uniformly; however, when such a disaster affects so many communities over such a large area—with each community varying in its past experience with severe weather conditions—one can expect numerous breakdowns in parts of the total system. The surprising and significant findings of this investigation were that the system had so few problems. Even better, most problems were minor or were at least partially compensated for by some redundancy in the system.

Many lives were spared because of the dedicated service and voluntary actions of many people—public servants, the communications industry, and citizens at large. Members of the team heard of specific incidents in which hundreds of lives were saved. Undoubtedly this total disaster warning system saved thousands from death and injury.

The following specific findings and recommendations are offered:

FINDING 1

Public education and awareness—community preparedness—saved many lives on April 3–4, and effective community action plans were found in some localities. However, several problem areas were noted.

(a) Many people do not know the tornado safety rules, or have never taken part in drills.

(b) Many communities lacked adequate action plans, spotter networks, sirens, etc. Some had plans that were not used.

(c) The team could find no uniform, concerted effort to incorporate tornado safety education and preparedness in the school system.

(d) Mobile homes were vulnerable and hard hit during the outbreak. Tiedowns and shelters, which can reduce the casualties, were rarely found in the disaster areas surveyed.

(e) Some radio and television stations apparently do not realize that the Federal Communications Commission authorizes them to stay on the air beyond normal operating hours during weather emergencies.

(f) The Emergency Action Notification Attention Signal (EANS) which activates the Emergency Broadcast System is seldom used—even when requested by the warning offices. There is some confusion over the authorized use of this system, but it was effective when used.

Recommendations

Community preparedness activities in cooperation with other Federal, State, and local government agencies should be expanded as rapidly as possible. To assure nationwide coverage, assignment of preparedness specialists to Weather Service Forecast Offices will go a long way toward helping in planning and education, as well as in other activities, such as the development of improved spotter networks and mobile home preparedness. NOAA, in cooperation with Defense Civil Preparedness Agency (DCPA) and Federal Disaster Assistance Agency (FDAA), should increase its efforts to promote the installation and use of sirens where needed as well as State legislation for mobile home tiedowns and shelters.

States should require all schools to hold tornado drills and to use tornado safety material in the school curriculum. NWS should continue to work with DCPA and State school officials in developing tornado safety literature, films, and slides for school use.

Working with the FCC, DCPA, and the Office of Telecommunication Policy, NWS should tell radio and television stations about the regulations granting authority to remain on the air beyond normal operating hours during a weather emergency. Better means to use the cooperative efforts of the industry in the Emergency Broadcast System should also be developed.

FINDING 2

Broadcasts over NOAA Weather Radio (VHF-FM) proved to be rapid means of sending warnings directly to hospitals, schools, local action agencies, or the public in St. Louis, Atlanta, Indianapolis, and Detroit. Such broadcast sites are few in number in the outbreak area and have limited range.

Recommendation

Expand NOAA Weather Radio as quickly as possible. Its capability for rapid and efficient transmission of warning messages, especially to local government offices, schools, hospitals, shopping centers, etc., would significantly improve our ability to disseminate tornado warnings. The tone alert capability of NOAA Weather Radio holds great promise for lifesaving actions.

FINDING 3

Networks and local warning radars were absolutely essential to the success of our tornado warning program. Offices without radars or radar remotes used coded or verbal radar information in issuing warnings, but were at a distinct disadvantage in tracking and warning about individual storms. The obsolete local warning radars still in use at several warning offices operated satisfactorily during this outbreak, but most required such continuous attention from maintenance personnel that their reliability in future outbreaks is doubtful.

Recommendation

Accelerate and complete the NOAA radar program* nationwide. Since visual imagery is an essential factor in being able to handle severe weather situations, every warning office that is not also a radar site should have a radar remoting device with dedicated lines and direct communication channels to the master radar station. In addition, provide a Video Integrator and Processor (VIP) for all radars in order to enable more rapid identification of severe storms.

FINDING 4

Lack of emergency power adversely affected the warning operations at our offices in Covington, Louisville, and Lexington, Ky.

Recommendation

Provide emergency power for all offices with county warning responsibility, all radar installations, and all NOAA Weather Radio transmitter sites.

FINDING 5

NOAA Weather Wire Service (NWWS) delivered a huge volume of severe weather information to the mass media for broadcast to the public, yet the extent and rapid movement of the storms gave rise to several problems:

(a) Manual message preparation causes teletypewriter distribution to be too slow for effectively disseminating tornado warnings. Yet this is the fastest means we now have for sending "hard copy."

(b) The intrastate character of NWWS requires relay of warnings for adjacent States over other channels, such as RAWARC. This relay caused delays. The greatest delays, of up to 2 hours, resulted from overloaded computer relays between RAWARC circuits, and occasionally even caused the transmission of expired warnings for nearby States.

Recommendations

Complete as quickly as possible the Automation of Field Operations and Services (AFOS) program of the NWS. AFOS uses available technology for data handling, message composition, forecast preparation, and warning dissemination. This use will enable us to respond more rapidly to severe weather situations through faster message preparation and interstate relay of warnings.

Until AFOS is implemented, and to reduce or eliminate interstate relays to get warnings on NWWS where needed, reexamine areas of county warning responsibility and/or the present configuration of both NWWS and RAWARC circuits. In addition, perform vigorous but judicious editing of NWWS traffic to ensure that unnecessary or outdated information is not transmitted.

FINDING 6

Too few radio and television stations subscribe to NWWS. Those stations relying on press wire service inevitably receive the information somewhat delayed. Yet, most of the public now receives its warnings by radio and TV.

Recommendations

NWS should continue its efforts to increase the number of NWWS subscribers.

Expand the NOAA Weather Radio to provide an additional means of getting warnings to radio and television stations for taping and immediate rebroadcast to the public.

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* The NOAA radar program is presented in detail in the *Federal Plan for Weather Radars,* November 1973.

FINDING 7

Satellite information was used to good advantage in identifying areas of potentially severe and on-going severe weather, but was limited by the lack of resolution and the daytime-only capability of ATS–3, particularly since many of the killer storms struck the southern part of the outbreak area after dark. More frequent satellite images proved to be an important tool for closely following the development of the storms on April 3–4. Lack of experience with this source of information limited its utility to some extent.

Recommendation

Implement, as quickly as possible, plans to provide all forecast offices, especially those in severe weather areas, with the capability to receive and interpret GOES data. Early implementation will accelerate benefits to be obtained from the high-resolution, around-the-clock coverage of this geostationary satellite.

FINDING 8

All warning offices responded with immediate warnings when credible reports or indications of storms were received. However, not all warnings were effective because of the lack of timely and positive information on the existence, location, and movement of all such storms. Thus, many people had specific warnings in time to take actions; others had no warning at all.

Recommendations

Continue research and development efforts in remote sensing of severe storms, and use proven techniques. Particularly promising are the recent developments in studying the electromagnetic signature of tornadic storms and the use of Doppler radar to identify small-scale velocity fields.

FINDING 9

The large number of watches, some of which overlapped in time and space, resulted in some confusion, both in our field offices and with the media. There was little or no lead time on the watches. With the exception of the tornadoes in southern and east central Indiana between 2:00 and 3:00 p.m. CDT, almost all tornadoes were in or close to valid watch areas.

Recommendations

Devise simplified watches for use during severe storm and tornado outbreaks. If an entire State is threatened, it shouldn't take four watches and the time and effort involved in writing four redefining statements to say so.

Establish a techniques development staff at the National Severe Storms Forecast Center, as we have at the National Hurricane Center, to aid in merging new and conventional data into improved techniques for forecasting and warning of severe local storms.

FINDING 10

The potential threat of the storm system was recognized 36 hours in advance. On April 2, selected NWS field units were alerted by the Central and Southern Region RWCCs, enabling advance preparations to be made.

Recommendation

When a potential threat is apparent, alert all NWS offices in the affected area. Issue specific directives to systematize the distribution of such alerts.

FINDING 11

The severe thunderstorm outlook issued early on April 3 was excellent because the area covered contained practically all the storms which occurred in the 24-hour period and indicated that more than the usual coverage of severe local storms was expected. This outlook was given national television coverage on the NBC TODAY Show and was incorporated into the early morning forecasts for some, but not all, of the affected states.

Recommendation

Consistent with NWS policy, the intent of the severe weather outlook should be used in State and zone forecasts.

FINDING 12

Several warning offices had lengthy telephone dissemination lists. Dial telephones are not effective in distributing tornado warnings if more than one or two calls are needed. Telephone outages and busy signals frustrated some attempts to disseminate warnings on April 3. On the other hand, local hot-line telephones were used to advantage in some metropolitan areas.

Recommendation

Eliminate as rapidly as possible the use of dial telephones to disseminate severe weather warnings. Encourage use of the local hot-line telephone where this channel is feasible.

FINDING 13

The National Warning System (NAWAS), operated by the Defense Civil Preparedness Agency, was used extensively and effectively for both collecting of severe weather reports and dissemination of warnings to local action officials.

Recommendation

Encourage fullest use and expansion of NAWAS.

Chapter 2

Description of the Outbreak

In terms of total number, path length, and total damage, the massive tornado occurrence of April 3-4, 1974, was more extensive than all previously known outbreaks. Of the 127 tornadoes so far documented, 118 had paths over a mile long. The total paths amounted to 2,014 miles, resulting in 315* deaths. By comparison, during the tri-State outbreak of March 18, 1925, seven tornadoes travelled 437 miles and caused 746 deaths. The Palm Sunday outbreak of April 11, 1965, spawned 31 tornadoes, which had paths totaling 853 miles, and killed 256.

The year 1973 went down in history as the year of the tornado. More than 1,100 tornadoes were reported—an all-time high. The first quarter of 1974 was just as busy, but severe weather forecasts generally were confined to a few watch areas on each storm day. This pattern was broken on Monday, April 1, when 11 severe weather watch areas were issued and more than 20 tornadoes developed from Alabama and Mississippi through the central States into Indiana and Ohio. Three deaths and much property damage were attributed to tornadoes. The storms of April 1 served to alert the forecasters to the potential for widespread outbreaks, and the impact of these storms was fresh in the minds of many people when they heard the watches and warnings of April 3. In Alabama and Tennessee, where severe damage occurred on both days, many lives were saved during the April 3–4 disaster because the public took protective actions that might not otherwise have been taken had it not been for the April 1 storms.

On Tuesday morning, April 2, the forecasters at the NSSFC determined that the developing storm system had the potential to produce severe thunderstorms the following day, although the precise location and timing of such activity was not yet evident. At that time, it appeared that the severe activity would occur somewhere in the middle or lower Mississippi Valley. Consequently, the Kansas City RWCC suggested in a teletypewriter message to 10 Central Region network radar stations that any needed maintenance be done by April 2. (Stations alerted were Garden City and Wichita, Kans.; Grand Island, Neb.; St. Louis and Monett, Mo.; Detroit, Mich.; Des Moines, Iowa; Minneapolis, Minn.; Marseilles, Ill.; and Evansville, Ind.) Meanwhile, the Fort Worth RWCC was phoning to advise several Southern Region WSFOs of the coming severe weather potential and the need for radar maintenance. (Offices contacted were WSFOs in Oklahoma City, Little Rock, Memphis, Birmingham, and Jackson.)

While this preliminary alert did not extend far enough east to include all the tornadoes that occurred, and did include a large area in the central and southern plains in which severe thunderstorms did not occur, it gave many NOAA offices over 24 hours in which to prepare for the outbreak.

Through the night on Tuesday, indications of the storms to come were accumulating but the tremendous magnitude and intensity of what was actually to occur, as well as the precise timing and location of the storms, were still not evident. Two severe weather watches were issued during the predawn hours on Wednesday, April 3, for portions of the lower Mississippi Valley, but little activity was noted in these areas. The pace increased in the NSSFC and field offices during the forenoon, as thunderstorms began to build. Severe Thunderstorm Watch No. 92 covering portions of the Ohio Valley was issued at 8:27 a.m. CDT. From that time until 3:00 a.m. CDT the next morning, NSSFC issued 28 Severe Weather Watches covering almost the entire area from the Gulf of Mexico to the Canadian border and from the Mississippi River to the East Coast (fig. 1 through 6). During this period, Na-

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* This death count, as is the count for each State given in subsequent pages, is from NOAA's Environmental Data Service report. Injuries and damage tallies are from the American National Red Cross report.

tional Weather Service Offices issued about 150 tornado warnings. (Chapter 3 deals more fully with the performance of the NSSFC and warning offices.) From the first reported tornado touchdown in Indiana about 9:30 a.m. CDT on April 3, until 8:00 a.m. CDT the next morning when the last two tornadoes of the outbreak touched down in North Carolina, a reported 127 tornadoes cut swaths of death and destruction from Georgia and Alabama north to Michigan (**map with report**). The major activity, however, occurred between 2:00 p.m. and 10:00 p.m. on April 3. In all, 13 States had tornadoes.

The rapid development and widespread extent of the tornado outbreak are evident in the reported times of the first tornado in the seven States struck during the afternoon hours of April 3. Around 2:00 p.m. CDT, tornadoes touched down in Bradley County, Tenn., and Gilmer County, Ga. Within 10 minutes, tornadoes were reported in McLean and Logan Counties, Ill. At 2:20 p.m. CDT, separate killer storms set down in the Indiana counties of Perry and Lawrence. In Ohio the first tornado was reported about 3:30 p.m. CDT, and the Brandenburg, Ky., storm touched down at 3:40 p.m. Alabama's first tornado followed by less than an hour, striking 8 miles west of Birmingham at 4:30 p.m. CDT.

For comparative purposes, for all the tornadoes reported during this outbreak, the mean path length was on the order of 18.7 miles whereas the mean path length for all tornadoes in 1973 was 4.7 miles. For all tornadoes in 1972 it was 3.3 miles. In a rating of intensity of tornadoes on a scale from F0 to F5 (table 1), six tornadoes in this outbreak had an intensity of F5. In 1973, only one tornado had an intensity of F5. In 1972, no tornadoes reached this intensity. In 1971, two tornadoes had an intensity of F5.

Of the casualties and losses suffered in the 13 States surveyed by the American Red Cross (table 2), some were caused by straight-line winds rather than tornadic storms, particularly those involving mobile homes. Some of the deaths reported by the Red Cross were caused by heart attacks and not by direct storm injury. Large hail during the severe thunderstorms and tornadoes contributed to the total damage. The States of Alabama, Georgia, Tennessee, Kentucky, Indiana, and Ohio were the region of greatest storm activity and damage. Detailed descriptions* of tornado activity in each State are provided in the sections that follow. The extremely large number of storms that occurred, and their rapid movement, magnified the problems involved in determining the number and sequence of events. Detailed studies of individual storms and further analyses may modify the descriptions given in this report.

* Numbers assigned to the tornadoes correspond to those given on the University of Chicago map furnished with this report.

Table 1.—Fujita-Pearson (FPP) tornado scale*

Maximum windspeed (mph)	Path length (mi)	Path width (yd)
F 0 40-72	P 0 less than 1.0	P 0 less than 18
F 1 73-112	P 1 1.0-3.1	P 1 18-55
F 2 113-157	P 2 3.2-9.9	P 2 56-75
F 3 158-206	P 3 10-31	P 3 176-556
F 4 207-260	P 4 32-99	P 4 0.3-0.9 mi.
F 5 261-318	P 5 100-315	P 5 1.0-3.1 mi.

* Fujita, T. Theodore, Tornadoes Around the World *Weatherwise* 26(2): 56-62, April 1973.

ILLINOIS

Thirteen tornadoes which killed two persons and injured more than 20, occurred in Illinois between approximately 2:07 and 5:00 p.m. CDT, April 3. Six primary tornado tracks have been identified in Logan, McLean, Macon, Champaign, and Vermilion Counites. Brief or less destructive touchdowns were reported in Christian, Coles, Edgar, Piatt, and Grundy Counties. The two deaths were in mobile homes, one in Decatur (Macon County) about 2:40 p.m. CDT, the other near Tolono (Champaign County) at 3:48 p.m. CDT. At Decatur over $3 million in damage was reported. Other hard-hit communities included Anchor (McLean County) and Bismarck (Vermilion County).

INDIANA

The largest tornado outbreak in Indiana history occurred during the afternoon and early evening hours of April 3. At least 20 tornadoes caused 49 fatalities, 768 injuries, and property losses to 5,966 families. There was a brief tornado touchdown at 9:30 a.m. CDT in an open field in Boone County; however, the major outbreak began about 2:20 p.m. CDT in the southcentral part of the State and ended shortly before 8:00 p.m. in the northeast. In all, 39 counties had damage (compared with 20 counties that had damage during the Palm Sunday storms of 1965, which killed three times as many people in the State). Nine people were killed in mobile homes. Most of the tornadoes in Indiana moved at speeds of 50 to 60 mph and several were visually observed to have multiple funnels.

Table 2.—Tornadoes of April 3-4, 1974*

Category	Total	Ala.	Ga.	Ill.	Ind.	Ky.	Mich.	Miss.	N.C.	Ohio	S.C.	Tenn.	Va.	W. Va.
Persons														
Dead	335	86	17	2	49	77	3		7	41		50	2	1
Injured	6,142	949	104	30	768	1,377	20	1	74	2,138	1	635	13	32
Hospitalized	1,183	296	37	14	203	280	6		17	162		155	1	12
Dwellings														
Destroyed	7,512	1,078	67	51	1,454	1,522	50	1	45	2,756		443	1	44
Major damage	5,946	780	97	40	1,420	1,520	30	25	46	1,362	6	498	38	84
Minor damage	8,390	1,076	88	49	2,004	1,552	60	8	103	2,201	3	986	169	91
Mobile homes														
Destroyed	2,091	421	78	4	584	484	45		79	74	4	276	9	33
Major damage	909	142	40	2	208	239	20	2	43	87	3	85	5	33
Farm buildings														
Destroyed	3,996	719	92	18	889	1,575	70	1	33	134	2	436	7	20
Major damage	2,871	299	55	2	754	1,231	85	30	9	54		340	5	7
Small business														
Destroyed or major damage	1,427	205	10	2	232	230		1	5	639	1	85		17
Families suffering loss	27,590	3,728	421	158	5,966	6,625	200	50	347	6,959	17	2,436	391	292

* Casualty and damage survey by American Red Cross.

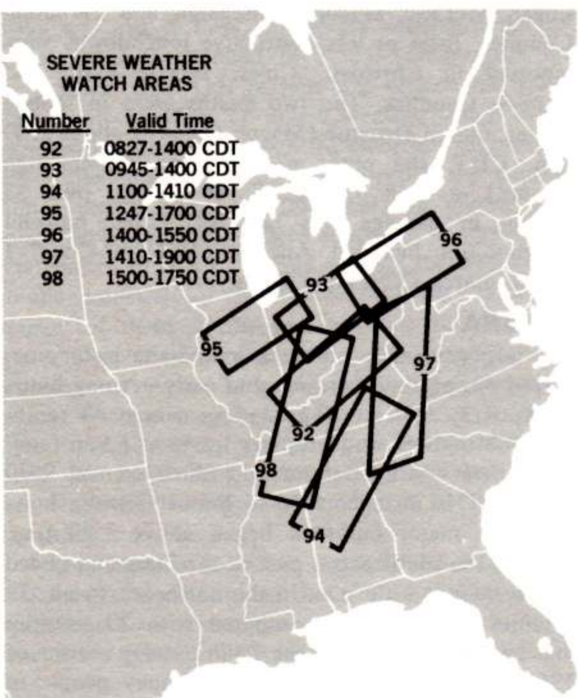


FIGURE 1.—Severe Weather Watch areas, numbers 92–98.

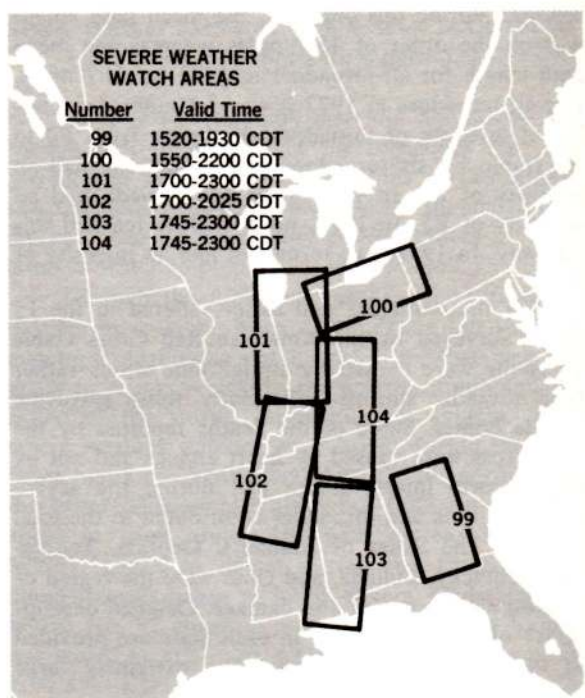


FIGURE 2.—Severe Weather Watch areas, numbers 99–104.

