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A Case Study in Forensic Meteorology: Investigating the 3 April 1956 Tornadoes in Western Lower Michigan

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ABSTRACT

An investigation into a historic tornado outbreak in southwest Lower Michigan yielded several significant findings and provided details about path length, duration, and intensity of each tornado. These findings are presented here, along with discrepancies that were found with the National Climatic Data Center's storm event database for the number of tornadoes and fatalities that occurred in this event. Potential strategies in forensic meteorology for future studies of historic tornado events also are presented, including suggestions for gathering and synthesizing data. Finally, strategies are discussed for using anniversary events to increase public awareness of severe weather.

1. Introduction

In early 2005, as the 50th anniversary of the worst tornado in southwest Lower Michigan approached, the Grand Rapids National Weather Service Forecast Office (hereafter referred to as NWS GRR) and members of the local emergency management community embarked on a project to commemorate the event. The primary purpose was to raise local public awareness of severe weather safety – specifically, the threat posed by strong tornadoes. This project was inspired in part by similar 50th anniversary events held for the F5 tornadoes in Flint/Beecher, MI, and Udall, KS in 2003 and 2005, respectively. The Hudsonville to Lakeview tornado of 3 April 1956 killed 17 people, injured 300 and caused $12 million (non-inflation-adjusted) in damage. This tornado, which is rated an F5 in the National Climatic Data Center's (NCDC) storm event database, was part of a significant tornado outbreak on 2 and 3 April 1956 that extended from Oklahoma to Mississippi and north to Wisconsin (Hanks and Nuebrand 1956) and produced at least two other strong or violent tornadoes in Lower Michigan. The original focus of the study was on the F5 tornado, but with the help of local libraries and emergency management agencies, evidence for the two other tornadoes also was compiled. Through eyewitness interviews, it was discovered that damage from the F5 tornado actually resulted from two separate tornadoes, yielding a total of four tornadoes in Michigan on that day. See Table 1 for a description of the tornadoes.

The early stages of the project involved planning the commemoration event with the local media and emergency management communities, and the production of a video documentary by NWS GRR. Dozens of eyewitnesses provided photos, home movies and personal accounts of the storm, which were used in the video documentary. It was distributed to the media and public and was broadcast on local public access television in time for the commemoration event.

Media kits also were distributed to local print and television media about a month before the anniversary, including tornado details such as path length, F-scale rating, fatalities, injuries and inflation adjusted dollar estimates of damage. This information was used in a local television station documentary on the storm and in several local newspaper stories published around the date of the anniversary.

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Table 1: Specifics on four tornadoes of 3 April 1956. See Fig. 1 for a map of their paths.

Tornado	Fatalities	Injuries	Rating	Time (UTC)	Path Length (mi)
Saugatuck to Holland	0	7	F4	2240 to 2300	9
Hudsonville to Lakeview	17	285	F5	2335 to 0050	52
Portage Point to Grand Traverse Bay	1	25	F4	2335 to 0045	50
Bangor to Lowell	0	12	F3	0015 to 0130	55

The project culminated on 3 April 2006 with the commemoration event. Data gathering continued after the anniversary as more information became available from people who learned about the project through media attention. Eyewitness accounts and several photos were included on an NWS GRR web page: www.crh.noaa.gov/grr/science/19560403/. A more comprehensive collection of stories and filmed interviews was put together as a book and DVD by the Grand Rapids Historical Society (Ostuno, 2008).

2. Data Sources

a. Eyewitnesses

About 150 eyewitnesses were found, most from the Hudsonville and Grand Rapids areas, where the F5 tornado did its most widespread damage. They included people who were in the path of the tornado, who witnessed the tornado but were not directly affected by it, and who were involved in the recovery and rebuilding. A series of videotaped interviews with about two dozen eyewitnesses was conducted by NWS GRR and the Hudsonville Emergency Operations Center. The interviewees were asked about their level of awareness to the tornado threat that day, and how they responded to the approach of the tornado. They also were asked to describe the impact the tornado had on their life and the local community. People who were members of the National Guard, media, and medical fields in 1956 were interviewed concerning the disaster response perspective. Several dozen written accounts also were collected, generally consisting of descriptions of the impact on individuals or families. Like all historic disasters, the tornado event made an indelible impression on those who witnessed it. Even 50 years later, virtually everyone who was old enough to remember the event could recall specific details of that day, including what they were doing, what the sky looked like, as well as the sights, sounds, and details of the damage inflicted by the tornadoes.

Eyewitness information was crucial to creating a detailed account of each tornado and its aftermath, including a re-analysis of the damage paths (Fig. 1) in space and time. Note that the F5 tornado path has been broken up into two separate paths. This yields a fourth tornado (referred to here as the Holland to Saugatuck tornado) that was rated F4 based on damage photos. The separation between these two tornadoes in space is 11 mi (18 km) and in time is about 30 min.

b. Newspapers

Several local newspapers along the paths of the tornadoes were searched for relevant articles. Papers for many of the smaller communities were published weekly, whereas daily papers were confined to the larger cities of Holland, Grand Rapids and Kalamazoo. Several libraries also had microfilm or digitized versions of the Detroit newspapers and the New York Times, each of which also contained news stories of the tornadoes. The daily papers typically had news stories for several days on the impact and recovery. Weekly papers carried stories of the impact in the first issue following the tornadoes, followed by stories about recovery efforts in the subsequent weeks.

c. Photographs

Four photos of the Saugatuck to Holland tornado were found, taken by two photographers. About two dozen photos of the Hudsonville to Lakeview tornado were found, taken by eight photographers. All but three of the photos of this tornado were taken from the northwest sections of Grand Rapids. There were no photos available of the tornado from north of Grand Rapids towards the more sparsely populated areas of

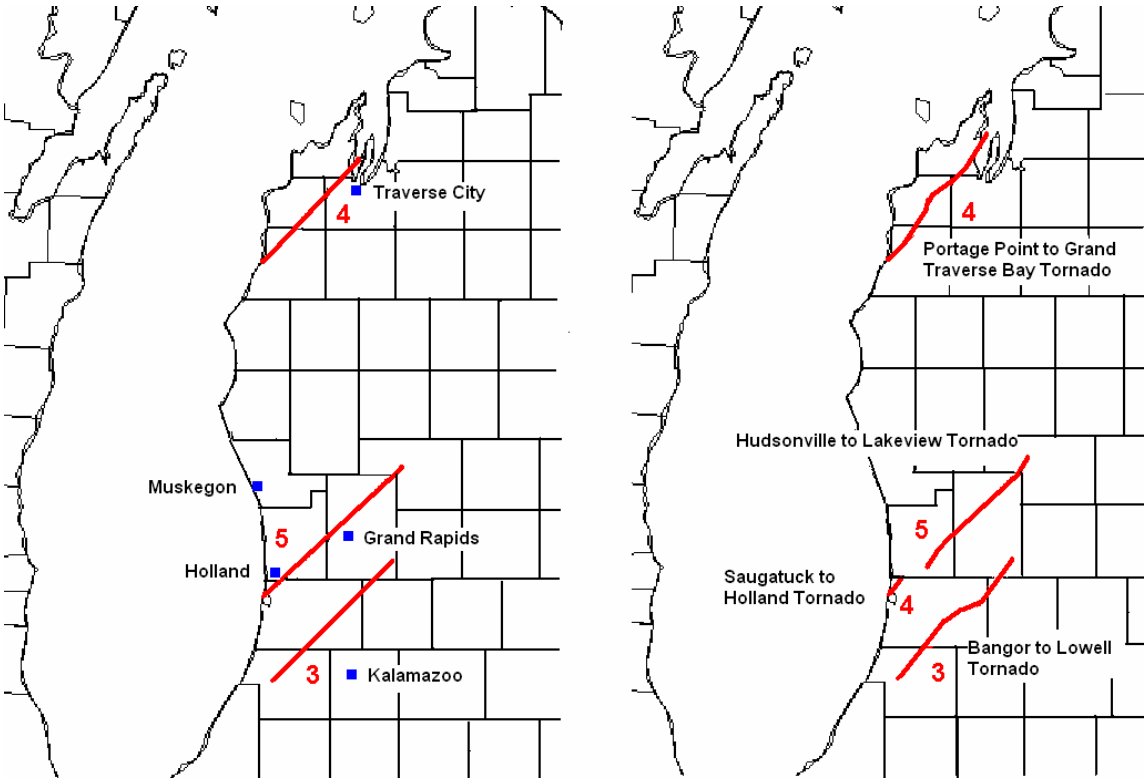


Figure 1: A comparison of paths of the tornadoes across Lower Michigan on 3 April 1956 and their Fujita scale ratings (Fujita, 1971). At left is the plot of three tornadoes from the National Climatic Data Center (NCDC) Storm Events database. On the right is the revised path of the tornadoes based on eyewitness and archival newspaper accounts.