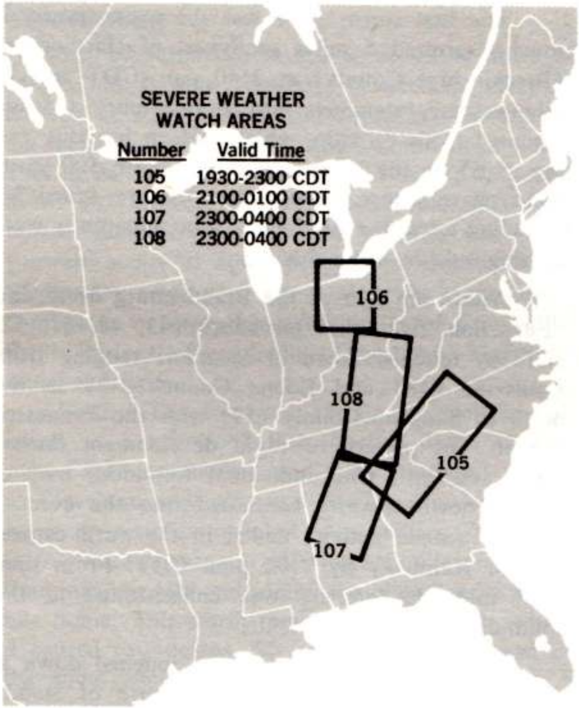


***FIGURE 3.**—Severe Weather Watch areas, numbers 105–108.*

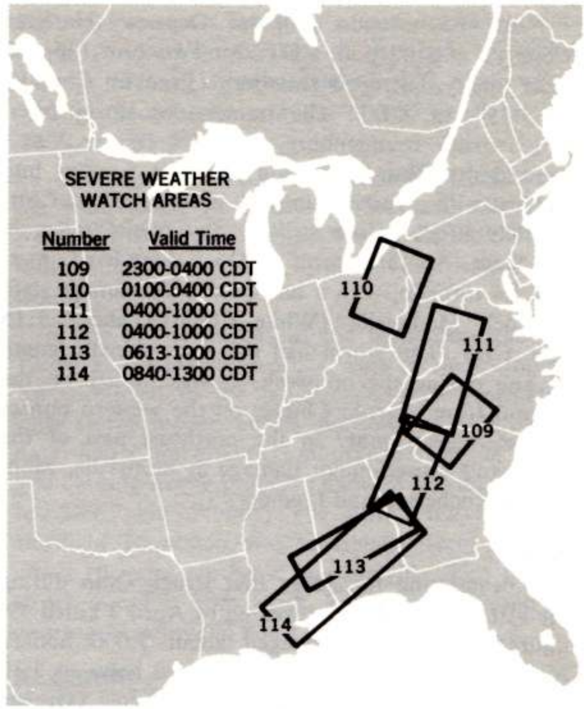


***FIGURE 4.**—Severe Weather Watch areas, numbers 109–114.*

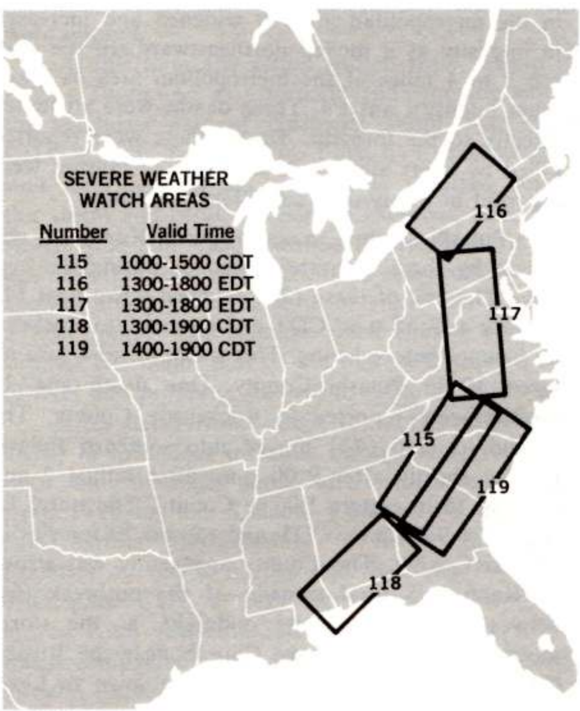


FIGURE 5.—Severe Weather Watch areas, numbers 115–119.

***FIGURE 6.**—Total area covered by Severe Weather Watch areas, numbers 92–119.*

An F5 tornado (40) hit Depauw (Harrison County) at 2:43 p.m. CDT. An F4 storm (36) almost totally destroyed Hamburg (Franklin County) at 3:35 p.m. CDT. The tremendous storm (47), which struck Brandenburg, Ky., at 4:10 p.m. CDT, crossed the Ohio River and travelled 5 miles into Indiana with a force estimated at F4 to F5, but fortunately lifted before striking any communities in the State. Another storm (13)—a long-lived, massive F4 tornado, with a half-mile wide damage path —struck Monticello (White County) about 5:15 p.m. CDT. This storm had the greatest path length of any during the outbreak. It was mostly on the ground from Warren County on the western border to LaGrange County in the northeast part of the State, and caused major damage at Rainsville, Monticello, Rochester, and Ligonier.

OHIO

The devastating tornadoes that struck Ohio during the afternoon and early evening of April 3 killed 39, injured 2,000, and damaged about 7,000 homes. Most of the tornado activity occurred between 3:30 and 5:30 p.m. CDT. Hardest hit was Xenia (Greene County), where one of the most intense tornadoes of the outbreak (37) roared in shortly after 3:30 p.m. CDT (4:30 p.m. EDT), leaving in its wake over 30 dead, more than 1,100 injured, and more than 1,000 homes destroyed. The damage path varied in width from one-quarter to one-half mile. This storm lifted near Plattsburg, but subsequent tornado touchdowns (38 and 39) occurred in its projected path through sections of Clark, Madison, and Franklin Counties.

Less than an hour later, between about 4:30 and 5:10 p.m. CDT, other tornadoes (43, 44, and 45) struck the western and northern portions of the greater Cincinnati area. Twin funnels were reported for two of these storms. These tornadoes caused four deaths, two in mobile homes.

Weaker tornadoes (23, 25, 27, 50, and 55) were reported between 7:00 and 7:30 p.m. CDT in Paulding, Putnam, Brown, and Adams Counties.

KENTUCKY

Between 3:40 p.m. CDT April 3 and midnight, at least 26 vicious tornadoes struck Kentucky—in the worst storm disaster in the State's history. These tornadoes killed 71 persons, injured 1,377, and caused damage estimated at $110 million. Losses were sustained by 6,625 families, and between 1,800 and 2,000 of the State's farms were damaged to some extent. The tornadoes affected 39 counties within a strip some 150 miles wide extending from north to south through the central part of the State.

The first storm (47) was the most severe. It touched ground 5 miles southwest of Hardinsburg (Breckinridge County) at 3:40 p.m. CDT and 30 minutes later slammed into Brandenburg (Meade County). This tornado, which had an intensity rating of F5 on the Fujita scale and a path 500 yards wide where it tore through Brandenburg, killed 31, including a number of children who apparently were playing outside after school.

Within an hour of the Brandenburg death and destruction, five other tornadoes (43, 48, 51, 52, and 59) touched down at locations ranging from Louisville (48) and Boone County (43) in the north to Simpson County (59) near the Tennessee border. The pattern of rapid development farther south and east, with individual tornadoes moving rapidly northeastward, continued into the evening hours. Tornado activity ended in the north-central part of Kentucky by 7:00 p.m. CDT. From then until midnight, activity was concentrated in the south-central part of the State.

The Louisville tornado (48) touched down at 4:37 p.m. CDT one-quarter mile north of Standiford Field. It was witnessed by National Weather Service employees at the Weather Service Forecast Office. This storm was on or close to the ground as it travelled through 10 miles of residential property in the metropolitan area. It widened and increased in intensity as it moved northeastward. In the eastern 3 to 4 miles of the metropolitan area its maximum intensity was F4. Three deaths were attributed directly to the tornado. Three others were reported killed by heart attacks. A total of 225 injuries were reported in Louisville and Jefferson County.

Pulaski County, in south-central Kentucky, was struck by three separate tornadoes during the evening. The first of these (74) touched down near Mt. Victory at 7:55 p.m. CDT and moved into Rockcastle County before lifting. This storm killed 6 and injured 30 in Pulaski County. One death and 10 injuries were reported in Rockcastle County. The second tornado (73) moved into southern Pulaski County shortly after 9:00 p.m. after killing 2 and injuring 16 in eastern Wayne County. The storm hit Alpine at 9:20 p.m. CDT and caused 29 injuries in Pulaski County. The County apparently was struck by Kentucky's final tornado of the outbreak (64) between 11:30 p.m. and midnight, as the storm moved from Piney Grove Church near the Russell County line through Nancy and Bobtown to Level Green (in Rockcastle County).

Killer storms also were reported in Boyle, Clinton, Franklin, Hardin, Madison, Nelson, Simpson, and Warren Counties.

TENNESSEE

At least 28 tornadoes lashed some 19 counties of Middle and Eastern Tennessee between the early afternoon of April 3 and 1:00 a.m. CDT the following morning—in the worst single outbreak of tornadoes in the State's history. The storms left 42 people dead, 635 injured, and caused approximately $30 million damage. Much of the business section of Etowah, a city of 5,800 people, was destroyed late Wednesday afternoon. There also was considerable damage in or near the communities of Cookeville, Estill Springs, Fayetteville, Cleveland, Maryville, Blair, and Erin.

Eastern Tennessee was the first to feel the outbreak, as a tornado (100) touched down at 2:00 p.m. CDT and moved across the southeast section of Cleveland and into rural Bradley County, resulting in property damage but no casualties. Two hours later, a second tornado (104) struck Cleveland, this time injuring 100 and killing the occupant of a mobile home. This storm moved on to Etowah, where it caused two deaths, 50 injuries, and left most of the town's business area in ruins. Meanwhile, a small tornado had touched down briefly about 3:00 p.m. CDT just northeast of Maryville (Blount County), injuring one person. At 5:00 p.m. CDT separate and brief tornado strikes were reported in Monroe County and Loudon County where two were injured.

At this time, the action shifted from eastern to middle Tennessee, as a tornado (65) moving across the southeast part of Nashville about 5:18 p.m. CDT heavily damaged the Edge o' Lakes subdivision. One heart attack victim was reported during this storm and property damage exceeded $500,000. About 6:00 p.m. CDT, two more tornadoes (66 and 81) occurred, one about 25 miles east-northeast and another about 35 miles south of Nashville, but only a few injuries and damage were caused by these storms. The major part of the outbreak, with its toll of lives and property, was yet to come to Tennessee.

After dark, from sunset to shortly after midnight, 18 tornadoes travelled through a narrow corridor, only 50 miles across at its widest, stretching from Franklin and Lincoln Counties on the Alabama border northeastward to Pickett and Scott Counties on the Kentucky line. Between 7:45 and 8:45 p.m. CDT a very destructive storm (90) moved from Alabama into Tennessee. This storm was accompanied along part of its path by a second tornado (92). Eleven people were killed and 121 injured in Lincoln and Franklin Counties. Between 8:00 and 9:00 p.m. CDT, 9 persons were killed and 1 died of a heart attack as a tornado (82) swept through Putnam County southeast of Cookeville; 7 died in Fentress County as a tornado (84) passed south of Jamestown; and 5 perished in Pickett County as two other tornadoes (72, 75) moved through Moodyville and the Caney Creek area to the Kentucky border.

Between 11:00 p.m. and midnight CDT, 3 people were killed in mobile homes and 120 others were injured by a storm in Overton County. Twenty more were injured as a tornado (79) struck Scott County.

The last tornadoes of the night occurred near 12:30 a.m. CDT on April 4. One of these, tornado 88, occurred in the main corridor of destruction. This storm moved across portions of White, Putnam, and Cumberland Counties, injuring 28 people and causing heavy property damage in Pleasant Hill, Mayland, and Woody. The other, the last killer storm in Tennessee, was an isolated tornado (101) about 10 miles northeast of Knoxville. This tornado struck a mobile home park, killing two children and injuring 21 people in Knox County.

ALABAMA

During the late afternoon and evening hours of April 3, at least eight tornadoes, including four extremely intense and long-lived storms, brought death and unequalled storm destruction to Alabama. Eighty-six persons were killed, 949 were injured, and damages exceeded $50 million. Sixteen counties in the northern part of the State were hit the hardest.

The activity began about 4:30 p.m. CDT, when a brief tornado touchdown (99) caused damage, but no casualties, in the Concord area 8 miles west of Birmingham. Less than an hour later, another tornado strike (112) caused tree and powerline damage 8 miles west of Jacksonville (Calhoun County). About 6:30 p.m. CDT a third tornado (108) hit Cherokee County, injuring 20 persons, while even more powerful storms were spawning farther to the northwest.

Alabama's major tornado activity began when a storm (90) touched ground near Newburg (Franklin County) at 6:30 p.m. CDT and plowed viciously northeastward. This tornado moved on the ground continuously for 85 miles in Alabama before it entered Tennessee. Reports at the time described it as "big and powerful and taking everything in its path." Severely damaged were rural areas of northern Lawrence County, the communities of Tanner, in Limestone County, and Harvest and Hazel Green, in Madison County. This tornado entered Limestone County about 7:05 p.m. CDT. At 7:35 p.m. CDT, in nearly the exact point of entry near the Tennessee River, a second major tornado (91) set down and followed the first tornado. Its 20-mile-long path varied from that of its predecessor by only a block to less than 2 miles. This storm struck hard and hindered rescue units moving into the area. Many communities were hit twice in 30 minutes. Well over half of Alabama's storm deaths and many of the injuries were dealt by these two tornadoes, which killed 55, injured 408, and caused destruction or heavy damage to over 1,100 buildings, more than 200 mobile homes, and numerous motor vehicles.

Even as these storms were occurring, other tornado activity was taking place farther south. At 7:00 p.m. CDT, a tornado (97) touched down 5 miles north of Aliceville (Pickens County) and moved almost continuously on the ground for nearly an hour before hitting Jasper (Walker County) at 7:58 p.m. CDT. It then began a skipping path northeastward and heavily damaged a four-block area in southeast Cullman about 8:40 p.m. This storm finally lifted over northeast Cullman County, leaving 3 dead and 178 injured.

As this tornado was dissipating, the final storms of the outbreak began their havoc. Earlier, strong winds and large hail had hit Columbus, just over the line in Mississippi, and a funnel cloud was sighted at Starkville, Miss. At 8:50 p.m. CDT a very powerful tornado (95) touched down 6 miles north of Vernon (Lamar County) and produced a path of destruction toward the northeast. It moved through Guin (Marion County) about 9:04 p.m. CDT, killing 23 and injuring 250 in the area. In Winston County, it left Delmar with 5 dead and heavy damage. In the Bankhead National Forest, it bit into deep gorges and exposed ridges and destroyed much timber. Shortly after this the tornado lifted, but another tornado (96) moved northeast to strike south Huntsville at 10:50 p.m. CDT. There was severe damage at the Redstone Arsenal and in south Huntsville. Staff members at the Weather Service Office in Huntsville were forced to temporarily abandon their hectic duties. Shortly after 11:00 p.m. CDT, this final storm of the outbreak in Alabama moved across Monte Sano (elevation 1,640 feet) just east of Huntsville, and broke up over western Jackson County. The final two tornadoes killed 28, injured 332, and destroyed or heavily damaged over 850 buildings, 250 mobile homes, and 60 small businesses.

GEORGIA

At least 7 tornadoes affected 13 northern Georgia counties during the outbreak. These tornadoes struck in two separate waves during the afternoon and evening hours. Though moving mostly through relatively lightly populated rural areas, these storms took a toll of 16 lives and caused 104 injuries and approximately $15 million damage.

The first tornado (113) struck about 2:00 p.m. CDT near the community of Cherry Log, located just northeast of Ellijay in Gilmer County, and moved across the eastern edge of Blue Ridge Lake in Fannin County. Five persons were injured and severe damage, estimated at $800,000, occurred to homes, trees, and utilities in its path.

After a break of several hours, activity began again. About 6 p.m. CDT another tornado (114) moved across Haralson County and caused one death just east of Buchanan. It then continued northeastward through Paulding County and curved north-northeastward into Bartow County, just west of Lake Allatoona. This storm caused 20 injuries and damage estimated at $2 million. The discontinuous path of damage indicates this storm may have originated in Cleburne County, Alabama.

While this tornado was still on the ground, another storm (109) touched down about 6:40 p.m. CDT just southwest of Sugar Valley community (Gordon County). This tornado passed through Resaca and into portions of Whitfield and Murray Counties and lifted about 7:20 p.m. CDT. It killed 9, injured 54, and caused damage estimated at $4.3 million.

Between 7:30 p.m. and 8:30 p.m. CDT, another killer tornado (115) moved through portions of Pickens, Cherokee, and Dawson Counties, causing 6 deaths, 30 injuries, and property damage estimated at $2 million. During the evening two more tornadoes (110 and 111) hit sections of Fannin County. One of these (111) moved on to cause deaths in Murphy, N.C. At 9:00 p.m. CDT, a tornado (116) touched down briefly near Dillard (Rabun County) in the extreme northeast corner of the State, and caused an estimated $90,000 damage to homes, businesses, trees, and utilities.

OTHER STATES

In addition to the tornado activity discussed above, tornadoes and/or severe thunderstorms wrought havoc to a lesser degree in a number of other States during the outbreak. Affected were Missouri, Michigan, Mississippi, New York, West Virginia, Virginia, North Carolina, and South Carolina.

Preceding the major tornado outbreak, a very severe thunderstorm struck St. Louis, Mo., about 1:05 p.m. CDT on April 3. This storm, which had high winds and hail the size of baseballs, caused 25 injuries and a record $45 million in damage.

Michigan was affected by several types of severe weather. Heavy snow and freezing rain hit portions of the upper peninsula, flash flooding from thunderstorm downpours washed out roads and a bridge in Sanilac County, and damaging wind gusts were reported in St. Clair County. The major activity came between 7:30 and 9:30 p.m. CDT, when tornadoes struck parts of six southeastern counties. The most severe of these entered the State from Indiana about 7:30 p.m. CDT, causing intermittent damage in southeast Branch County and southwest Hillsdale County, then continuous damage from just west of Hillsdale to just west of Clark's Lake (Jefferson County) where it lifted. This storm accounted for Michigan's two deaths and 31 of 37 reported injuries. The two deaths and 27 of the injuries were in mobile homes. Weaker tornadoes were reported later in southeast Hillsdale County and from Monroe County into south Detroit (Wayne County). One of these storms killed eight persons in Windsor, Ontario.

Severe activity was reported in Mississippi between 5:00 p.m. and 11:00 p.m. CDT, including one tornado and several funnels aloft. Large hail and local wind damage affected six counties in the extreme eastern part of the State. The tornado (98) skipped across Jones County around 5:00 p.m. CDT to cause one injury and damage estimated at $150,000.

In New York, a small tornado (46) struck about 10:00 p.m. CDT. This tornado caused minor damage to the business section of Frewsburg (Chatauqua County).

North Carolina had two separate periods of severe activity. The first wave struck between 8:00 and 10:00 p.m. CDT. At least three tornadoes caused six deaths and many injuries in the extreme western counties. The communities of Stecoah (Graham County) and the Bealtown section of Murphy (Cherokee County) were in the paths of these storms. About 9:00 a.m. CDT the following morning, Cherokee County again had tornado activity. Brief touchdowns were reported at Marble and Brasstown. At the same time, 140 miles to the east-northeast, a skipping tornado injured several persons and caused damage south of Lenoir (Caldwell County).

While South Carolina recorded no tornadoes, a series of severe thunderstorms invaded the northwest part of the State during the afternoon and early evening. Communities damaged included Travelers Rest, Campobello, Pickins, Spartanburg, and Greenville, where three injuries occurred.

During the predawn hours of April 4, a squall-line struck West Virginia and extreme western Virginia. It moved eastward as the morning progressed. The area south and east of Beckley, W. Va., was struck by several tornadoes between 4:00 and 5:00 a.m. CDT. Thirty-two persons were injured and a child in a mobile home was killed by these storms.

In Virginia, damage was widespread, with 19 counties affected by severe thunderstorms or tornadoes. At least four tornadoes occurred. One of these (124) struck near Saltville (Smyth County) about 3:30 a.m. CDT April 4, where it caused property damage but no injuries. Another (126) touched down about 5:00 a.m. CDT just outside Roanoke near Salem (Roanoke County). This storm caused over $500,000 damage,. including extreme damage to two apartment houses. Virginia's single death occurred when a thunderstorm gust destroyed a mobile home in Washington County before sunrise.

Chapter 3

The Warning System

The survey team examined all phases of the total warning system, from the production phase, performed at the various NOAA offices, through the communications and dissemination stages, including the efforts of the mass media, to the public response phase at the community and individual level. The following sections describe the results of this examination.

PRODUCTION

The production portion of the total warning system is based on three components: observations and analyses, forecast preparation, and warning preparation. These components are linked by various communication systems. Coordination among the components is an important part of the production subsystem.

The observations, of which there are thousands each day, come from regular observing locations including NOAA's Weather Service Offices, Department of Defense installations, and FAA-manned stations; special stations and networks, such as spotter groups, cooperative observers, and law enforcement officials; radar stations and upper air observing sites; and satellite platforms with various types of imagery which are analyzed and interpreted by specialists in NOAA's Satellite Field Service Stations (SFSSs). The basic severe weather forecasts, termed Severe Thunderstorm Outlooks, Severe Thunderstorm Watches, and Tornado Watches, are prepared by the Severe Local Storms Unit (SELS) of the National Severe Storms Forecast Center (NSSFC) in Kansas City. NSSFC also contains the Radar Analysis and Development Unit (RADU), which is responsible for collecting and correlating all the radar reports throughout the Nation and preparing a composite plot of these each hour. Weather Service Forecast Offices (WSFOs) and Weather Service Offices (WSOs), each with designated county areas of responsibility, are charged with tailoring the severe weather forecasts for local use and for the preparation and issuance of severe weather warnings. Much of the coordination required in this activity was performed by the Regional Warning Coordination Centers (RWCCs) located in each of the NWS regions.

The following sections discuss how the system operated during the period from April 2 to April 4.

Early Actions (8:00 a.m. CDT April 2 to 8:00 a.m. CDT April 3)

The potential threat of the storm system was recognized well in advance. As early as 8:30 a.m. CDT on April 2, the Kansas City Satellite Field Service Station requested that the ATS-3 satellite be operated in a Severe Weather day mode (requiring more frequent satellite photographs) on April 3. Later that morning, the National Severe Storms Forecast Center alerted all Central Region Offices having network radars that latest numerical prognoses indicated any necessary maintenance should be done that day. Discussions were held with the RWCC in Fort Worth and a similar alert went from that office to Southern Region field offices.

During the afternoon of April 2 SELS requested special "midnight" upper air observations from 12 rawinsonde and 11 pibal stations for 0600 GMT on April 3. (Scheduled upper air observations are taken at 0000 and 1200 GMT.) The developing storm also was causing forecasters concern as to placement and timing of high wind and heavy snow warnings from sections of the Rockies and Plains States into the Upper Mississippi Valley, as well as marine advisories along the Gulf Coast. The extra observations were subsequently used to better define the warnings and advisories. (Special Weather Bulletins on the major spring storm were begun the morning of the 2d and written each 6 hours thereafter by the RWCC in Kansas City, with emphasis being placed on the heavy snow warnings and travelers advisories.)

In the evening hours of the 2d SELS issued tornado watches for portions of Texas, Oklahoma, and Arkansas. Warnings were issued and some severe weather was reported but activity was quite minor when compared with the outbreak to come.

Shortly after midnight, the SELS forecaster was closely watching developments and timing a line of pressure rises moving rapidly eastward across central Texas. Around 4:00 a.m. CDT, April 3, Tornado Watches 90 and 91 were issued for portions of Texas, Louisiana, Arkansas, Missouri, Kentucky, Tennessee, and Mississippi. A few warnings were issued for portions of these areas during the early morning, but the necessary ingredients for widespread severe weather were still lacking. (One of the watches was cancelled shortly after 7:00 a.m. CDT, the other expired at 9:00 a.m.)

Meanwhile, using all available guidance, produced by the National Meteorological Center (NMC) at Suitland, Md., late data and analyses, and locally prepared forecasts, the assistant SELS forecaster was formulating the 24-hour severe weather outlook for the period beginning at 7:00 a.m. CDT. Normally sent at 4:00 a.m. CDT, this outlook was delayed by the tornado watches the morning of the 3d and was transmitted at 4:19 a.m. The outlook indicated scattered, as opposed to the more usual few, severe thunderstorms and read as follows:

SCATTERED SEVERE THUNDERSTORMS EXPECTED TODAY AND TONIGHT FROM NORTHEAST TEXAS ACROSS ARKANSAS, SOUTHEAST MISSOURI, ILLINOIS, INDIANA, OHIO, WEST VIRGINIA, KENTUCKY, TENNESSEE, WESTERN VIRGINIA, WESTERN NORTH CAROLINA, EXTREME NORTHWEST SOUTH CAROLINA, NORTHERN AND CENTRAL ALABAMA, NORTHERN AND CENTRAL MISSISSIPPI, NORTHERN HALF LOUISIANA, AND NORTHWEST GEORGIA. STRONG LOW PRESSURE AREA EXPECTED INTO NORTHEAST MISSOURI BY 0000Z WITH COLD FRONT SOUTHWARD THROUGH EASTERN ARKANSAS AND LOUISIANA. STRONG SOUTHERLY WINDS WITH COOLING ALOFT EXPECTED TO GIVE SEVERE THUNDERSTORMS . . . WITH ACTIVITY SPREADING EASTWARD DURING THE PERIOD.

The area outlook included practically all the tornado and severe thunderstorm activity which occurred in that 24-hour period.

The SELS midnight shift also requested special "noon" rawinsonde and pibal observations for 1800 GMT on April 3, from stations in Tennessee, Louisiana, Mississippi, Alabama, Georgia, North Carolina, and Illinois.

The severe weather outlook issued by SELS is routinely given nationwide public distribution through the SKYWARN presentation on the NBC TODAY show each morning. It also is incorporated into State, zone, and local forecasts as the forecasters in the WSFOs adjust the outlook for timing, etc., for their areas of responsibility. Some mention of severe or locally heavy thunderstorms was made in the early morning State forecasts issued for Illinois, Indiana, Mississippi, Tennessee, and Kentucky.

At 6:30 a.m. CDT, WSO Peoria entered a thunderstorm outlook on the Illinois NOAA Weather Wire Service (NWWS) to the effect that a few severe thunderstorms were expected that day over Illinois and southeast Missouri. At 7:45 a.m. CDT, WSFO Cleveland sent the following message on the Ohio NWWS:

TO RADIO AND TV NEWS DIRECTORS FOR INTERNAL PLANNING ONLY AND NOT FOR BROADCAST . . . . SCATTERED SEVERE THUNDERSTORMS EXPECTED TODAY AND TONIGHT ACROSS MOST OF OHIO.

Especially noteworthy are the advance public issuances made by WSFO Birmingham during the early morning of the 3d. While the Alabama State forecasts issued at 4:45 a.m. CDT had no mention of severe thunderstorms, by the time the zone forecasts were released at 5:00 a.m., the northern and western zone forecasts made mention of the possibility of locally severe thunderstorms by evening. The Alabama Weather Summary issued at 5:40 a.m. read, in part:

ALABAMA READY FOR ANOTHER BOUT WITH THUNDERSTORMS

THUNDERSTORMS WILL OVERSPREAD ALABAMA FROM THE WEST THIS AFTERNOON AND TONIGHT AND SOME OF THEM COULD BECOME SEVERE. THE SITUATION WILL BE WATCHED CLOSELY TODAY AS THUNDERSTORMS ENTER NORTHWEST ALABAMA THIS AFTERNOON AND SPREAD EAST AND SOUTHEAST OVER THE STATE THIS AFTERNOON AND TONIGHT. THEY WILL BE LOCALLY HEAVY OVER MOST OF THE STATE WITH THE HEAVIEST ONES LIKELY OVER THE NORTH AND CENTRAL COUNTIES.

THE LATEST DEVELOPMENTS ARE BLAMED ON THE STRONGEST STORM SYSTEM OF THE SPRING SO FAR. THE DEEP LOW IS CENTERED OVER KANSAS THIS MORNING MOVING NORTHEAST . . .

At 6:00 a.m. CDT, this was followed by a historical weather feature containing information that April 3 was the anniversary of killer tornadoes which hit Saugatuck, Mich., in 1956 and Wichita Falls, Tex., in 1964.

By 8:00 a.m. CDT April 3 most of the NOAA warning system was ready and portions of the mass media had been alerted. Local officials in some areas and some of the general public had received word that severe thunderstorms were expected. The more precise watches and warnings were yet to come.

The Prelude (8:00 a.m. CDT to noon CDT April 3)

By 8:00 a.m. CDT showers and thunderstorms were apparent from eastern Illinois and western Indiana southward to northern Mississippi, and by 8:35 a.m. a line of heavy thunderstorms stretched from near Terre Haute, Ind., to near Hopkinsville, Ky., and on southward into extreme northeast Mississippi. This line moved very rapidly northeastward to extend by noon from northwest Ohio to eastern Kentucky, through the northeastern portions of middle Tennessee, and into northeast Alabama. Meanwhile other strong thunderstorms were developing from near St. Louis, Mo., to near Springfield, Ill., and a few heavy cells were building in western Kentucky, near the Illinois border.

At 8:23 a.m. CDT, SELS transmitted their preliminary notification to all offices that Severe Thunderstorm Watch Number 92, valid from issue time until 2:00 p.m. CDT, would be issued for portions of southeast Illinois, southern Indiana, northern Kentucky, southwest Ohio, and western West Virginia. This Watch, which included the information that portions of the watch area might require later upgrading of storm intensity, was issued at 8:27 a.m. and transmitted at 8:34 a.m. Appropriate offices issued redefining statements and revised their State, zone, and local forecasts to include severe thunderstorms, if this had not already been done. The Watch issuance was also the signal that each office with county warning responsibility would also prepare periodic statements on the progress (or lack thereof) of severe weather in its area. (This pattern of watch issuance, preparation of redefining statements, revision of forecasts, and release of periodic severe weather statements was to be repeated 22 times in the following 24 hours, with field offices in two or more States involved each time.)

Shortly after 9:00 a.m. CDT, as the leading line of heavy thunderstorms was approaching central Indiana, the WSFO at Indianapolis used a precut tape on the Indiana Weather Wire to give rapid preliminary advice that a severe thunderstorm warning would be issued for Indianapolis and some counties (unnamed) in the area. Before they were able to clarify this warning, radar gave indications of a possible tornado over northeast Boone County, a short distance north-northwest of Indianapolis. A tornado warning was issued at 9:20 a.m. CDT, for four counties in the path of this storm, and a call from the State Police confirmed a touchdown at 9:30 a.m. CDT somewhere between Lebanon, Ind., and Route 31, but this was in open country and damage was not reported. The severe thunderstorm warning for Indianapolis and six counties to the south of the area included in the tornado warning was issued at 9:25 a.m. CDT. Hail up to 1 inch in diameter was reported in the area.

At 9:44 a.m. CDT, SELS issued Tornado Watch Number 93, valid from issue time until 2 p.m. for portions of northern Indiana, northwest Ohio, extreme southeast Michigan, and western Lake Erie. At 10 a.m. CDT, severe thunderstorm warnings were issued by WSOs in Fort Wayne, Ind., and Huntsville, Ala., and at 10:10 a.m., SELS issued Tornado Watch Number 94, valid from 11 a.m. until 4 p.m. CDT for portions of northeast Mississippi, northern Alabama, extreme northwest Georgia, middle and eastern Tennessee, and southern Kentucky. Two border counties in southwest Virginia were within the outlined area, and were included in a redefining statement issued by WSO Richmond following coordination calls involving that office, Eastern Region RWCC, and SELS.

At 10:45 a.m. CDT, WSO Toledo issued a tornado warning for six Ohio counties based on a report of a tornado in Van Wert County relayed to them by the State police. Subsequent investigation showed minor damage, primarily to trees and probably due to straight-line thunderstorm winds. Between 10:15 a.m. and noon, the leading line of heavy thunderstorms, being monitored by radar and satellite, had resulted in five other severe thunderstorm warnings for 27 counties stretching from sections of Indiana and Ohio into Georgia and Alabama. The Suitland SFSS was keeping warning offices in Ohio and West Virginia posted on the rapid movement of this line. Meanwhile, the western line developing over Illinois had prompted warnings for three counties in that State, and satellite pictures at the Kansas City SFSS were showing the beginning of a third line of activity in Kentucky.

To recap: by noon, portions of 11 States were included in tornado or severe thunderstorm watch areas; two tornado warnings and nine severe thunderstorm warnings had been issued; numerous State, zone, and local forecasts had been updated to include mention of severe activity; and the constant stream of status reports, severe weather statements, and reports of severe weather was underway. All radar stations in the affected area were in operation, and most of them were already quite busy issuing coded and narrative radar reports and calling warning offices in their coverage area. Satellite pictures were being received and analyzed by the SFSSs in Kansas City and Suitland, and movie loops and interpretation messages for input to the SELS unit and field offices were being prepared.

The Mammoth Outbreak (noon to midnight April 3)

Although severe thunderstorms developed in Indiana as early as mid-morning on April 3, and hail the size of golf balls was reported in South Carolina as late as the evening of the 4th, most of the tornadoes and resulting deaths and destruction occurred in the 12-hour period between noon and midnight on the 3d. In this 12-hour period, NOAA offices in 18 States issued more than 150 tornado warnings or extensions, over 100 severe thunderstorm warnings, 15 tornado watches and associated redefining statements, and countless severe weather statements, all-clear bulletins, flash-flood watches and warnings, radar summaries, and updated forecasts. This vast output is even more remarkable when it is noted that almost three-fourths of the tornado warnings were released in the 6-hour period between 2:00 p.m. and 8:00 p.m. CDT. In the hour between 7:00 and 8:00 p.m., 26 tornado warnings or extensions were issued for sections of nine States. Table 3 gives the time distribution, and figure 7 the geographic area (by counties), for warnings issued April 3–4, 1974.

Special mention must be made of the outstanding performance of WSFO and WSO staffs during the outbreak. Many people worked long hours, some with little break following the severe weather outbreak of April 1–2. While most offices were adequately staffed for a normal severe weather situation, the extent, number, and speed of movement of storms on April 3-4 strained the system, particularly in some of the smaller offices. When asked what he would do differently for the next tornado outbreak, one MIC at a WSO replied, "Nothing except call in one more man." Even though hard-pressed, station staffs reacted swiftly and effectively.

The widespread and rapidly-developing severe storm activity also put added stress on NSSFC. Most of the tornadoes were in valid watch areas, but of the 14 watches issued between 8:27 a.m. and 7:30 p.m. April 3, 10 were "current" watches, that is, they were valid at time of issuance. The longest lead time for watches in that period was 50 minutes. In addition, a substantial problem was the difficulty experienced by the warning offices, as well as mass-media personnel and wire-service editors, in keeping up with the great number of watches. As seen in table 4, several States were simultaneously affected by three or even four tornado watches during the late afternoon and early evening. Overlapping of watch areas also contributed to the confusion.

Table 3.—Time distribution of tornado and severe thunderstorm warnings issued April 3-4, 1974

Hour beginning at (CDT)	Tornado warning	Tornado warning extended	Severe thunderstorm warning
April 3			
09	1		1
10	1		4
11			4
12	1		8
13	2		6
14	10	1	9
15	21	1	12
16	19	1	10
17	24	2	13
18	15	2	9
19	24	2	4
20	8		5
21	10		8
22	3	1	3
23	11	1	12
April 4			
00	1		8
01	3		5
02	3		5
03	1		4
04	1		2
05			2
06	2		
Subtotal:	161	11	133
	(Total: 305)		

Coordination and cooperation between NSSFC, the RWCCs, and field offices was very good, considering the time pressure imposed by the outbreak. Some problems did occur, but these were mostly minor and mainly due to lack of faster communications channels between these offices. In situations involving more than one squall line, there is always the danger of premature all-clear actions. This occurred once on April 3, but the involved office recovered rapidly, issued additional warnings, and no apparent harm was done.

An examination of individual warnings transmitted over NWWS during the outbreak indicates the value of drills and experience in the preparation of such warnings. Nearly all of the warnings were of high quality, understandable, and followed the