Rockford and Trufant. There were no photos found of the Portage Point to Grand Traverse Bay tornado or the Bangor to Lowell tornado. Although both tracked for more than 50 mi (80 km), the paths crossed sparsely populated areas. The latter tornado also occurred after sunset.

After 50 years, it is possible that some original photos may have been lost, destroyed or forgotten. One remarkable find was three color slides of the F5 tornado at the time of its fatalities in the Hudsonville area. The photographer died in 2005 and the slides were provided by a relative, who stated that the photographer had carefully organized and labeled them. Otherwise, these slides may have been overlooked, even with the media coverage of the anniversary.

Several photos were particularly useful in the forensic investigation of the tornado event. One, obtained during the early stages of the project, showed the thin rope-like funnel of the Saugatuck to Holland tornado in its dissipating stage (Fig. 2). The trained NWS spotter who provided the photo, and who was a member of a local historical group, knew several eyewitnesses that had observed the tornado dissipate from just south of Holland.

A series of photos of the Hudsonville to Lakeview tornado at Standale were labeled with the times that they were taken (Fig. 3). This was useful in corroborating other eyewitnesses' accounts of the storm's timing.

Not surprisingly, photos of the damage produced by the tornadoes were much more common than photos of the actual tornadoes. Several hundred damage photos were collected over the course of the project. Most were black and white prints, but there were several dozen color slides. About half of them were labeled with the exact location, and about eighty percent with the general location. These photos played an important role in a reassessment of the Fujita (F) scale ratings for three of the tornadoes that appear in the NCDC database, as well as a rating for the Saugatuck to Holland damage path.

Figure 2: The Saugatuck to Holland tornado is seen here in its eighth mile on the ground. The damage path would end after one more mile. Photo credit: Jarvin Kleiman.

d. Movie footage

In addition to photos, 16 mm black and white and 8 mm color film of the F5 tornado were found. Both were taken from the northwest part of Grand Rapids. The 16 mm film consists of about two min of footage shot by a Grand Rapids television journalist from the roof of his house. The 8 mm clip is only about 10 s in length, but shows amazing detail, including the evolution of a suction vortex. It can be viewed at: www.crh.noaa.gov/grr/science/19560403/video/ .

About 15 home movies of the damage in the Hudsonville and Grand Rapids areas were collected and used to illustrate eyewitness accounts in the video documentary.

3. Methodology

a. Data collection

Articles about the impending 50th anniversary of the historic tornado event were published in the Holland and Grand Rapids, MI, newspapers, respectively. These are the two largest circulation daily newspapers in the areas affected. The articles included a request for eyewitness accounts, photos or home movies of the tornado event, resulting in several dozen responses. Local emergency management personnel and historical societies were very helpful in publicizing the search for eyewitnesses as well.

Archives of local newspapers were another primary source of detailed information such as specific areas affected, times of occurrence and names of those who had property damage. Combining the names and locations (usually a township) of those mentioned in the newspaper articles with plat maps showing property owners, it was possible to "connect the dots" in terms of plotting the damage path across an area (Fig. 4). Archives of local papers and plat maps can be found at local libraries. Some libraries have digitized versions of local newspapers equipped with search functions, making it easier to find pertinent articles on historic weather events. Local historical societies are another source of local newspapers and special collections of memorabilia. Several such societies were able to produce local newspapers from 1956 when local libraries could not. See Appendix A for a listing of the sources used in this study.

There were occasional errors in the earliest editions after the event. An injured person was listed as a fatality and names of some of the victims were misspelled. When checking newspaper archives, it is a good idea to look for stories at the end of the year "wrap-up" editions and again on the first year anniversary. These retrospective stories often are very detailed and give a good general summary of the important aspects of the event. Also, errors typically occurring in the initial reports usually are corrected in later stories.

b. Data management

Photos and slides were digitized using a scanner with 300x300 dots per inch (dpi) resolution. This resolution, or higher, is recommended if the photos are to be reproduced for print or electronic media. Home movies in VHS format were digitized using a DVD video recorder. Commercial photo labs were used to transfer 8 mm and 16 mm film to DVD.