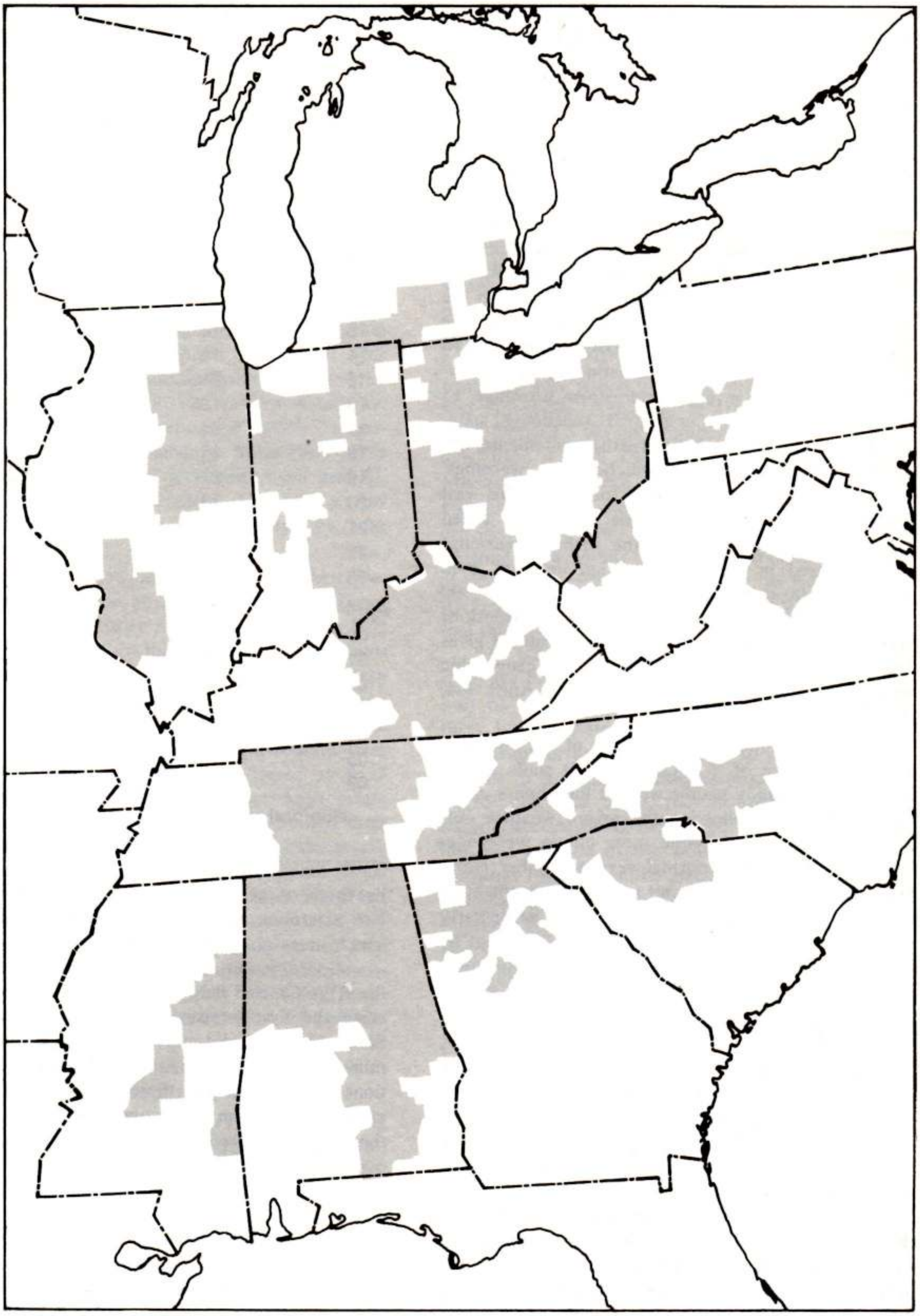


***FIGURE 7.**—Counties for which tornado warnings were issued April 3-4, 1974.*

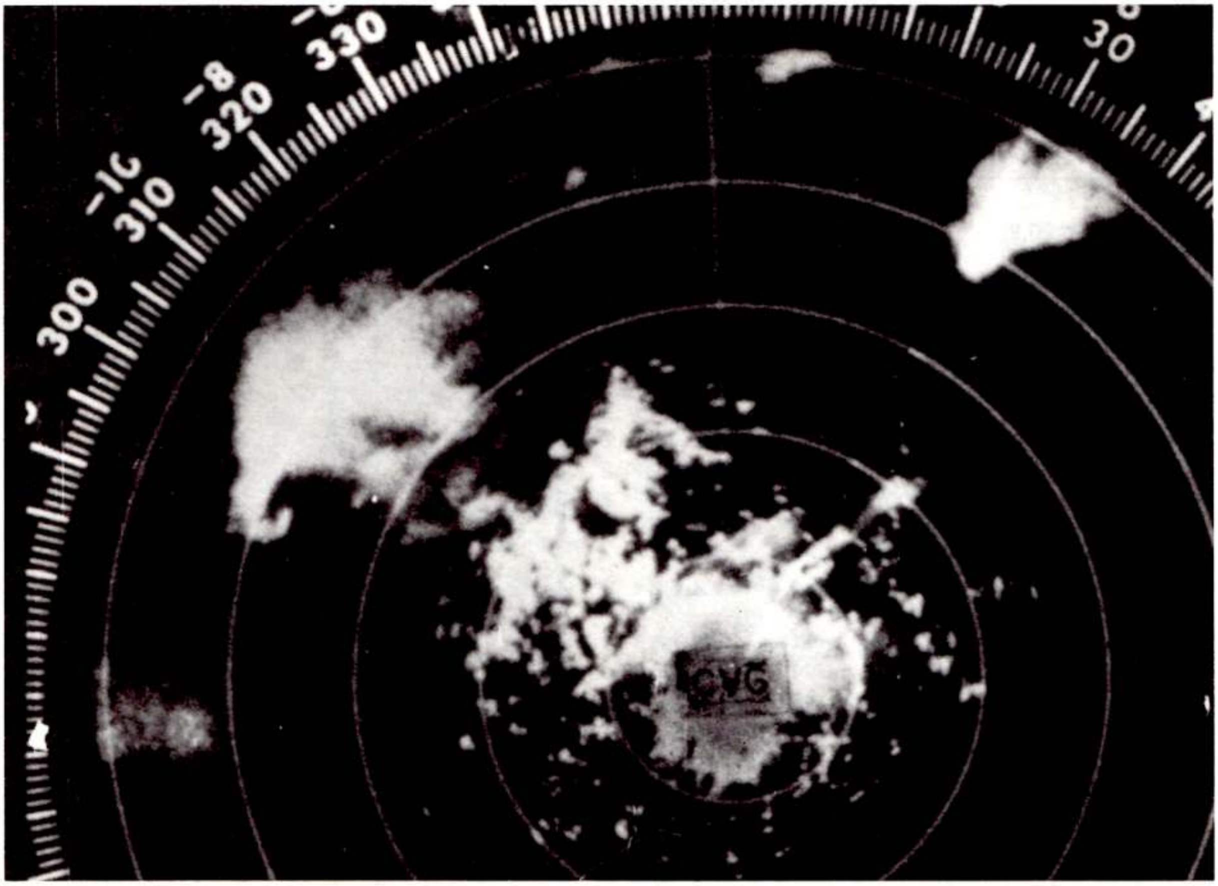


***FIGURE 8.**—Hook echo depicted on image of radar scope.*

prescribed format. In a few cases haste or inexperience resulted in poorly worded or incomplete warnings. Enough warnings were issued with incorrect times (both local and GMT) to indicate this needs added attention in some offices. It is encouraging to note that only one issuance, from the hundreds made during the outbreak, wrongly applied the terms "watch" and "warning."

The value of our network and local warning radars in issuing timely forecasts and warnings cannot be emphasized enough. More than half the warnings released were based on radar observations, rather than on visual sightings or reports of severe phenomena. In some cases the more reliable combination of visual sighting and radar tracking was utilized most effectively. More than 160 "hooks," or distinctive radar echoes frequently associated with tornadic activity, were reported during the outbreak. Not all hooks were associated with actual tornadoes on the ground, and every tornado could not be detected by this means, but warnings issued on the basis of hook echoes undoubtedly saved lives in Ohio, Kentucky, Alabama, and Tennessee. Figure 8 is an excellent example of a hook echo as depicted on a radar scope.

Warning offices get their radar information in one, or a combination, of several ways: direct accessibility to the radar set, use of radar remotes (termed WBRRs), or by using coded radar reports supplemented by telephone reports of significant storms from nearby radar stations. Warning offices with direct accessibility to radar had a distinct advantage during the fast breaking and moving storms of April 3. An excellent example of this was seen during the early afternoon in St. Louis. Although no watch had been issued for the area, the network radar gave indications of developing thunderstorms to the west and a severe thunderstorm warning was issued prior to the very damaging wind and hailstorm that struck the city. Local warning radars in Huntsville, Ala., and Louisville, Ky., were used quite effectively to indicate and track tornadoes, as were the larger network radars in Centreville, Ala., and Covington, Ky.

Table 4.—States affected and number of watches in each State

Date and time (CDT)	Watches in effect*	Fla.	Mo.	Ill.	Ind.	Mich.	Ohio	Penn.	N.Y.	W.Va.	Va.	Ky.	Ark.	Tenn.	Miss.	Ala.	Ga.	N.C.	S.C.
April 3																			
0827	#90,92		1	1	1		1			1		2	1	1					
0900	92			1	1		1			1		1							
0940	92,93			1	2	1	2			1		1							
1100	92,93,94			1	2	1	2			1	1	2		1	1	1	1		
1247	92,93,94,95			2	3	2	2			1	1	2		1	1	1	1		
1400	94,95,96			1	1	2	1	1	1	1	1	1		1	1	1	1		
1410	95,96,97			1	1	2	2	2	1	2	1	1		1			1	1	1
1500	95,96,97,98			1	2	2	3	2	1	2	1	2		2	1	1	1	1	1
1520	95,96,97,98,99			1	2	2	3	2	1	2	1	2		2	1	1	2	1	2
1550	95,97,98,99,100			1	3	2	3	2	1	2	1	2		2	1	1	2	1	2
1700	97,98,99,100, 101,102		1	2	4	2	4	2	1	2	1	4	1	3	2	1	2	1	2
1745–1750	97,99,100,101, 102,103,104	1	1	2	4	2	4	2	1	2	1	4	1	3	2	2	3	1	2
1900	99,100,101, 102,103,104	1	1	2	4	2	3	1	1	1		3	1	2	2	2	2		1
1930	100,101,102, 103,104,105	1	1	2	4	2	3	1	1	1	1	3	1	3	2	3	2	1	1
2025	100,101,103, 104,105	1		1	3	2	3	1	1	1	1	2		2	1	3	2	1	1
2100	101,103,104, 105,106	1		1	3	2	3				1	2		2	1	2	2	1	1
2300	106,107, 108,109				1	1	2			1	2	1		2	1	1	2	2	1
April 4																			
0100	107,108,109, 110						2	1		2	2	1		2	1	1	2	2	1
0400	111,112									1	1			1		1	1	2	1

* Number assigned to watch at time of issuance.

The radar remotes reportedly worked quite well when a dedicated line and a telephone hot line connected the radar station to the warning office. This arrangement is available in a number of warning offices, including Birmingham (dedicated line to the Centreville radar) and Chicago (dedicated line to the Marseilles radar). Remote operation using the dial-up procedure was not satisfactory in all cases, and NSSFC was able to obtain very little information from WBRRs during the outbreak. Probable causes for this were that the commercial lines or tie-ins to the radar were busy, or that the radar was not being operated in the mode which allowed remote operation when the call was attempted.

Warning offices that had to rely for their radar information on coded teletypewriter reports and specific calls to or from radar stations operated at a distinct disadvantage during the rapidly changing conditions of April 3. Even though radar operators did an outstanding job in trying to keep the offices under their "umbrella" informed, the time element and widespread activity made the task extremely difficult. In more than one instance warning offices issued "blanket" warnings because they knew severe storms were in the area, although they did not know the exact location, extent, or movement of the storms.

The network radar at Charleston, S.C., was out of service for maintenance from 12:20 p.m. EDT on April 3 until 2:45 p.m. EDT on April 4. Other network radars (Athens and Waycross, Ga.; Bristol, Tenn.; and Wilmington, N.C.) were alerted and "covered" for Charleston during this outage. In addition, local warning radars at Columbia, S.C., Raleigh, N.C., and Atlanta, Ga., were operating near the storms. Warnings were issued based on available radar returns. Because of the effective coverage of nearby radars, the outage at Charleston did not seriously affect the warning service.

Satellite information available at the Kansas City and Suitland SFSSs was used to good advantage in identifying areas of potentially severe and ongoing severe weather, but was hampered by the limited resolution and day-time only capability of ATS–3. The Kansas City SFSS staff closely coordinated its efforts with those of the NSSFC and Kansas City RWCC, and also provided information to the Ft. Worth RWCC. Both SFSSs communicated directly with warning offices on several occasions and satellite information was utilized as input for certain warnings and all-clear bulletins. It is worth noting that the satellite interpretation message prepared by the Kansas City SFSS at 2:00 p.m. CDT was sent, as prescribed, over the RAWARC circuits with an administrative heading. On one circuit, this message was broken several times by priority traffic before it finally got through. Since this message contained pertinent facts about the three lines of active convection and their rapid movement, it was useful information for the warning offices.

The Covington WSR-57 was out of action for over 3 hours on the evening of April 3 because it lacked emergency power. Fortunately, the worst of the tornadoes had already occurred by this time, and some backup was provided from the Wright-Patterson AFB and FAA air-traffic radars. The Huntsville local warning radar was able to operate continuously because emergency power was available. This made it possible to operate without the power surges that affect commercial power during storms. At Louisville, although power was not low, the many surges made the radar inoperative from time to time. Only the exceptional performance by the electronic technician, who changed parts and recalibrated at frequent intervals, kept the radar performance at a reasonable level. In addition, the Lexington WSO was without power from 7:38 p.m. CDT April 3 to 2:44 a.m. CDT April 4. This included the period when storms were active in the Lexington area. A mobile city police unit manned by the police relayed reports from the WSO beginning at 8:30 p.m. CDT, but the office had to rely mainly on the Federal Telephone System (FTS) and intermittent use of the National Warning System (NAWAS) for its communications. WSFO Louisville prepared and issued formal warnings for Lexington's county responsibility area.

COMMUNICATIONS

The components making up the internal communications system used by NOAA are described in Appendix A. On April 3–4, the teletypewriter circuits performed remarkably well. There were occasional outages but this is considered normal and procedures exist to restore service with a minimum of disruption.

The logs maintained by the NWS Communications Division at Suitland and the NSSFC Communications Section at Kansas City indicated the following. There were no outages on Service A during the period. On Service C, circuits 30, 32, and 35 were out of service from 4:00 p.m. to 6:00 p.m. CDT on April 3. These circuits are in the northeast, southcentral, and southwest parts of the country. On RAWARC, Suitland had an outage on circuit 23422 from 1:17 p.m. to 1:21 p.m. CDT on April 3. The logs also indicated several brief outages in the computer relays over RAWARC. Relays from circuit 23424 were reported out at 10:45 a.m. CDT on April 3; a similar outage was reported for relays from circuit 23421 at 10:20 a.m. CDT on April 4. During the early morning of April 4, lightning hits on the circuit reportedly caused repeating of relays to circuit 23421 and garbling of relays to 23420. This occurred at 4:10 a.m. CDT, and was followed by computer outage caused by a lightning strike at Suitland. Kansas City made manual relays from 4:32 a.m. to 4:46 a.m.

At 4:30 p.m. CDT on April 3, a large portion of the National Facsimile circuit was disabled when a storm demolished a microwave tower at Sharon, Ind. Within minutes, the Communications Division at Suitland began sending charts over an alternate circuit to Kansas City, where the communications unit patched back into the Western Union-operated circuit. This restored service to most of the country. By 5:40 p.m. CDT, Western Union, by alternate routing, had returned the circuit to normal operations.

These outages reportedly had little or no effect on the performance of the NWS warning system.

The fact that the communications systems functioned normally does not necessarily mean that they served the purpose of communicating severe weather issuances adequately. Each of the systems has a volume limit. Service A provided observations in timely fashion and warnings for aviation were disseminated quickly. The Service C outages occurred when synoptic surface and upper air rawinsonde observations were not scheduled so no loss of observational data resulted; however, had the outages occurred during data collection and distribution periods the loss of data might have been critical. RAWARC circuits operated at full capacity and functioned well in moving traffic in a constant flow, but were not equal to the demands of relaying the volume of traffic issued by WSFOs and WSOs.

For example, there were 148 Severe Thunderstorm, Tornado, and Flash Flood Warnings on circuit 23420 on April 3. Of these, 86 were entered directly on the circuit by the warning office involved. The remaining 62 were relayed from other RAWARC circuits: 3 from 23421, 30 from 23422, and 29 from 23423. For the 86 warnings entered directly on the circuit, the average time lapse between issue time and transmission time was slightly less than 10 minutes. This means, for example, that warnings issued by offices located in Indiana were available in Ohio for subsequent relay on the Ohio NWWS in 10 minutes, on the average. On the other hand, the average time for warnings to be relayed to 23420 from other RAWARC circuits was 1 hour. These included a tornado warning issued by Memphis at 6:27 a.m. CDT that was relayed to 23420 4 minutes later and a tornado warning issued by Springfield, Ill., at 4:15 p.m. CDT that was relayed to 23420 2 hours and 10 minutes later. Twenty-six of the 62 warnings relayed to the circuit were relayed after their period of validity had expired.

Transmission of warnings to other warning offices on a common RAWARC circuit was excellent. Transmission requiring a RAWARC relay was inadequate. The fact that the computer at Suitland is programmed to stop sending when the circuit is broken, either by deteriorating signal conditions or by the intentional seizing of the circuit by a station, contributed to the delays. When a computer transmission is interrupted, the computer stops and backs up to the beginning of the interrupted message and waits for the circuit to become idle before starting over. Stations issuing warnings on 23420 broke the computer relays when necessary in order to get their warnings out quickly. The computer was trapped, being unable to transmit when the circuit is busy, and 23420 was busy that day.

Kansas City, as monitor for the RAWARC circuits, issued an appropriate administrative message at 3:54 p.m. CDT restricting secondary traffic on circuits 23420, 23421, 23422, and 23423. Unfortunately, this message was entered directly only on circuit 23421. It was relayed on 23420 by the computer 2 hours later. It took 4 hours after the administrative message was issued before warnings were relayed to circuit 23420 in less than 1 hour.

Tornado watches issued by NSSFC were entered directly on all RAWARC circuits by Kansas City. This eliminated any delay that might be caused by the long traffic queues in the computer.

Therefore, in reviewing the performance of RAWARC, the team noted a serious shortcoming in the timely relay of information between RAWARC circuits.

The team learned that prior to April 3, the NWS had already begun making a change that should alleviate the problem of long delays in the relay of warnings between RAWARC circuits. The computer's basic operating program permits two queues to be formed for most transmit circuits. Bulletins designated as primary traffic go in one queue, the remaining bulletins are designated as routine traffic and go in the other queue. When it begins to transmit, the computer unloads the primary queue first. During a meeting in March 1974, NWS representatives from the offices concerned agreed to designate Tornado, Severe Thunderstorm, and Flash Flood Warnings as the only priority traffic on RAWARC circuits. This greatly reduces the traffic designated as priority and should improve the relay time for warnings significantly. This change was fully implemented on May 1, 1974.

DISSEMINATION

As discussed in Appendix A, the dissemination portion of the total warning system is made up of a complex, locality-dependent mix of several communication channels. The following sections describe the operation of these channels on April 3–4.

Mass Media and NOAA Weather Wire Service

A very important element in the dissemination process during the outbreak was the active participation by television and radio stations. This is treated more fully later in this chapter. As far as can be determined, most stations did not hesitate to interrupt normal programming for warnings as they were received. There were numerous cases in which radio and television stations performed extremely well, including an outstanding performance on the part of a radio station in the path of the storm which devastated Brandenburg, Ky. The announcer of this small FM station observed the tornado coming and continued to broadcast a warning until the station was literally destroyed.

Most people interviewed in Louisville were listening to WHAS Radio, the key Emergency Broadcast System station, prior to and during the tornado there. WHAS provided full-time warning coverage and was broadcasting a live telephone message from John Burke, Meteorologist-in-Charge of the Louisville WSFO, when the tornado-producing storm approached the airport. He was watching the storm and, although a distinguishing funnel was not visible, it looked vicious enough and was close enough that he said something to the effect, "Here it comes, I've got to go." Understandably, many people took shelter because of that vivid eyewitness report.

Written warnings were delivered to the mass media (and in some areas to the State police, local officials, civil defense operation centers, etc.) over the NOAA Weather Wire Service (NWWS) for subsequent broadcast to the public. Those cooperating stations which subscribe to this teletypewriter service were able to receive written warnings as rapidly as the system available today could deliver them. Since the preparation of written messages remains largely a manual operation, disseminating warnings over NWWS is slower than the voice channels available at many warning offices. Nevertheless, NWWS is given high priority because of the great potential for reaching the public through mass media.

Examination of the dissemination logs of one WSFO, which was staffed to simultaneously disseminate warnings over several channels, show that it took an average of 1 to 2 minutes after the severe event was reported or indicated to send a voice warning over the National Warning System (NAWAS) hotline, 7 minutes to disseminate over NOAA Weather Radio, and slightly over 9 minutes to complete dissemination over NWWS. Information gathered from other warning offices indicates that it takes a minimum of 4 to 5 minutes to prepare a warning and transmit it on NWWS after deciding that a warning is needed and what area should be warned. Since many severe local storms exist for only a few minutes, and because it takes time for reports to reach the warning office and for broadcasters to read the warning, the present capability for preparing written warnings is not adequate for all such events.

While NWWS was available in practically all the area affected by tornadoes (the exceptions are New York and southern Virginia), the vast majority of radio and television stations depend on the press wire services to provide them with the written warnings. A survey of NWWS subscribers throughout the area hardest hit by the storms produced the following statistics on number of radio and television stations subscribing to NWWS and the ratio (percent) of those subscribing to total number of such stations in the State: Alabama—37 (20%); Georgia—21 (9%); Illinois—56 (23%); Indiana—43 (24%); Kentucky—26 (17%); Missouri—61 (38%); Ohio —43 (18%); and Tennessee—31 (16%). These statistics do not tell the entire story. Since the subscribing stations tend to be clustered in the larger population centers, and are not evenly distributed throughout the State, dissemination to outlying areas is less effective than in the larger cities. It is clear that more subscribers to NWWS would improve the warning system. Costs to subscribers for local connection and printer rental, which are rising along with everything else these days, are most frequently given as the reason for not subscribing to NWWS. Several station managers pointed out that weather information routinely available over NWWS is "sellable" to sponsors, and some stations have found it more economical to purchase teletypewriter printers.

Generally, each NWWS circuit serves only one State; and the transmission of warnings for nearby areas of adjacent States requires time-consuming relays, generally made over the RAWARC circuits. As was noted in the section on Communications, excessive delays occurred in computer relays between certain RAWARC circuits on April 3. This contributed to one warning office relaying 25 expired warnings for an adjacent State over their NWWS circuit. Expired warnings also were relayed in two other States. This promoted confusion on the part of broadcasters who seldom had time to edit the vast amount of material pouring in to them during the outbreak; many could only broadcast it as received. As one television weather man put it: "NWWS needs more selectivity; it gives me more than I want to know."

Quite a few NOAA offices have warning responsibility for counties in more than one State, and have worked out special procedures to get the warnings on the required NWWS circuit, but all this takes time, and in three instances the procedures didn't work on April 3. While these were only a small fraction of the warnings issued, it does indicate that some attention should be paid to this problem on a station-by-station basis.

An examination of the NWWS traffic shows that the broadcast stations were swamped with material during the outbreak, that relay of warnings from adjacent States contributed to the confusion by delayed transmission, and that shorter messages and judicious editing would have helped matters. An example of this is found in the narrative radar summaries, which are quite informative during normal weather conditions. But when individual storms are moving at 50 to 60 mph and numerous warnings are being issued, the time lapse of 35 to 50 minutes between observation time and transmission time of these summaries made them outdated and actually confusing to the broadcaster, in many cases.

The lack of NWWS in New York and in southern Virginia (these areas will have this service available shortly) meant that severe weather messages reached most of the radio and TV stations over press wire circuits after relays over RAWARC or other channels. There are some local teletypewriter circuits in these areas, but these generally serve only the immediate area around the warning office.