The large amount of material collected required careful tracking and filing. Names and contact information of the sources of the photos were recorded, along with names of the photographers, if known. Digitized photos were placed in subfolders named after the photographer. If the photographer was unknown, then the name of the person who provided the photos was used. The subfolders then were placed into folders named for each of the tornadoes.

c. Strategies for future studies of historic weather events by NWS offices

Researching historic local weather events can be a worthwhile activity for several reasons. In addition to refining knowledge of, and correcting errors in the official documentation of the details of these events, publicizing extreme event anniversaries can increase severe weather awareness among the general public. Relations between the NWS office and the local print and electronic media also can be enhanced by the collaboration that occurs during such a project.

Figure 3: The Hudsonville to Lakeview tornado moving through Standale. Photo credit: George Davis.

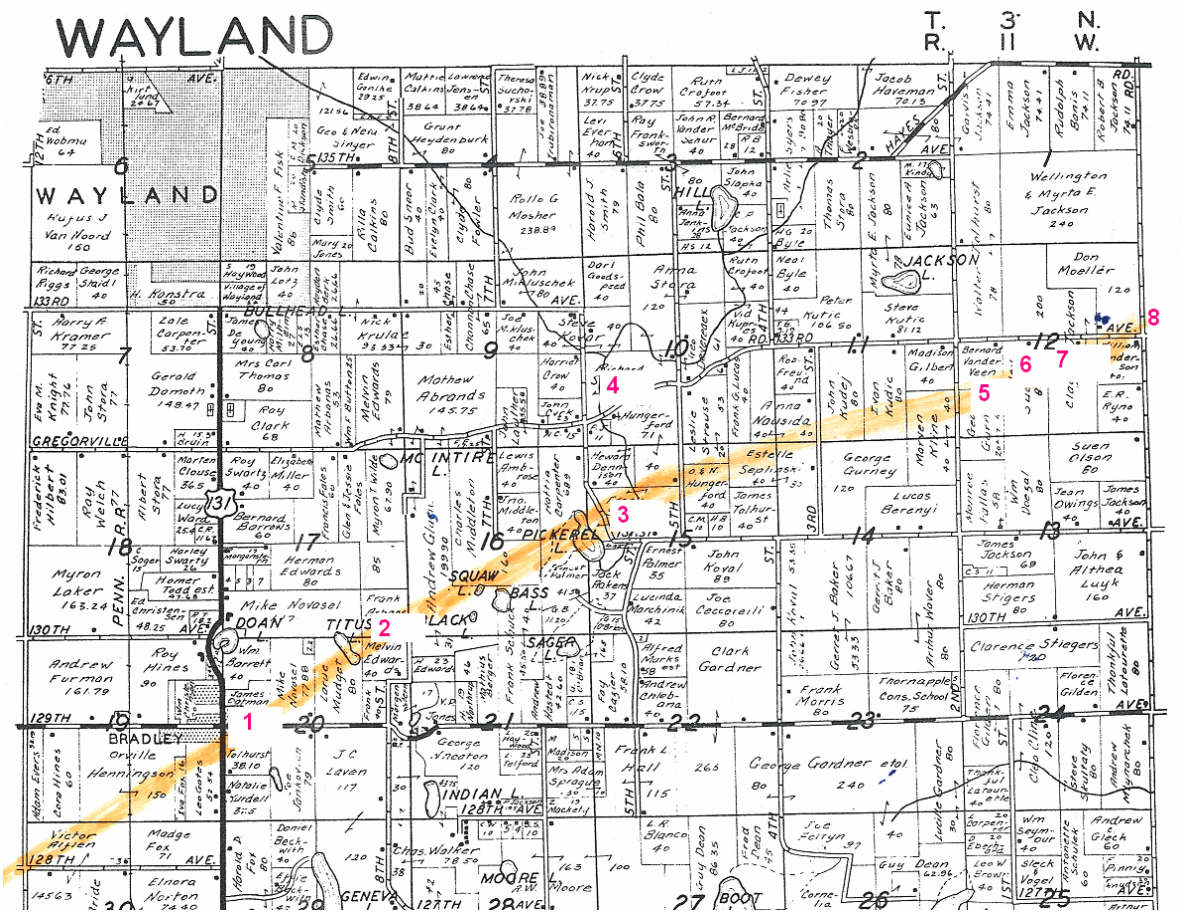


Figure 4: A section of a 1954 plat map of Wayland Township in Allegan County, MI, with locations of damage noted in local papers and by eyewitnesses. Numbers 1 through 7 were locations of trees down. Number 8 is the location of an outbuilding that had its roof blown off. The orange line is the estimated path of the tornado or peak winds of the rear flank downdraft based on the distribution of the damage reports. Map courtesy of the Allegan Public Library.

Local media can be used to both gather and present information on these events. Video documentaries detailing the first-hand accounts of storm survivors can be especially effective in reinforcing the message of severe weather safety. These documentaries can be produced independently by the NWS office or through joint projects with local schools, libraries, historical societies and media.

Depending on the scope of the projects, data gathering should begin six months to a year prior to an event's anniversary so that photos and stories can be prepared for web presentations or video documentaries. Preparation for anniversary events should involve local officials, especially city government and emergency management agencies who can help plan events and provide facilities and logistics, as well as take part in press conferences and produce media packages.

One of the first tasks is to establish the meteorological details of the event. Many historic events may already be documented in the meteorological journals. For those that are not, local observations and other climatological data must be collected. There are several potential sources for this information, including state, regional and national climate data centers.

After reconstructing the meteorology of the event, the next step is to document the impact of the event. Eyewitnesses may be found through local media or emergency management agencies and, in the National Weather Service, through public outreach activities such as SKYWARN training. For this event, appeals for eyewitnesses in local newspapers resulted in several dozen responses. About 75% of the responses were through the phone and the rest via email. For a 50th anniversary event such as this, the age group of eyewitnesses can be expected to be mostly elderly. The age group of those responding

ranged from about 55 to 95 years old, with the median age around 75. Despite the advanced age of the older eyewitnesses, many of their accounts included considerable detail about the weather conditions and other aspects of the event.

However, some eyewitnesses may confuse the details of one tornado with others that occurred through the years. For example, the Hudsonville to Lakeview tornado damage path was crossed by an F4 tornado during the 1965 Palm Sunday tornado outbreak (Fig. 5).

The Bangor to Lowell tornado damage path was crossed by that of an F2 tornado in the 1965 Palm Sunday outbreak, and was within a mile of an F2 tornado path from 21 April 1967. Several eyewitnesses sent in photos of damage from the 1965 and 1967 events, believing that they were photos of the damage from the 1956 event. Careful analysis of the photos revealed clues that they were not from 1956, such as the styles of cars and dress in the photos and even the photographic material itself.

Libraries and historical societies are the primary sources for archives of local newspapers. They also may have special historic collections that include newspaper articles, photos or personal accounts of the event. Newspaper articles are useful for determining details on the location of the damage. Several local papers included names and addresses of farms, homes and businesses that suffered damage. Red Cross records also included names and locations of people who had required aid in the wake of the tornadoes. Combining this information with archival plat maps was an effective means of plotting the tornado paths.