National Warning System (NAWAS)

NAWAS, operated by the Defense Civil Preparedness Agency, played an important role as an effective communication link during the outbreak. A great many of the warnings issued on April 3–4 were based solely, or in part, upon information received via NAWAS. Over 60 storm reports arrived over NAWAS at WSFO Birmingham, while WSFO Indianapolis received more than 100 severe storm reports. Most tornado warnings for Indiana were based on reports from the State Police who observed the storms and gave up-to-the-minute reports. The warning issued about 30 minutes before a tornado hit Monticello, Ind., was based on a report over the Illinois NAWAS, on which Indianapolis has a drop. Tornado reports received over NAWAS were used by WSFO Louisville in issuing warnings for the Brandenburg and Louisville storms, with the warning for Brandenburg issued about 15 minutes before the tornado struck and the Louisville warning issued with a lead time of 40 minutes. Other tornado warnings based on reports received over NAWAS were issued by the WSOs at Cincinnati and Columbus, Ohio. One of these warnings put a family of 10 in their basement a few minutes before a tornado destroyed their house. Senator Howard Baker commended the Tennessee Highway Patrol for their work in giving our warning offices storm reports over NAWAS.

Examination of the logs of several warning offices indicates the NAWAS was the most rapid means of sending warnings used in the outbreak. In several instances local officials were given tornado warnings several minutes before the manual preparation of written warnings was completed. WSO Springfield, Ill., used NAWAS to have the sirens sounded in Danville, Ill., 15 to 20 minutes before a tornado passed a short distance north of Danville to strike the small town of Bismarck.

It must be noted that NAWAS also has a limit on the traffic it can handle. In one State, traffic was so heavy that it threatened to overwhelm the State Police communications unit. It has been suggested that NOAA offices in that State work to reduce traffic to the absolutely essential items.

NOAA Weather Radio (VHF-FM)

NOAA Weather Radio, with its tone-alert capability, has proven to be a valuable channel for rapidly sending warnings directly from the warning office to the general public, schools, hospitals, local action officials, and on occasion to mass media for immediate transcription and rebroadcast. During one past tornado situation, this system dramatically showed its worth as a backup channel when a tornado knocked out the teletypewriter service between Kansas City and St. Joseph, Mo. On this occasion, a radio and television station in St. Joseph was able to copy the VHF transmission of warnings from the Kansas City warning office. On April 3, NOAA Weather Radio broadcast warnings in St. Louis prior to the severe hailstorm there, and tornado warnings were broadcast directly from NOAA Offices in Atlanta, Chicago, Indianapolis, and Detroit. Since the effective range of NOAA Weather Radio is only about 40 miles from the transmitter site, and so few transmitters were available in the area affected by the outbreak, this dissemination channel was quite limited in its usefulness on April 3. The planned expansion of this system will do much to strengthen the warning system. This capability, along with tone-alert receivers in all schools, hospitals, factories, and in local government facilities, would be an important asset to NOAA's ability to provide rapid and effective dissemination.

Telephone

Dial telephone dissemination of warnings, while quite rapid when only a few calls need to be made, is not effective for placing a number of calls during tornado warning situations. The team found that too many warning offices have lengthy call lists, particularly when few radio or television stations in a responsibility area subscribe to NWWS. An examination of the dissemination log at WSO Chattanooga shows how the normal problems of telephone communication (busy signals, waiting to speak to the right individual, etc.) are magnified during severe weather. This office took nearly an hour to call everyone on its warning list with a tornado watch. After severe storm activity began the service was hampered by busy signals and a telephone outage. This outage, affecting its Georgia counties of responsibility, made it necessary for Chattanooga to pass its responsibility off to WSFO Atlanta. Atlanta, in the spirit of cooperation which marked the entire NWS during the outbreak, immediately began issuing warnings for Chattanooga's counties in northwest Georgia, but this points up a serious weakness inherent in telephone dissemination. It is imperative that offices work to reduce telephone warning lists.

Hotline telephones, located in some metropolitan areas, have been quite effective in disseminating warnings. These most often do not include mass media outlets, but frequently tie-in to the community's siren system.

Miscellaneous

While WSO Chattanooga had problems with its telephone dissemination, and few stations in southeast Tennessee are on the NWWS, that office did make excellent use of a special dissemination channel on April 3–4. Through arrangements with one of the local radio stations and agreements between this station and others in southeast Tennessee, the warnings issued by the WSO are taped and broadcast by the first station, then picked up and broadcast by others. This system, routinely used each hour to transmit the latest forecast and weather conditions, was used for all warnings issued by that office during the outbreak and is considered a vital part of the station operation.

Another special dissemination channel was used in Fort Wayne, Ind. This system, termed the Emergency Alerting Radio System (EARS), is used to trigger Tone Alert Monitor receivers whenever severe weather or other potential disaster situations occur. Warnings issued by the Fort Wayne WSO are sent over police-type radio to the city Communications Center, where the dispatcher copies the warning, sets off a two-tone signal, and reads the warning over the radio. The tone alert signal activates special receivers located in hospitals, all the county news media, telephone and utility companies, and city and county offices. The system, operated by the city, reportedly worked very well on April 3 and is now being added to the schools in the county.

USER AND PUBLIC RESPONSE

Everywhere the survey teams went—and especially in Guin, Ala., Brandenburg, Ky., Monticello, Ind., and Xenia, Ohio—the question was the same: "How could anyone have survived?"

Education somewhere, at some time, through some means, had to be the answer. The people in those towns and elsewhere in 11 States heard weather watches and warnings over radio and television; were notified by their neighbors, relatives, or friends; saw the tornadoes approaching; or heard the ominous roar of the tornado. In interviews with people in all the hard hit areas, the team found very few who were unaware that they were under a severe weather threat.

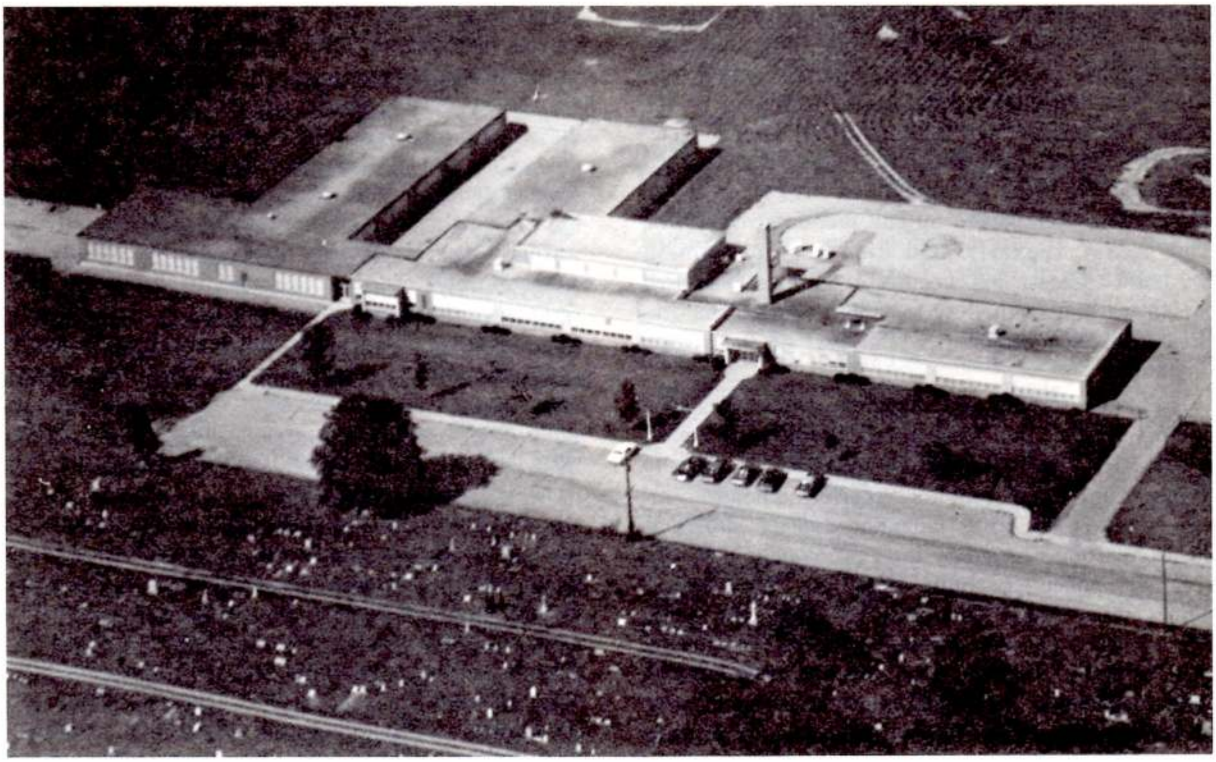
But most importantly, they knew what to do when the time came to take action. They all seemed to know that a basement, if they had one, was the best place to be. Those who had storm cellars or basements shared them with neighbors who didn't have them. Others went into closets, under beds, in ravines, behind a sofa, under stair wells, in the center of the home, under dining room tables, and in the halls of large well-constructed brick buildings. They got out of gymnasiums and large open rooms, stayed away from windows, protected their heads from flying debris, and opened windows and doors to relieve pressure. They survived one of the most severe storms of record.

Many of the people who took evasive actions did so with plenty of time to spare, but many others did so in the last few seconds. Although they all seemed familiar with safety rules, their understanding of Weather Service terminology—the watch and warning—varied State by State, and city by city. In Alabama, and for the most part in Tennessee, the residents interviewed were precise in defining the meaning of the two terms and knew how to apply the advice. But in other cities and States, the people gave answers indicating some confusion and, in some cases, completely wrong information. Some who said they knew the difference between the two terms took the wrong actions.

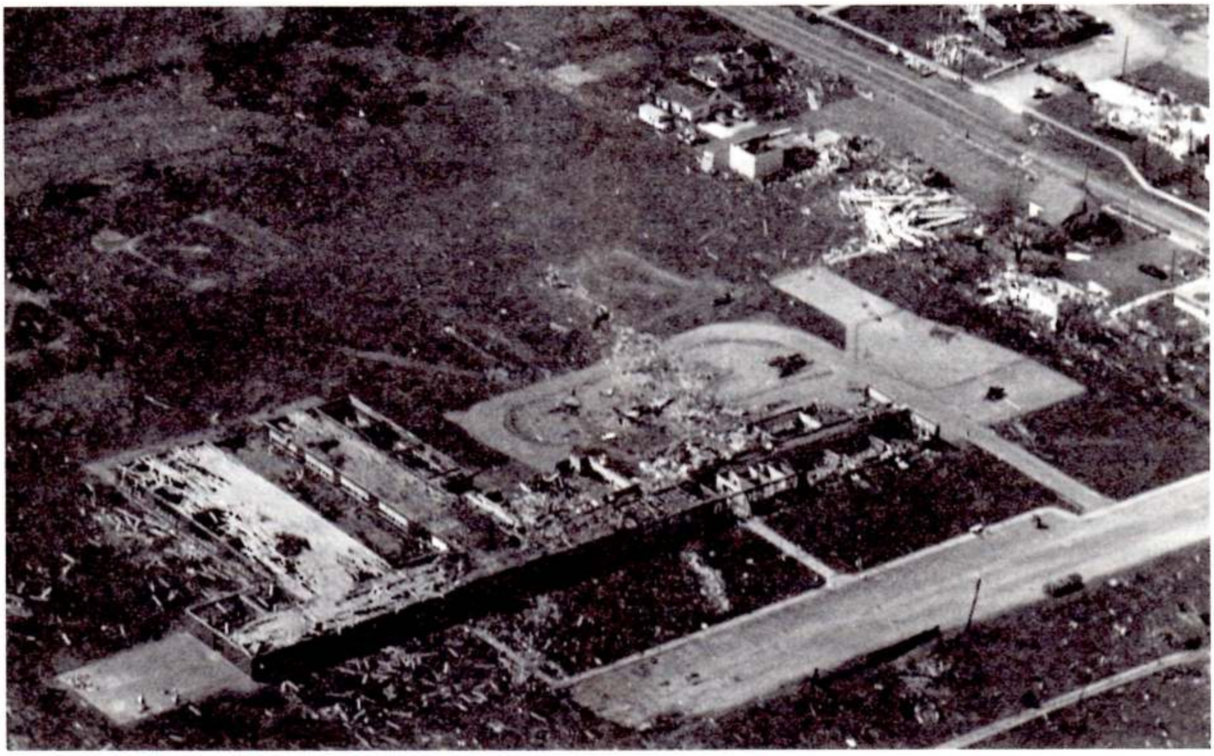
As behavioral scientists have noted repeatedly, the actions of the people and organizations seemed to be directly related to the experience of the community with the phenomena—in this case, the tornado. In those areas where the frequency of tornadoes is greater, community and individual readiness was high. Alabama is the best example among the six hardest hit States. On the other hand, reactions in Kentucky, Indiana, and Ohio were slower. Some people who heard the warnings seemed oblivious to the threat and took actions in the last 30 seconds when the tornado was bearing down on them. Others remained exposed and survived only through good fortune. Disaster researchers have found that most people would rather believe they are not in danger and that the advice they were getting was "just another cry-wolf episode," or "it couldn't be that bad," or that it "wouldn't happen to them." The team was surprised to find a large number of old fashioned storm cellars, detached from the house itself, often used in Alabama. In the hard hit parts of Tennessee, it was rare to find homes with basements.

Schools

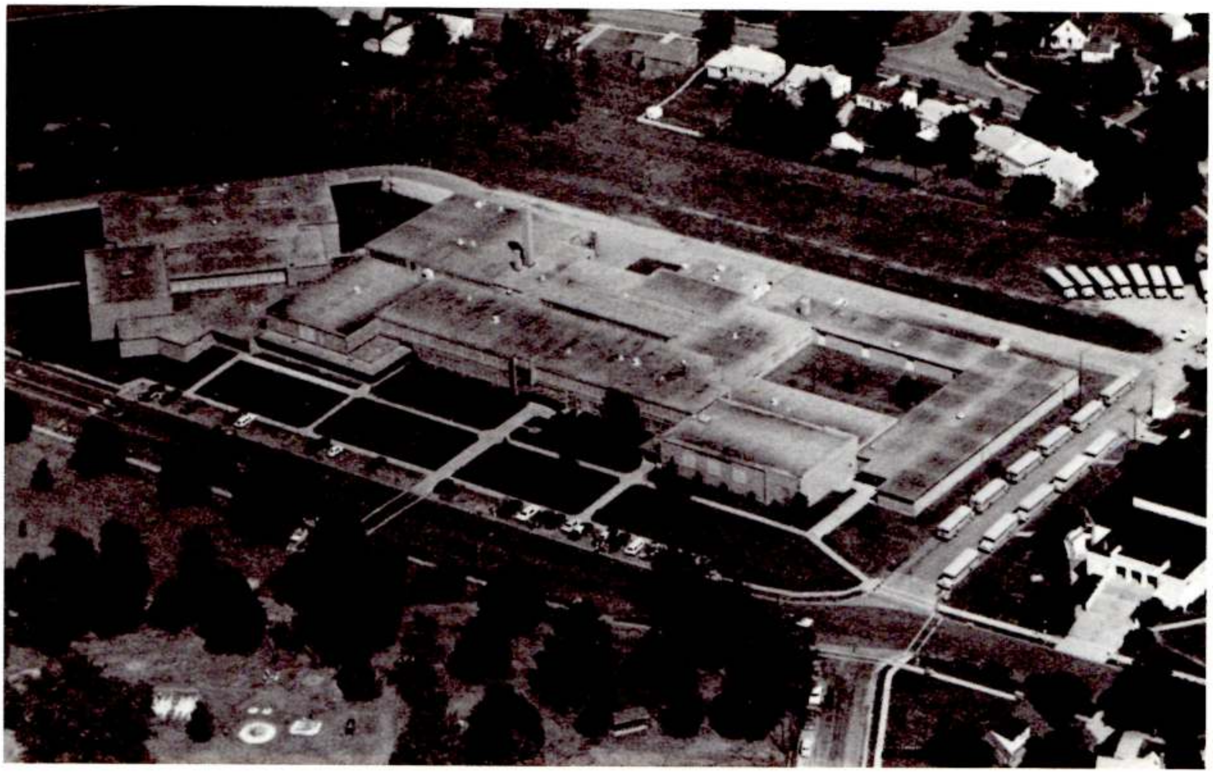
In Xenia, Ohio, five schools were in the direct path of one of the most powerful and destructive tornadoes in our Nation's history. When it passed, three of the schools were destroyed almost completely. The other two were extensively damaged. The accompanying pictures show the before and after effects of this tornado on the Xenia schools. The tornado struck about 4:30 p.m. EDT. More than 5,000 students and teachers were out of school. Had the April 3 tornado occurred 2 hours earlier, without well executed tornado plans and prior drills, hundreds might have died. School damage was severe in other States, but there too tornadoes struck mostly after school hours.



Simon Kenton Elementary School, Xenia, Ohio.

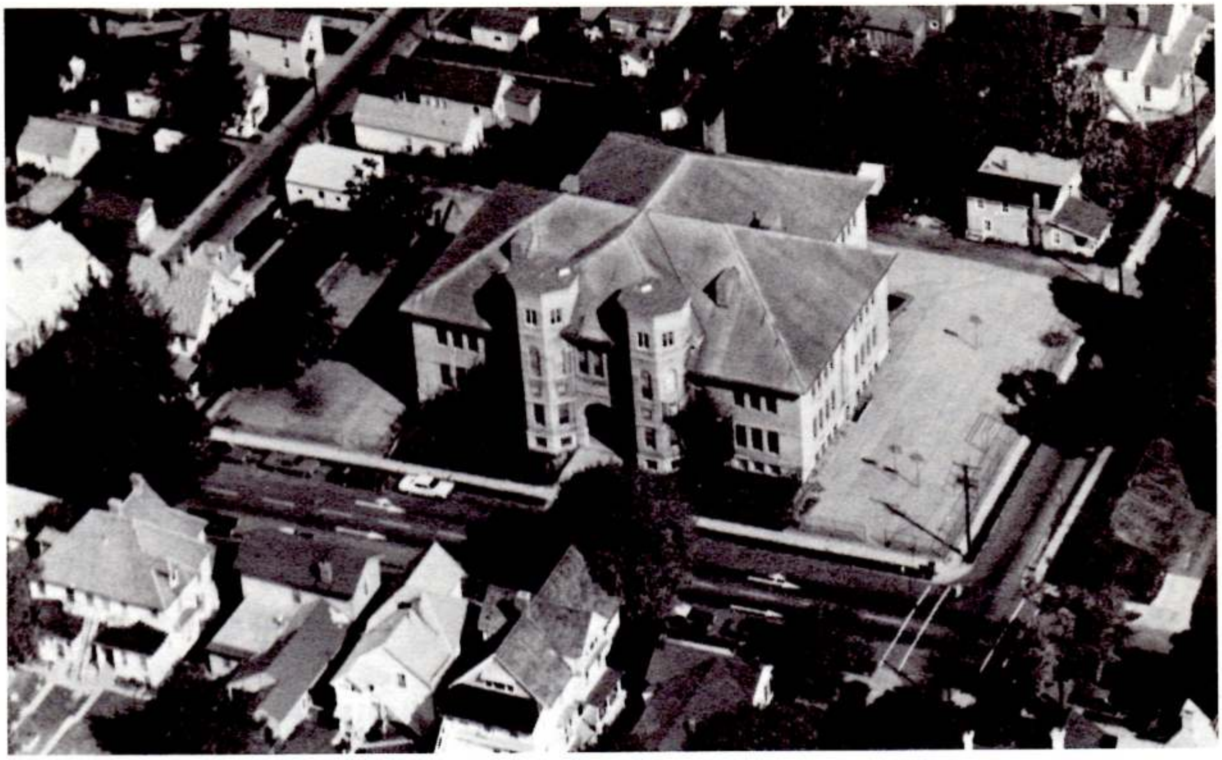


Damage to school and nearby residences.



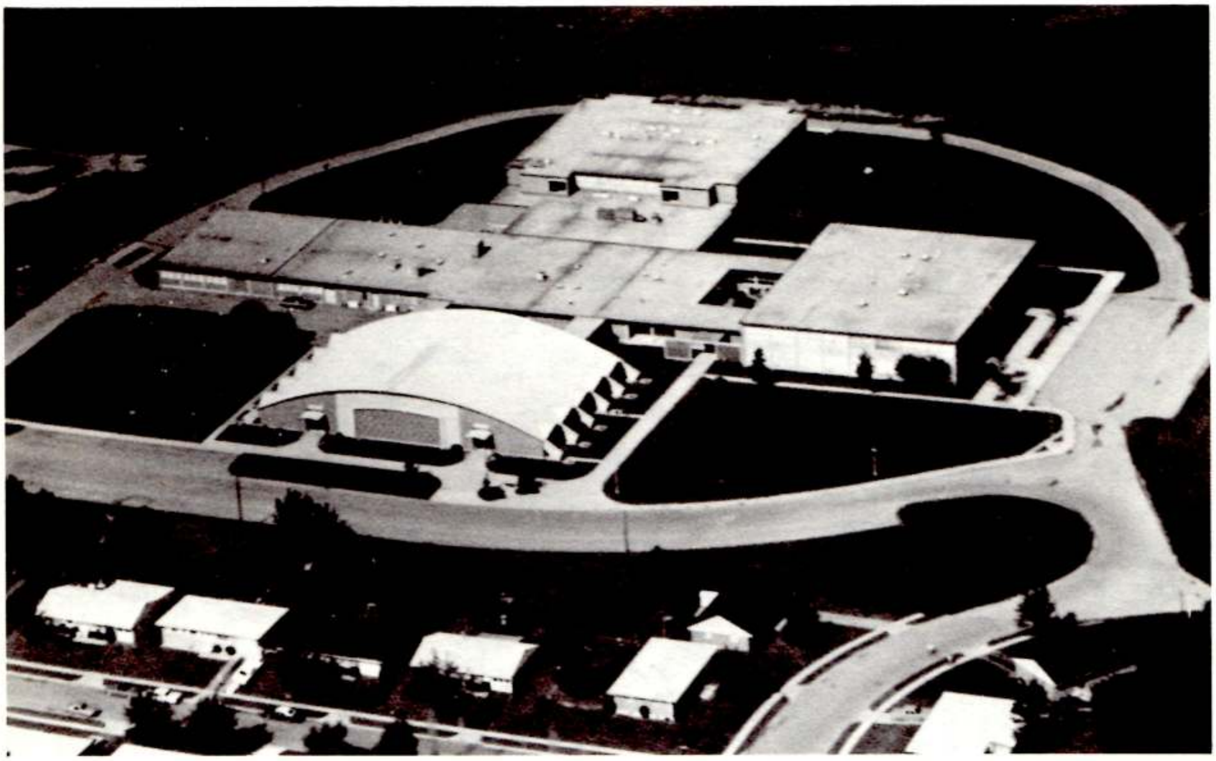
Xenia High School, Xenia, Ohio.

Damage to school and nearby residences.

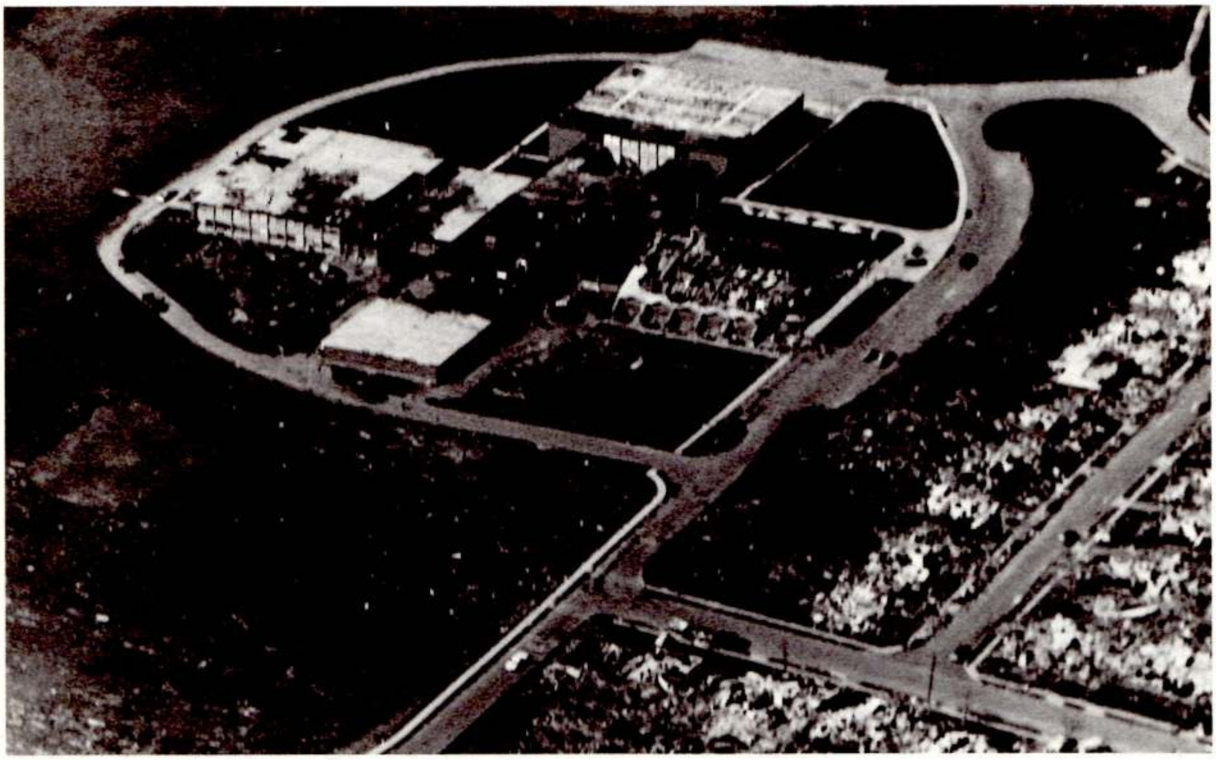


McKinley Elementary School, Xenia, Ohio

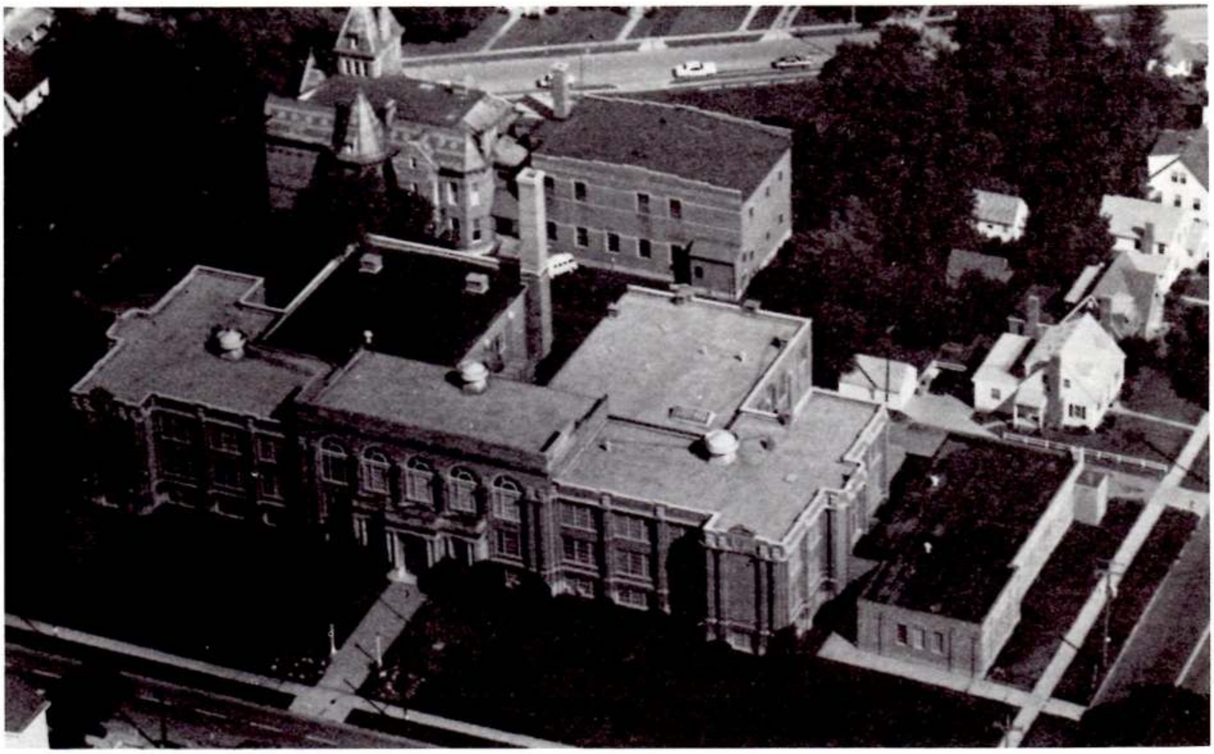
Damage to school and nearby residences.



Warner Junior High School, Xenia, Ohio.

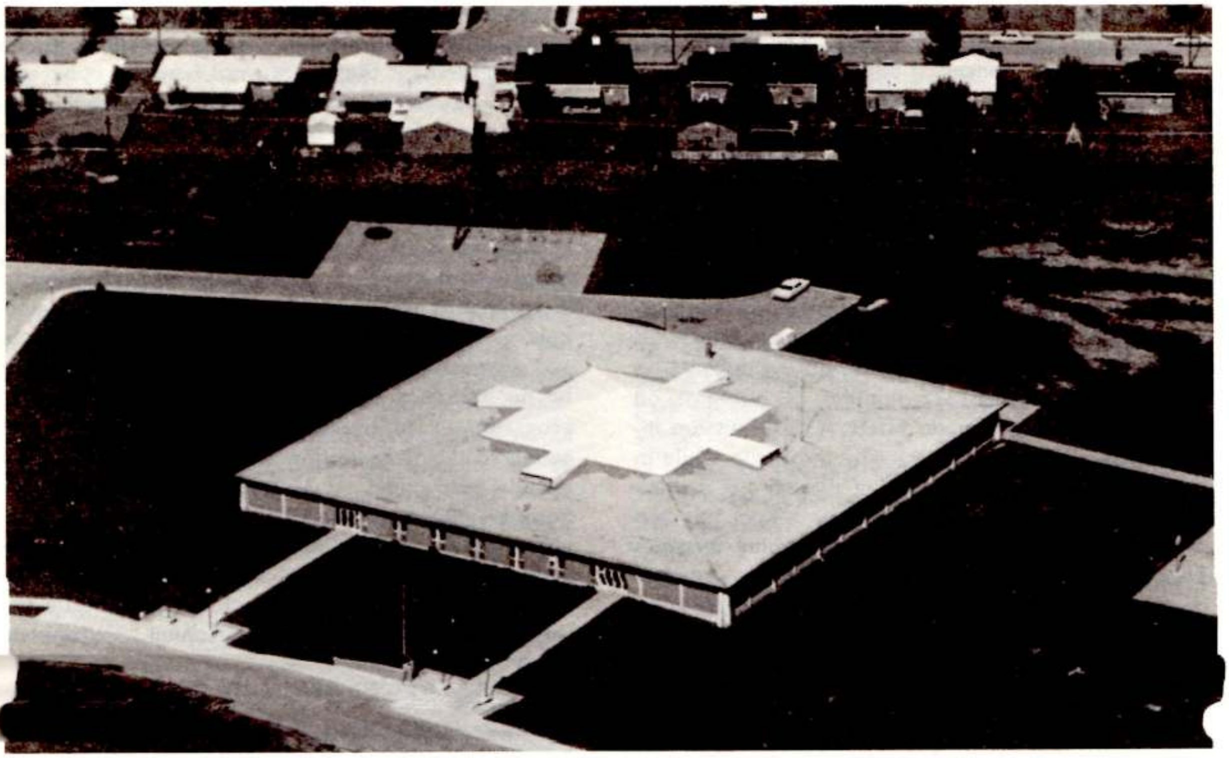


Damage to school and nearby residences.



Central Junior High School, Xenia, Ohio.

Damage to school.



Arrowood Elementary School, Xenia, Ohio.

Damage to school and nearby residences.

There is evidence of disaster planning in some schools, but very little in others. The team could find no uniform, concerted effort to incorporate tornado education and preparedness in the school system.

During 1973, in Mississippi, there were two dramatic examples in which tornado drills saved the lives of hundreds of children. Mississippi has a statewide requirement for the regular conduct of tornado drills.

In the April 3 outbreak there were isolated examples where education and preparedness in schools saved lives. In Hanover, Ind., a high school physics teacher spent the last 25 minutes of his class on April 2 discussing tornado safety. The discussion included the danger of being hit by a tornado while in a vehicle and advocated leaving the car for a ditch or ravine. The next day a Hanover school bus was on a collision course with an approaching tornado. One of the students who'd been in that physics class convinced the driver to stop and everyone headed for a ditch. The bus was demolished but none of the passengers was injured. Many Indiana schools were damaged. At Monroe Central High School (10 miles east of Muncie) students were dismissed early when a watch was issued for their area. The teachers who remained posted a lookout and when a tornado was spotted they went to a predetermined interior hallway. The school was destroyed but the interior hallway remained intact and no one was injured.

Radio and Television

According to the 1973 Broadcasting Yearbook, a total of 64.8 million homes, or 96.4 percent of all U.S. homes (excluding Alaska and Hawaii), had television sets as of September 1972. The Radio Advertising Bureau (RAB) estimated that 64.1 million U.S. homes, or about 98.6 percent, were radio equipped in 1972.

The number of working radio sets in the United States totaled 353.5 million in 1972. It was estimated (by RAB) that 251.8 million of these were home and personal radio sets and 101.7 million were out-of-home receivers.

The number of adults (18 years of age and over) reached by radio in one day is estimated at 92,100,000 (75.1 percent), and by television 80,900,000 (65.9 percent).

The National Weather Service relies heavily on radio and television to get the watch and warning information to the public. Media surveys have shown that relatively few people are viewing television or listening to radios between noon and 6:00 p.m., with a sharp increase in the 6:00 p.m. to midnight time period.

With the exception of Alabama and Tennessee, where most of the tornadoes occurred in the evening hours, many of the death-dealing tornadoes in the other hardest hit States occurred between noon and 6 p.m., the period when the average viewer or listener spends less than one hour "tuned in." However, just a few listeners can spread the message by word of mouth and these statistics may paint a worse picture than actually exists.

In all States the survey team heard glowing tributes to the role played by radio and television in disseminating watches and warnings, reporting sightings, and giving specific instructions to their listeners and viewers. With few exceptions, there seemed to be no hesitancy by stations in interrupting regular programming to broadcast tornado warnings. The action of the radio station at Brandenburg, Ky., has already been noted. At Monticello, Ind., a radio station also issued warnings based on sightings. A television station in Cincinnati, Ohio, showed the tornado "live" by setting its cameras on its roof. In Louisville and Cincinnati direct feeds on radio by National Weather Service personnel contributed greatly to public response.

NOAA Weather Wire is the National Weather Service's prime means of getting watch and warning information to the broadcast media and the wire services. In the hardest hit States of Alabama, Tennessee, Kentucky, Ohio, Indiana, and Georgia the survey team found that only 17 percent of all radio and television stations in those States subscribe to the NOAA Weather Wire. Those stations without NOAA Weather Wire rely on one or both of the two major wire services for their weather information.

The unusual and extensive lead time of 1 to 1½ hours for warnings in several instances gave the wire services time to disseminate weather warnings to radio and television stations. But news directors or other broadcast officials told the survey team that under normal fast breaking situations:

"They (wire service) can't keep up with the warnings. Sometimes there is as much as a 45 minute delay."

"The time-lag (on the wire services) in moving weather can be huge and disastrous if it (Tornado Warning) happens at the time of the split."

"The (wire service) can't possibly move weather fast enough on a situation like April 3."

The reason given most often by stations for not being on NOAA Weather Wire is the cost. Monthly costs in the six hardest-hit States are $42 in Alabama, $50 in Tennessee, $81 in Indiana, $41 in Kentucky, $91 in Georgia, and $82 in Ohio. It is also worthy to note that some interstate rates are lower than intrastate. Those stations with NOAA Weather Wire in many cases had the teletypewriter too far removed from the control room to hear the alarm bell and no signal light to indicate urgent messages.

The number of reports—watches, warnings, redefining statements, revisions, and reissues—together with overlapping times and the extent of the severe weather over wide geographical areas taxed the National Weather Service and radio and television staffs to the maximum. Broadcast personnel who dedicated themselves to staying on top of the weather situation by dropping all other programming, said all they could do was "just read the material as it came off the Weather Wire." The result in some cases was confusion by listeners as to whether they were indeed in a valid tornado watch or warning area. But apparently the saturation of watch-warning information did create an awareness that the threat was real and imminent and kept the public alert to later protective actions.

The team received comments from several radio and television stations that indicate that many still do not realize that the FCC authorized them to stay on the air during weather emergencies beyond their normal operating hours. There is also some confusion over the authorized use of the Emergency Broadcast System and the Emergency Action Notification Attention Signal (EANS) in emergency weather situations.

Community Preparedness

The NOAA Survey Team did not attempt a detailed review of community action warning plans and operations in the field. However, a group of representatives from the Defense Civil Preparedness Agency (DCPA) did visit several disaster areas in Kentucky, Ohio, Indiana, Tennessee, and Alabama, and shared their findings with the NOAA team. The primary purpose of the DCPA task group was to determine the effectiveness of local civil defense organizations.

They found that Alabama, Tennessee, and Ohio had well-planned operations. Indiana and Kentucky were not as well prepared. The NOAA team reached similar conclusions, but noted considerable improvements in recent years in Indiana and Kentucky.

In Indiana, numerous community warning drills before the tornado season undoubtedly contributed to community readiness and better warning performance in some cities. However, most of the towns hit in Indiana were relatively small, remote from population centers, and out of television range from larger cities. Few had effective civil defense organizations or spotter networks.

The National Warning System (NAWAS) means of intrastate and interstate emergency landline communication used by safety officials was used extensively and effectively for tornado warnings in the April 3 outbreak.

The DCPA task group found that mobile home tiedowns were not used at any of the locations they visited. In examining the destruction or damage of mobile homes, National Weather Service personnel rarely found evidence of tiedowns and shelters in mobile home parks. The team did learn of at least one case where such a shelter was used very effectively. We were told the story of a mobile home park operator knocking on doors to get people into shelter.

One of the best examples of effective planning and operations found in any place was in Huntsville, Ala. An excerpt from the DCPA task group's report follows:

"Madison County has a warning plan and a NAWAS drop. Weather warnings may come from the NWS at the Huntsville airport or the State Police. If the NWS considers the warnings are of extreme urgency, NAWAS is used first. Otherwise, a tape is punched and the message is sent on wire before it is put on NAWAS.

"When the county Civil Defense (CD) Coordinator receives a warning, he telephones the television and radio stations, sounds the 15 city CD/fire sirens, informs the educational TV station and MUZAK, as well as radioing all government departments. All of this action is generated at the Emergency Operation Center (EOC). Additionally, he utilizes his CD net to shelters, radio stations, Red Cross and the hospitals. The county schools are alerted by tone-activated receivers. The city schools employ the Educational Television (ETV) system. All schools throughout the area have internal plans and warning systems.

"At the first notification of a tornado watch, the EOC was activated. Watches were posted periodically throughout the day from NWS to the radio and television stations. When the warning came through, the CD coordinator sounded the sirens; radio/TV stations were notified, and the warnings were sent out.

"All indications from the area are that the citizens reacted very well and were able to take advantage of shelters."

The value of sirens was demonstrated vividly in the April 3 outbreak. DCPA expects that they will receive many applications for matching funds for the installation of sirens in the next year.

The warning system for Louisville, Ky., consists of 15 Civil Defense sirens and 22 fire sirens, all of which were activated by the National Weather Service Forecast Office in Louisville. In Cincinnati, for the first time in the 18-year history of the Hamilton County CD system, the Director of CD sounded the sirens to alert the population of a tornado approaching the city from the southwest. The alert was sounded on 125 sirens covering 70 percent of the County's population. According to the *Cincinnati Enquirer*, the sirens "undoubtedly saved hundreds of lives and prevented thousands of injuries."

In February 1974, before the onset of the tornado season, the National Weather Service conducted Tornado-News Media meetings in Alabama (Huntsville), in Georgia (Atlanta), and in Kentucky (Bowling Green and Hopkinsville). The meetings stressed preparedness and enlisted news media cooperation in dissemination and education efforts. The meetings were well attended by the media and local civil defense and safety officials. Many newspapers and radio and TV stations followed up with public service announcements and publication of tornado safety rules and other vital information. Similar meetings have been held in more than 50 cities in 26 tornado-prone States in the past 5 years, including every State affected by the April 3 outbreak.