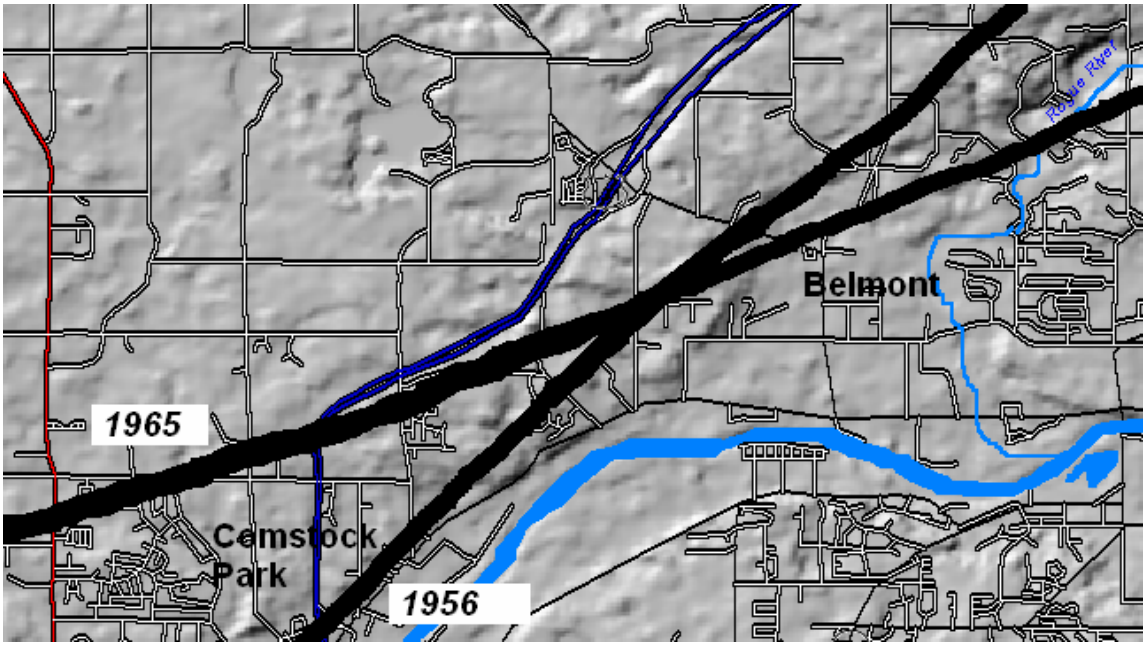


Figure 5: The Hudsonville to Lakeview tornado path was crossed north of Grand Rapids by an F4 tornado during the 11 April 1965 "Palm Sunday Outbreak". One farm was hit by both tornadoes. The 1956 tornado destroyed the farm house. A pole barn was put up on the site of the house, only to be destroyed by the 1965 tornado. Background map courtesy of the United States Geological Survey.

Local television stations may have archival news footage or documentaries of the event. A Grand Rapids television station had a locally produced program from 1964 about tornadoes that included video footage, and even an audio recording, of the Hudsonville to Lakeview tornado as it passed by Grand Rapids.

Details on damage estimates can be found in Red Cross records, while details on fatalities can be found in county government records of the medical examiner and coroner. Newspapers and hospital records can give information on the number and types of injuries. It should be noted that both newspapers and official documents occasionally misspell names and contain other errors. In general, details should be confirmed