In addition, community preparedness and tornado spotters meetings between the NWS and city, county, and State civil defense directors and law enforcement officials are conducted regularly before the tornado season. The payoff in community readiness was apparent in places like Birmingham, Huntsville, Cincinnati, Atlanta, Louisville, Nashville, Chattanooga, and Indianapolis.

More than a quarter of a million NOAA publications dealing with tornado safety were distributed to the people in Ohio, Indiana, Alabama, Kentucky, and Tennessee, by the NWS and State civil defense before the onset of the 1974 tornado season.

The question about the watch and warning terminology was repeatedly raised in the States not usually exposed to frequent tornadoes. In the small rural community of Guin, Ala., however, everybody interviewed was able to correctly distinguish between the watch and warning. This suggests that frequency of tornado occurrence and continual education do help in differentiating between the terms.

The survey team feels that the combined effort of the preseason planning and preparedness, education, and dissemination of information, the outstanding performance by National Weather Service staffs during the long-lasting ordeal, and the dedicated and superb job of the broadcast media in relaying weather information to the public resulted in saving thousands of lives during the April 3-4 outbreak.

Chapter 4

Meteorological Analysis of the Storm

Modern meteorology began about a century ago with the realization that weather systems are associated with atmospheric patterns several thousands of kilometers in scale. However, in the last couple of decades it has become evident that important atmospheric processes occur over a wide spectrum of interacting scales. Although large or synoptic scale systems delineate general weather patterns, the particular types, severity, and variability of local weather events occur on a smaller scale known broadly as the mesoscale. To better understand the development of the April 3d storms, an examination of both the synoptic and mesoscale meteorological conditions associated with this outbreak was undertaken.

LARGE-SCALE METEOROLOGICAL ANALYSIS

The stage for the severest outbreak of tornadoes in almost a half a century was being set as early as Tuesday morning, April 2, 1974. At that time a rapidly moving upper air trough was crossing the Great Basin area of the western United States. The surface low pressure center associated with this trough was located in southeastern Utah, with a cold front trailing southwestward through northwestern Arizona and southern California (figure 9). A very strong mid-tropospheric jet stream associated with the upper level trough was present over the southern Rockies and the low pressure center was expected to intensify and move eastward during the next 24 to 36 hours. A shallow dry polar air mass covered the central portion of the United States.

From 7:00 a.m. CDT Tuesday, April 2, to 7:00 a.m. CDT April 3, as the deepening upper trough crossed the Great Divide, a surface low formed, deepened 10 millibars over eastern Colorado, and continued to deepen as it moved eastward into central Kansas (figure 10). To the north and west of the low a wide band of snow, heavy at times, was occurring. Under the strong upper jet stream, the cold front moved at an average speed of 35 miles per hour from the east slopes of the Rockies across Texas. Ahead of the cold front over the Gulf States and Tennessee a rapid influx of low-level moist unstable tropical air had occurred.

During the next 24 hours when most of the tornadoes occurred, from 7:00 a.m. CDT Wednesday, April 3, to 7:00 a.m. CDT April 4, the low pressure center filled slightly and moved rapidly northeastward towards Lake Michigan (figure 11). The surface cold front continued its rapid motion across the middle Mississippi and Ohio Valleys, while south of the low, cold dry air swept rapidly eastward directly into the area occupied by the warm moist Gulf air. The vigorous dynamic activity which ensued from the clash of these air masses resulted in the spawning of at least three extremely intense tornado-producing squall lines.

By 7:00 a.m. CDT on Thursday, April 4, there was evidence that the original cold front had dissipated and reformed 100 miles to the west over the central Ohio and Tennessee River Valleys, as a second 500-mb trough moved across the Great Plains. The new cold front awaited the advancement of the second 500-mb trough and then moved across the Appalachians and off the east coast on April 5 at a much slower rate (10-15 knots) than the original cold front. A tornado outbreak did not occur east of the Appalachians with this second cold front.

MESOSCALE METEOROLOGICAL ANALYSIS

The space and time scale associated with severe local storms is smaller than either the present upper air network (average spacing 400 km, observations once every 12 hours) or the surface network (spacing 100 km, hourly observations). To assist in bridging this gap between the small systems producing local severe weather and the larger scale data acquisition networks it is necessary for the forecaster to rely upon relatively new technologies—radar and high resolution satellite imagery. These tools permit the forecaster to expand upon present surface analysis techniques and thereby to more clearly

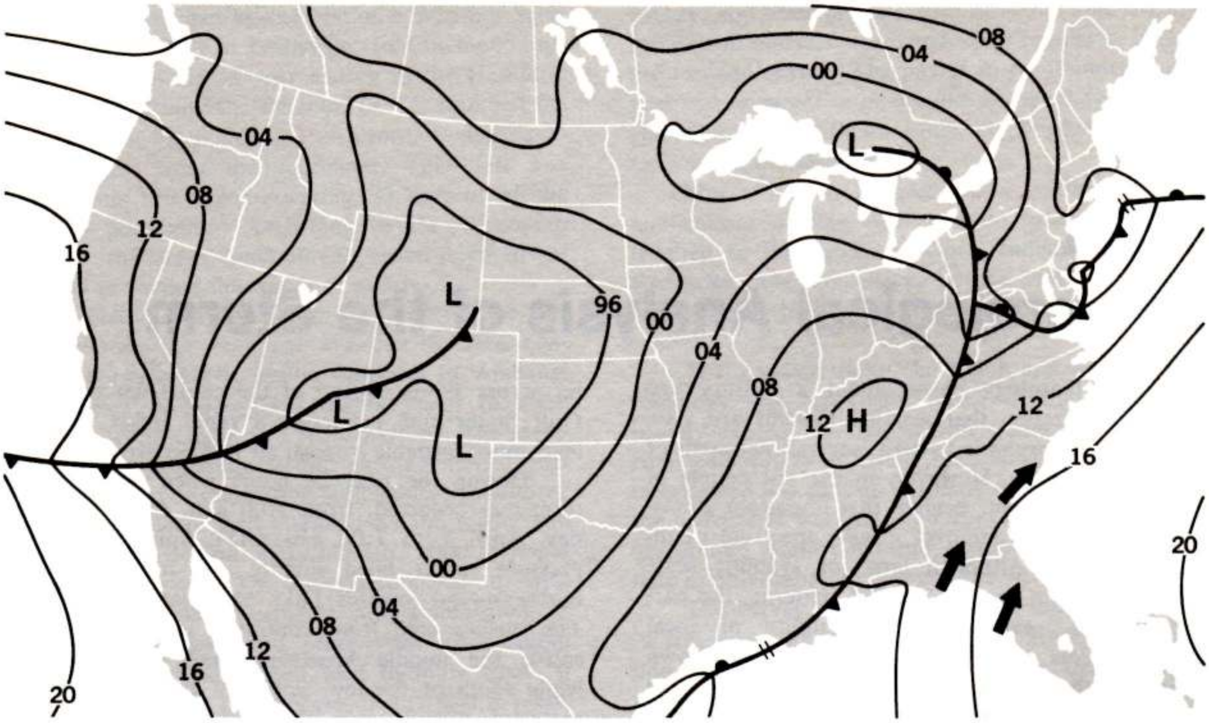


FIGURE 9.—Surface weather chart for 7:00 a.m. CDT Tuesday, April 2, 1974. Arrows represent influx of low level moisture. Pressure in millibars.

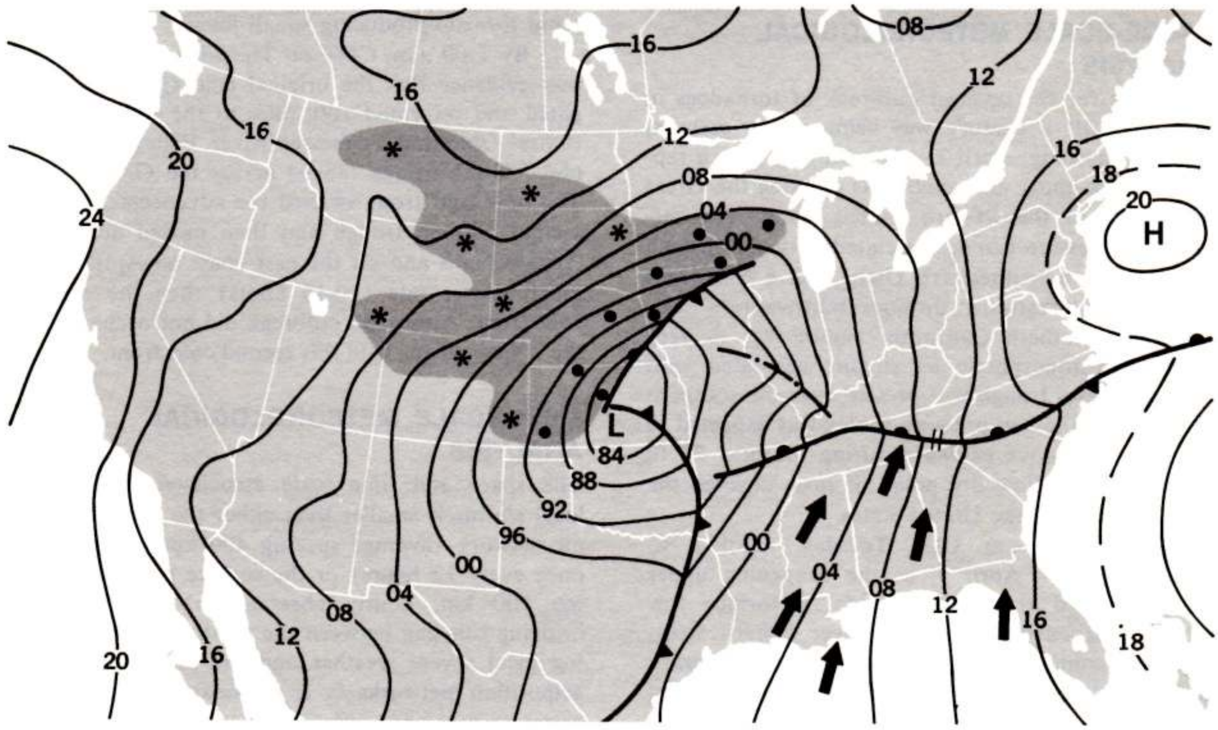


FIGURE 10.—Surface weather chart for 7:00 a.m. CDT Wednesday, April 3, 1974. Shaded area indicates precipitation; dots represent rain, asterisks represent snow. Dashed-dotted line indicates squall line.

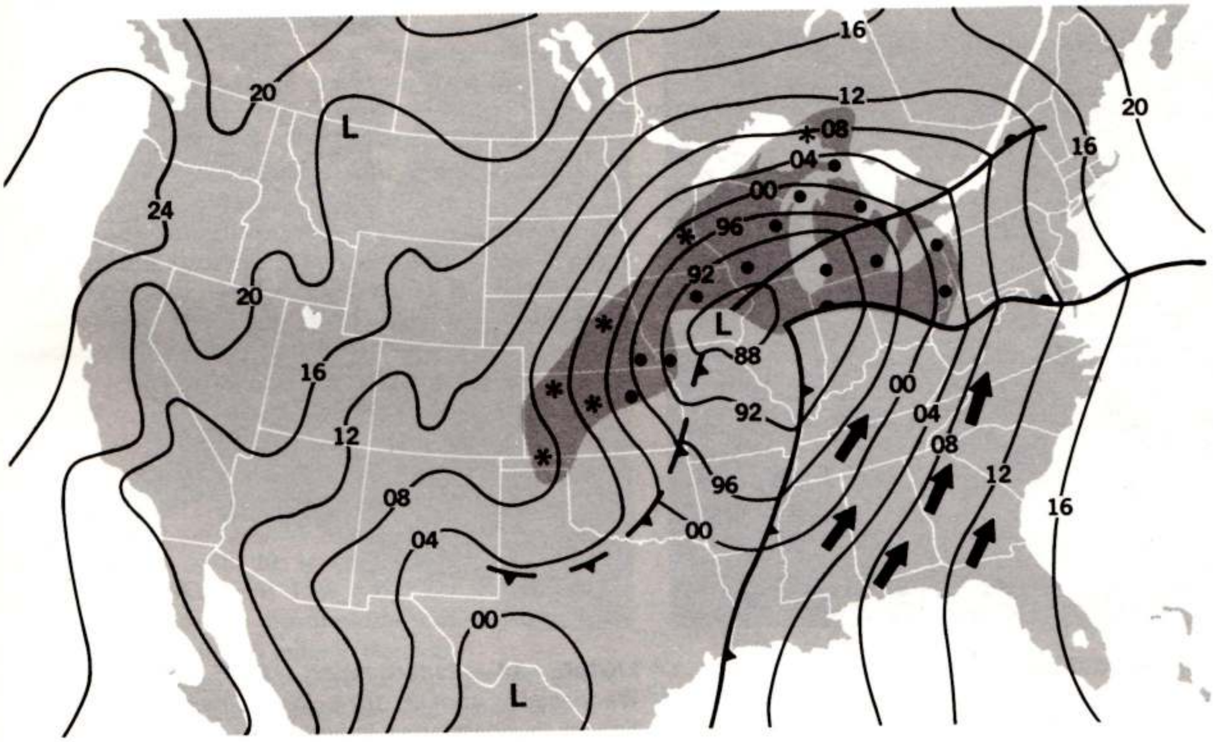


***FIGURE 11.**—Surface weather chart for 7:00 p.m. CDT Wednesday, April 3, 1974.*

identify, evaluate, and predict movement of mesoscale systems which spawn individual severe thunderstorms or small groups of tornadoes that would most likely go undetected through the present observational network.

In this connection conventional surface data were utilized by forecasters at the National Severe Storms Forecast Center (NSSFC). Every 1 to 2 hours selected surface data was automatically plotted and subsequently analyzed. Particular emphasis was paid to changes in the pressure field because past experience has indicated a strong correlation between pressure field changes and the location and movement of tornado-producing mesoscale systems.

In addition, the NASA Geostationary Applications Technology Satellite #3 (ATS-3) was used in real time during the April 3 outbreak by National Environmental Satellite Service's (NESS) Satellite Field Service Stations (SFSS) at Washington and Kansas City to assist in the preparation of operational forecasts and warnings. To accomplish this objective, each SFSS was manned by a team of specialists in the interpretation of satellite imagery. The Washington SFSS was responsible for the Weather Service's Eastern Region plus the States of Georgia and Michigan; the Kansas City SFSS was responsible for the remainder of the States covered by the outbreak. Additionally, the Kansas City SFSS provided input to the collocated NSSFC and the Weather Service's Central Region Regional Warning Coordination Center.

For use in conjunction with the satellite photographs, hourly network radar reports are received at the Radar Analysis and Development Unit (RADU) in NSSFC. From these reports composite maps of thunderstorm areas, heights, intensities, and movements are prepared and forwarded to the NSSFC forecaster as well as transmitted as scheduled via facsimile to all Weather Service Offices.

On the day prior to the outbreak (April 2) the Kansas City SFSS requested that the ATS-3 be committed to a tornado operational mode for the following day. On the day of the outbreak, pictures were taken every 13 minutes instead of the normal 30 minutes from 1:49 p.m. CDT to 6:24 p.m. CDT at which time insufficient illumination over the outbreak area forced discontinuation of the operation.

On April 3, satellite photos as early as 8:42 a.m. CDT showed a line of convective activity developing from Lafayette, La., northeastward to Clarksville, Tenn., and then looping back to near Paducah, Ky (fig. 12). Subsequent pictures throughout the morning indicated that the impulse or short wave originally located in southern Illinois (fig. 12, point A) had moved rapidly northeastward into potentially unstable air and would be capable of trig-

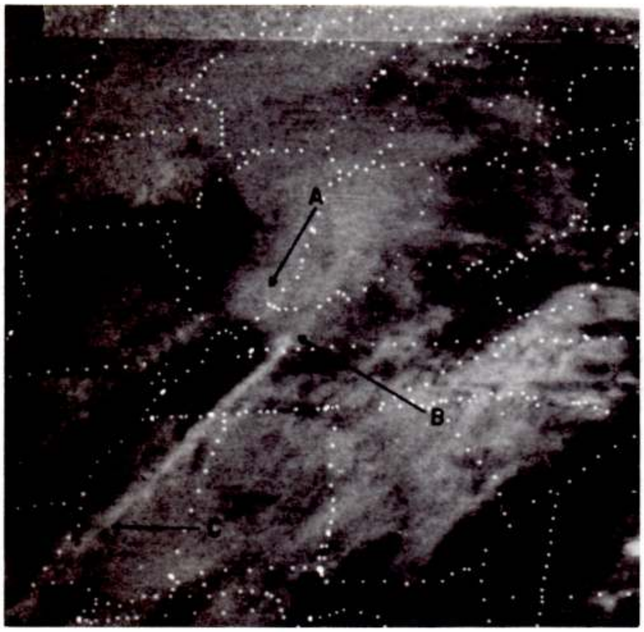


FIGURE 12.*—ATS-3 satellite picture for 8:42 a.m. CDT Wednesday, April 3, 1974. Convection at A is an upper-level impulse which subsequently moved rapidly northeastward through the Ohio Valley. Points B and C are the end points of a line of thunderstorms.*

FIGURE 13.*—Radar report, 11:35 a.m. CDT Wednesday, April 3, 1974. Solid lines represent line of thunderstorms imbedded in area of scattered thunderstorms. Thunderstorm tops are given in hundreds of feet and movement, indicated by arrow, in knots.*

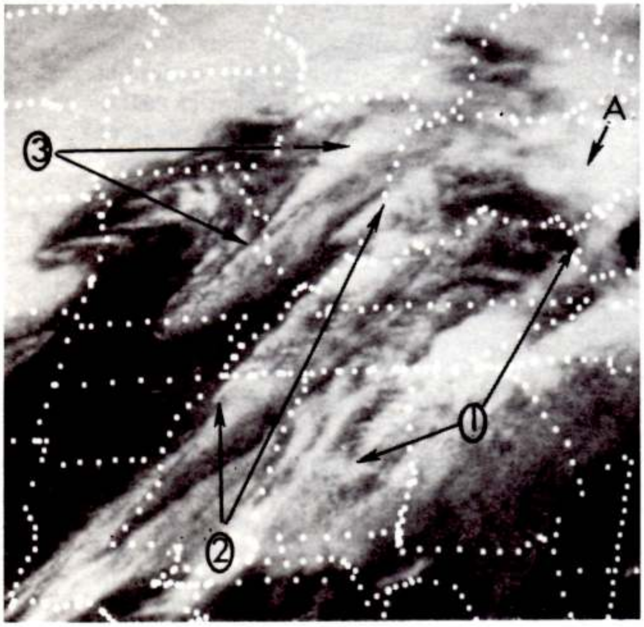


FIGURE 14.*—ATS-3 satellite picture for 12:53 p.m. CDT Wednesday, April 3, 1974. Numbers bracket the end points of the three separate squall lines.*

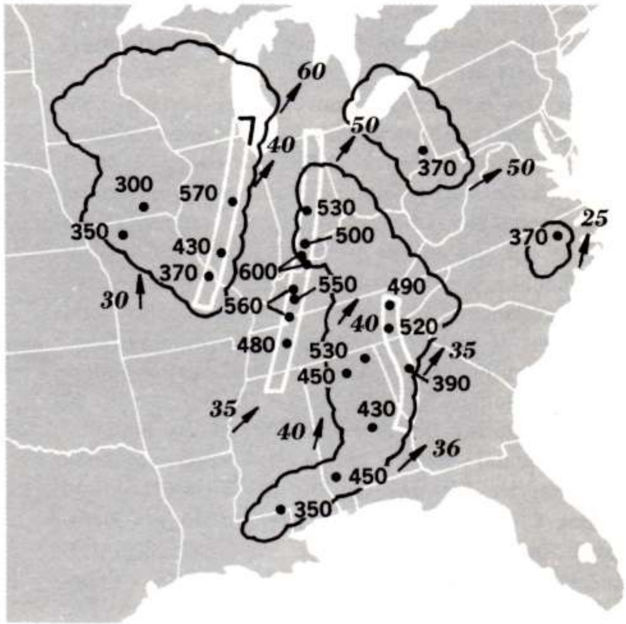


FIGURE 15.*—Radar report, 2:35 p.m. CDT Wednesday, April 3, 1974.*

gering severe weather in eastern Ohio and West Virginia. The Washington SFSS transmitted this information to the affected areas over the Radar Report and Warning Coordination network (RAWARC) at 11:30 a.m. CDT. Radar reports at this time indicated a squall line, with cloud tops well above 40,000 feet extending from the northeast corner of Indiana to southcentral Ohio southwestward into northern Alabama (fig. 13). By 12:53 p.m. CDT the latest satellite photo showed that at least three distinct squall lines were developing in the Mississippi and Upper Ohio Valleys (figure 14).

Moving at a speed of nearly 80 knots the upper-level impulse A had driven northeastward from western Kentucky into south-central Ohio. Based upon these observations, the Washington SFSS, at 1:00 p.m. CDT, notified Charleston, W. Va., that thunderstorms were rapidly moving eastward toward West Virginia, with the severest weather expected north of Charleston. At 3:00 p.m. CDT, Wheeling, W. Va., had a severe thunderstorm with hail, and a reported funnel cloud 6 miles to the east.

By 2:00 p.m. CDT both satellite photos and radar analysis depicted three separate squall lines: one from the southern shore of Lake Michigan southward through Illinois into Missouri, a second from southwestern Indiana into western Kentucky and Tennessee, and the third from eastern Tennessee south into northwestern Georgia and southwestward through east-central Alabama. Satellite pictures and radar returns used in monitoring the presence of these rapidly moving lines of thunderstorms indicated these thunderstorms had developed well ahead of the cold front.

Radar reports over the next hour noted that the thunderstorm tops associated with the second squall line were as high as 50,000 to 60,000 feet (fig. 15), well above the tropopause and indicating the severe nature of these storms. Satellite photos throughout the morning had shown clearing behind impulse A and ahead of the second squall line. In conjunction with the advection of dry air at middle levels, this clearing allowed the air mass in between to become convectively unstable. These conditions contributed to the devastating tornadoes at Brandenberg and Louisville, Ky., and Cincinnati and Xenia, Ohio, as the squall line moved into the potentially unstable air mass.

During the afternoon, satellite imagery was able to detect small areas capable of initiating severe local storms, as at St. Louis, Mo., and Brandenberg, Ky. In addition, satellite imagery was used to verify the accuracy of numerical guidance packages (in this case the Barotropic prog was good, while the Baroclinic guidance was much too slow).

In short, radar and satellite data were absolutely essential for effectively issuing severe weather watches and warnings covering the large number of tornadoes spawned in this outbreak.

Appendix A

Description of Communications And Dissemination Systems

Efficient communications systems are vital to the total warning effort, serving to deliver necessary data and information to forecast centers and warning offices, effect required feedback and coordination, and finally to disseminate timely warnings to the public and action agencies. From NOAA's point of view, these systems may be divided, although there is some overlap, into internal *Communications* systems and external *Dissemination* systems. These systems employ four basic devices: teletypewriter, facsimile, radio, and telephone.

1. COMMUNICTIONS SYSTEMS

a. Teletypewriter: Three teletypewriter networks are included in this category. These are the Radar Reporting and Warning Coordination (RAWARC) network, the Service A teletypewriter network, and the Service C teletypewriter network. Circuit maps of these networks are shown in figures 16, 17, and 18, respectively.

RAWARC, a land-line network consisting of five circuits covering the 48 conterminous States, has the primary function of collecting and distributing radar reports and storm warning information. The Communications Center (KKCC) at the NSSFC in Kansas City is the monitor station for all circuits. The Technical Control Section at Suitland, Md., monitors the computer relay operation of the system. Traffic on RAWARC, which moves at 100 words per minute, is basically unscheduled and handled according to a priority system, although a scheduled collection of radar reports is made each hour. Tape preparation by stations on RAWARC remains essentially a manual operation, which makes the system slower than it might be wished, and some warning offices still were not equipped with RAWARC on outbreak day.

Service A is a long-line teletypewriter network operated by the FAA and has as a main function the collection and distribution of hourly surface aviation observations. These observations are collected and stored in the FAA's Weather Message Switching Center (WSMC) at Kansas City. This computer-controlled center sends the observations over the circuits according to programmed distribution patterns, and also provides forecast centers and warning offices with a request/reply capability to obtain observations only occasionally needed for their operations.

Service C is also a long-line teletypewriter network operated by the FAA. This network serves to collect and distribute basic synoptic surface and upper air observations, and is also controlled by the WMSC in Kansas City. Stations are polled according to a prescribed sequence for scheduled traffic and the data are relayed to other circuits of the network as needed.

b. Facsimile networks: These networks are designed to distribute information in graphical form. They provide the various centers and warning offices with scheduled charts depicting analyses, forecasts, and selected observational data. The bulk of the traffic is guidance material prepared by the National Meteorological Center (NMC) in Suitland, Md. Other information transmitted on facsimile includes digitized satellite mosaics from the National Environmental Satellite Service (NESS) and, from the NSSFC, composite radar charts and graphic severe thunderstorm outlooks.

c. Telephone: Telephone is used internally, primarily for the coordination of forecasts and warnings. It provides a rapid, though not foolproof, means of contact between NOAA offices. Both commercial and Federal Telephone System (FTS) lines are used. The major drawback of this communications device is that channels and/or telephones are frequently busy when needed most.

2. DISSEMINATION SYSTEMS

The vital dissemination phase of the total warning system may be basically thought of as a double-branched communication channel wherein watches and warnings flow rapidly from NOAA warning offices to local action officials on the one hand and to the general public on the other. In actual prac-

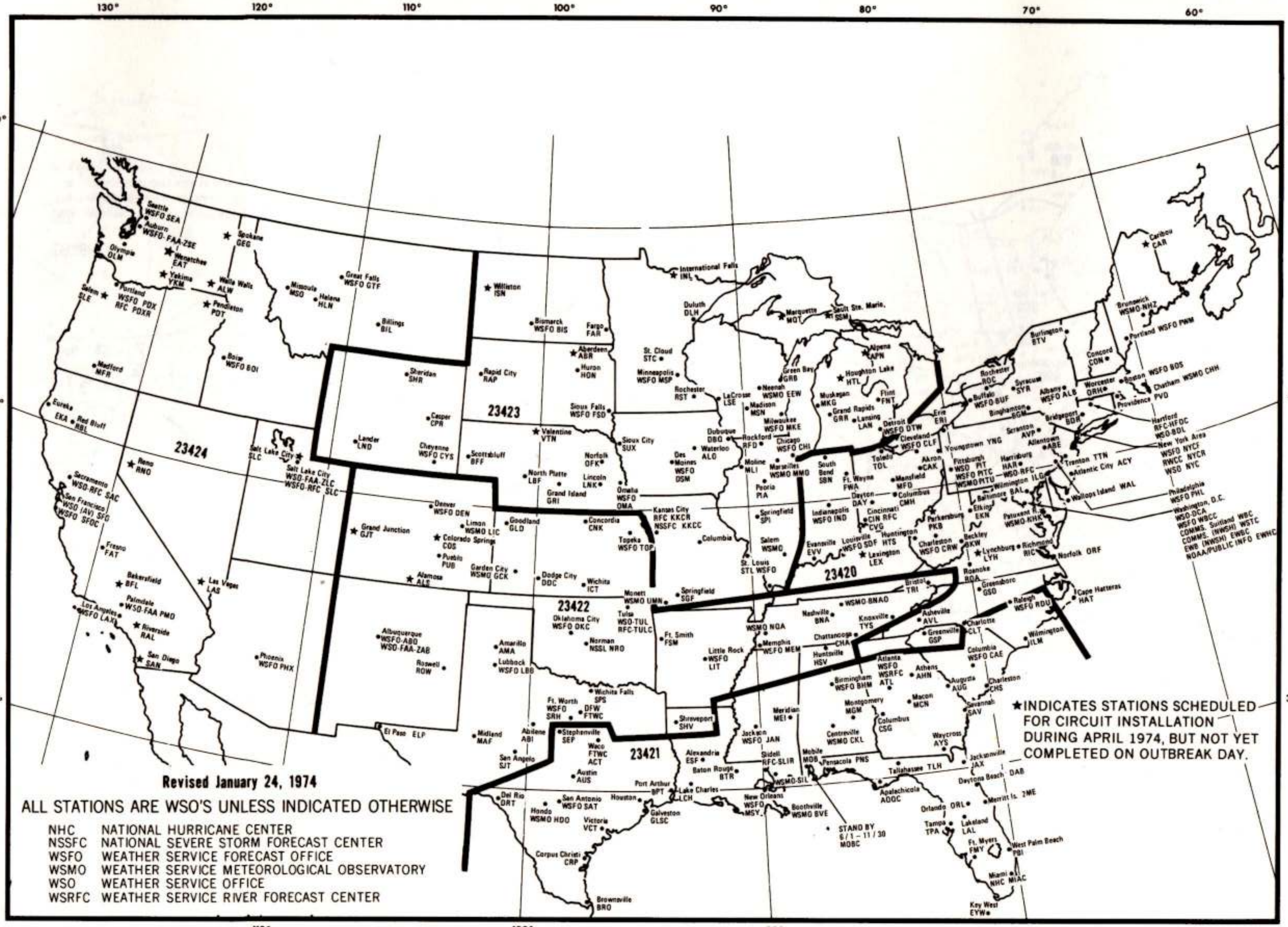


***FIGURE 16.**—Radar Reporting and Warning Coordination (RAWARC) network.*

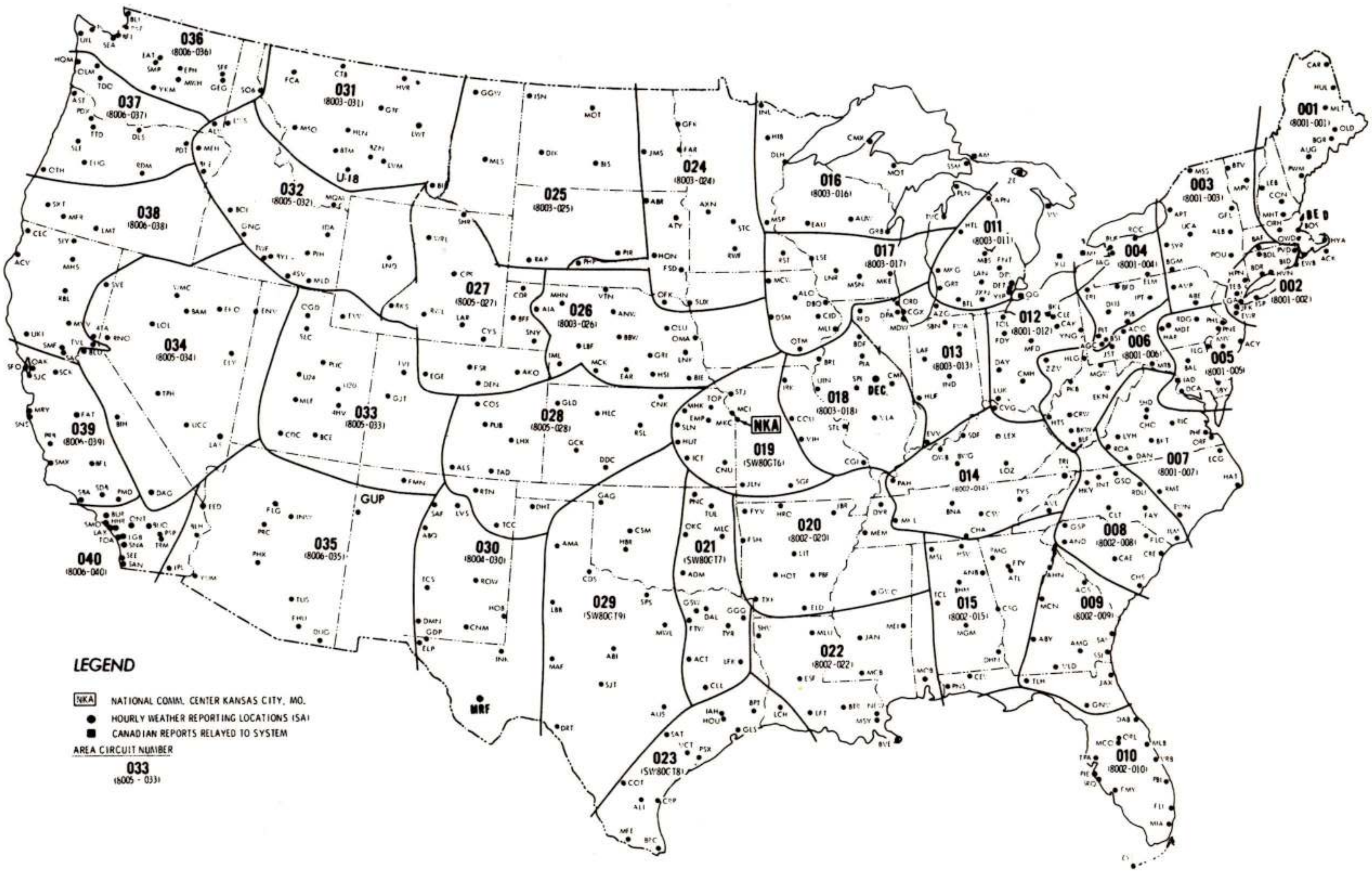


FIGURE 17.—*Service A teletypewriter network.*

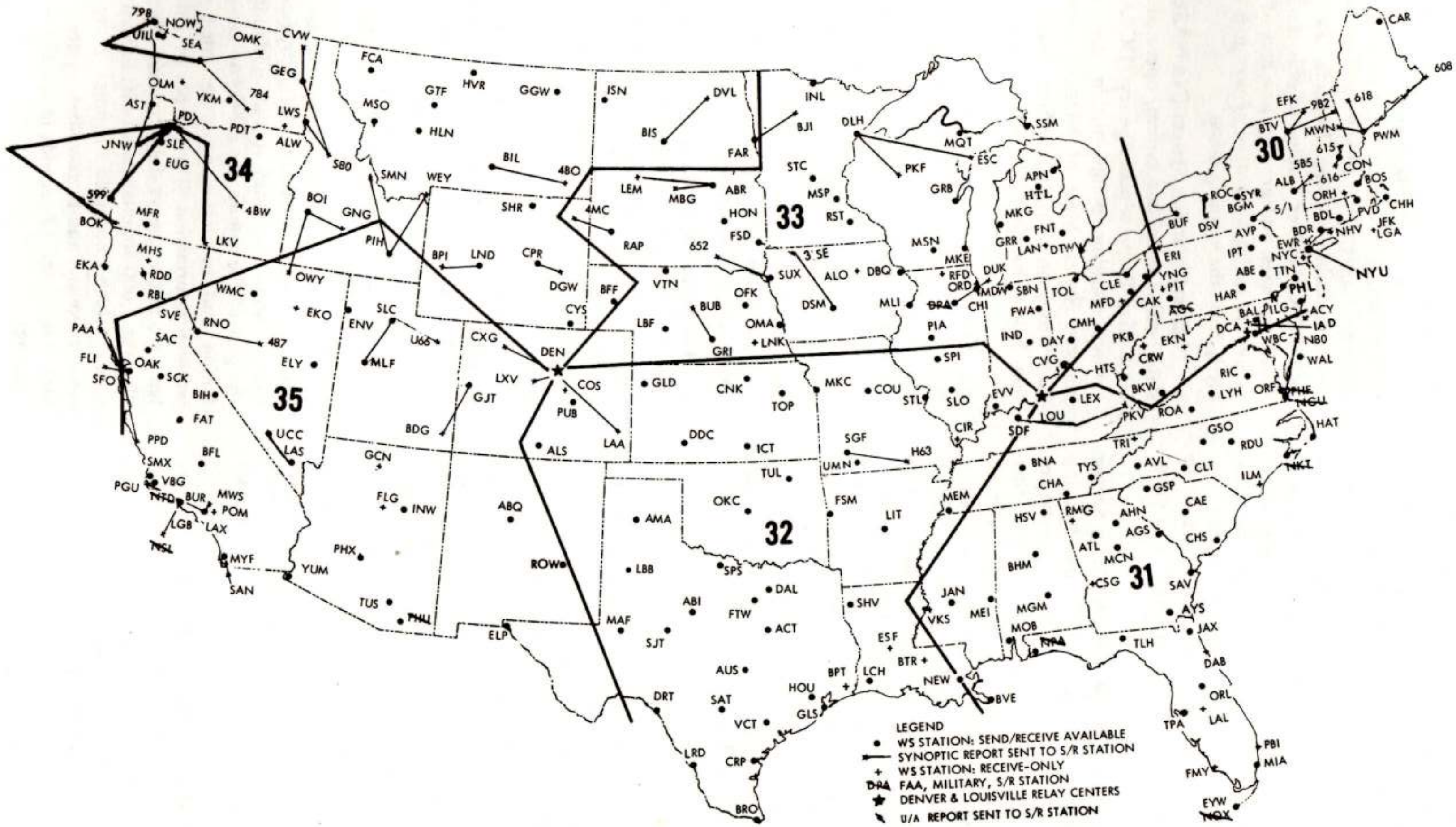


FIGURE 18.—*Service C teletypewriter network.*

tice, this simple concept consists of a complex mix of radio, television (both broadcast and cable), telephone, and teletypewriter systems, with varying delivery times. There is considerable variation from State to State and from rural to urban location in the makeup of the mix of techniques used to get the word to the public. While the most rapid means of delivering warnings from the NOAA offices to either branch of this dissemination channel are the voice transmission devices available, the "hard copy" capability of the teletypewriter circuits still results in the most effective widespread dissemination in many instances.

a. NOAA Weather Wire Service (NWWS): Severe weather issuances from the NSSFC and warning offices are distributed to mass media, government agencies, and local officials via this teletypewriter service. Primarily intrastate in nature, these circuits provide warnings directly to those radio and television stations which avail themselves of the service and to the press wire services for subsequent relay to their customers. NOAA pays the line charges to any city where NWWS subscribers are located, and the subscriber pays for connection charges and local equipment. NWWS transmission of severe weather warnings is given first priority, due to the potential for reaching a great number of people through radio and television, but it must be noted that the preparation of hard copy warnings is more time-consuming than the voice dissemination methods. While NWWS is not yet available in 12 States, the service was installed through practically all the area affected by the massive tornado outbreak. Since each NWWS circuit generally serves only one State, interstate relays of warnings are made by RAWARC circuits or, if this is not possible, over NWWS overlay circuits.

Where advance arrangements have been made, warning offices may use NWWS to activate the Emergency Broadcast System (EBS) through request of the Emergency Action Notification Attention Signal (EANS). EBS makes use of the voluntary cooperation of non-government broadcast stations, and the final decision to use or not to use EANS rests with the radio or TV station. When used, the EBS station precedes transmission of each warning with a tone alert signal which turns on properly equipped muted receivers.

b. NOAA Weather Radio (VHF–FM): A certain number of warning offices are equipped with VHF–FM transmitters and send out continuous weather broadcasts. So far, these stations are concentrated along the coasts for dissemination of weather information to marine interests, but locations of a limited number of the stations were within the tornado outbreak area. The signal from these transmitters travels line-of-sight and is therefore limited to approximately 40 miles from the transmitters, which also have the capability of sending a tone alert signal to activate specially equipped receivers during warning situations. In areas served by NOAA Weather Radio, schools, factories, local action agencies, and growing numbers of the general public are taking advantage of warnings received directly from the warning office.

c. National Warning System (NAWAS): This interstate hotline telephone system, operated by the Defense Civil Preparedness Agency (DCPA), connects various warning points within each State and between States. Most of NOAA's warning offices have drops on at least one State system. Each station has a hand-set for transmission and a loud speaker that constantly monitors this party-line circuit. Severe weather issuances are made available on NAWAS immediately after they are prepared and may be subsequently relayed on local or State Police communications systems. An important feature of this system is the feedback it provides to the warning office, both with reports of severe weather and with some indication of local response to the warnings. During rapidly breaking situations, NOAA warning offices may also use this system for instant coordination of warnings.

d. Telephone: Most warning offices have telephone call lists for severe weather warning dissemination. At stations where the NWWS, NAWAS, EBS, and NOAA Weather Radio dissemination arrangements are effective, the telephone list is usually short. However, some stations have excessive lists with as many as 40 telephone numbers to call in order to ensure dissemination of warnings. Even when the station is aided by automatic dialing equipment, this is a very poor way of issuing short-fused warnings. In some metropolitan areas, telephone hotlines connect the warning office with local police, fire departments, or civil defense offices for rapid dissemination of warnings.

Automatic telephone answering systems, while not considered too effective for short-fused warning dissemination since they require initiating action on the part of the public, do allow "on-demand" distribution and confirmation of recorded watch and warning information. Three types of automatic systems are in use: heavy-duty systems, which can handle over 1,000 simultaneous calls; limited-access systems, which normally handle 2 to 10 calls simultaneously; and large-volume systems which provide abbreviated (7 seconds in length) forecasts and warnings.