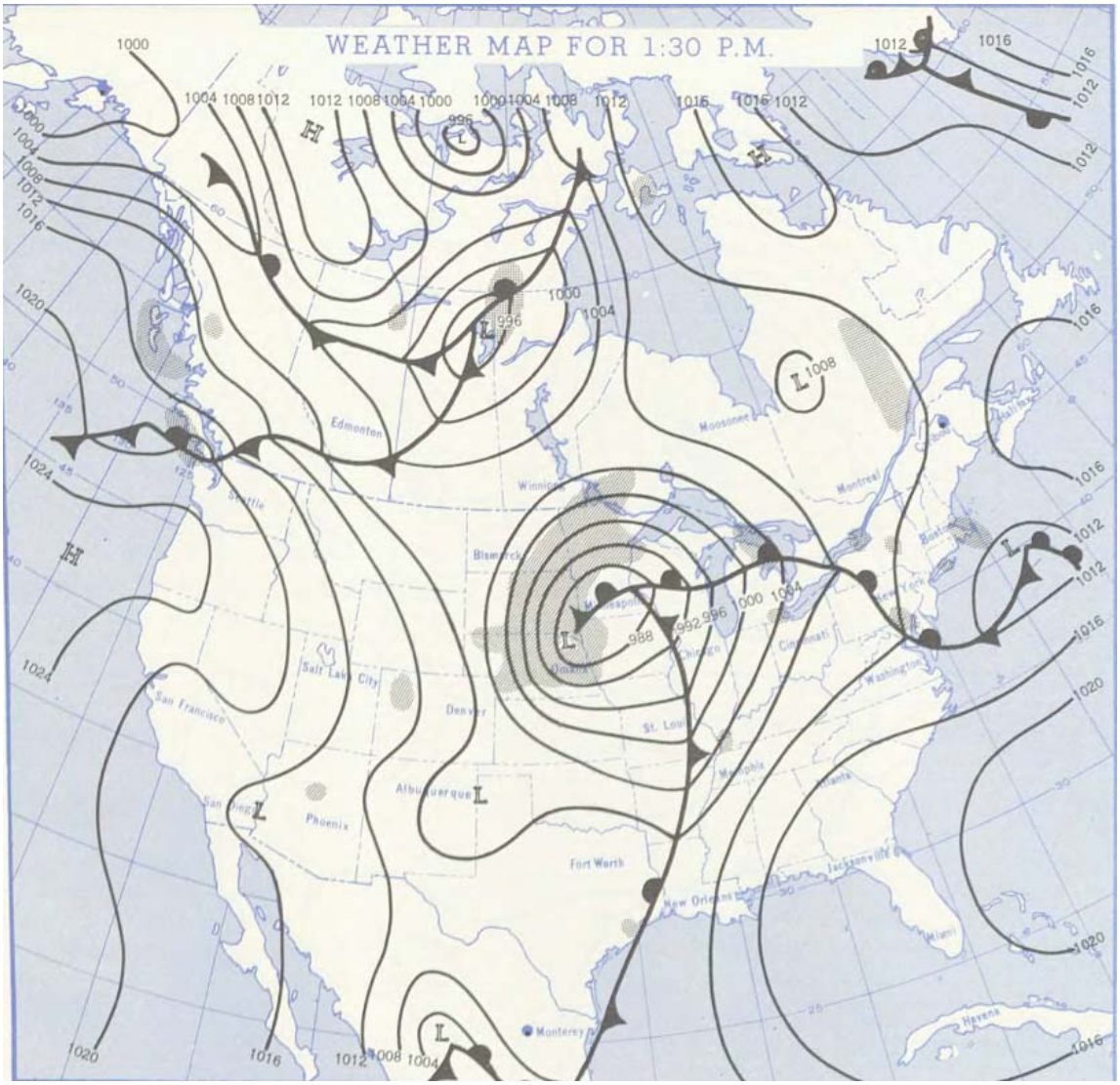
by at least two separate sources such as newspapers, official records, and eyewitnesses. This is especially true for the details in accounts that are received second hand. In these cases, another, preferably primary source of information should be used for confirmation.

4. Findings

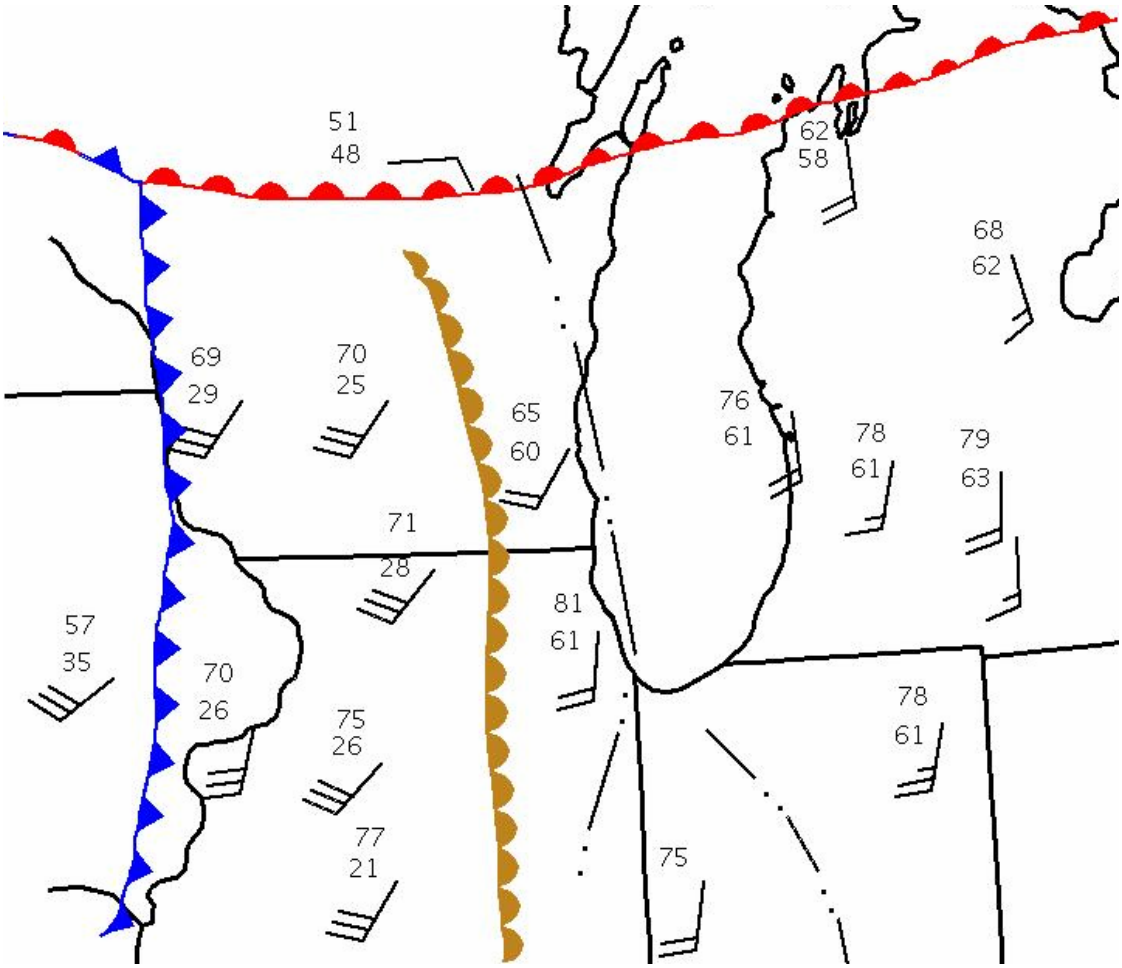
a. Meteorological conditions

Surface weather conditions on the afternoon of 3 April 1956 featured a deep low pressure center over the upper Midwest and a warm front across northern Lower Michigan (Fig. 6a). Strong southerly winds had transported warm and moist air into Wisconsin and Lower Michigan, with a record high temperature of 78° F (26 °C) set that afternoon at Grand Rapids. Dewpoint temperatures were above 60 °F (16 °C), even near the Lake Michigan shore (Fig. 6b).

A pronounced drop in dewpoint temperatures across northern Illinois indicated a dryline in this area, and suggests a deeply mixed layer of drier air had been advected well north of its source region in the southern Plains or desert Southwest. The 500 hPa map (Fig. 7) shows a closed low centered over northwest Wisconsin with a full-latitude trough extending to the southwest U.S. Strong southwest winds at 500 hPa covered much of the area that experienced severe weather on 3 April, including a radiosonde-observed wind of 135 kt (69 m s^{-1}) at Little Rock, AR.



(a)



(b)

Figure 6: 3 April 1956 surface weather maps. (a) 1830 UTC. Courtesy of the National Oceanic and Atmospheric Administration (NOAA). (b) 2030 UTC, adapted from Fig. 8 of Hanks and Neubrand (1956). Squall lines were analyzed across northern Indiana and western Lake Michigan. Plotted features are conventional. Thermal units are in °F and winds are in kt, where each full barb represent 5 m s^{-1}.

Two of the tornadoes that struck Michigan on 3 April 1956 began at or very near the Lake Michigan shore, and may have begun as tornadic waterspouts over the lake. Climatologically, it is rare for tornadoes to occur on the Lake Michigan shore, especially in early April. Only one other significant tornado is noted by Grazulis (1993) to have begun over Lake Michigan in March or April during the period from 1880 to 1989, inclusive. This occurred during the outbreak of 28 March 1920. Lake Michigan surface water temperatures are typically only about 40 °F (5 °C) in early April. The stabilizing effect of its relatively cold waters on convective storms apparently was circumvented by the strong southerly surface winds, as there is no evidence of cool lake air from the station observations near shore. Indeed, the air temperature of 76 °F (24 °C) and the dewpoint temperature of 61 °F (16 °C) observed at Muskegon is quite remarkable for early April.

b. Public awareness and reaction to warnings

Severe weather, including killer tornadoes, struck Wisconsin about four hours before the first tornado in Michigan on 3 April 1956. A tornado forecast (the 1956 equivalent of a tornado watch) was issued by the National Severe Storms Forecast Center (NSSFC) for part of western Lower Michigan (Fig. 8) more than three hours prior to the first Michigan tornado. Civil Defense leaders were notified of the tornado forecast and at least one school district

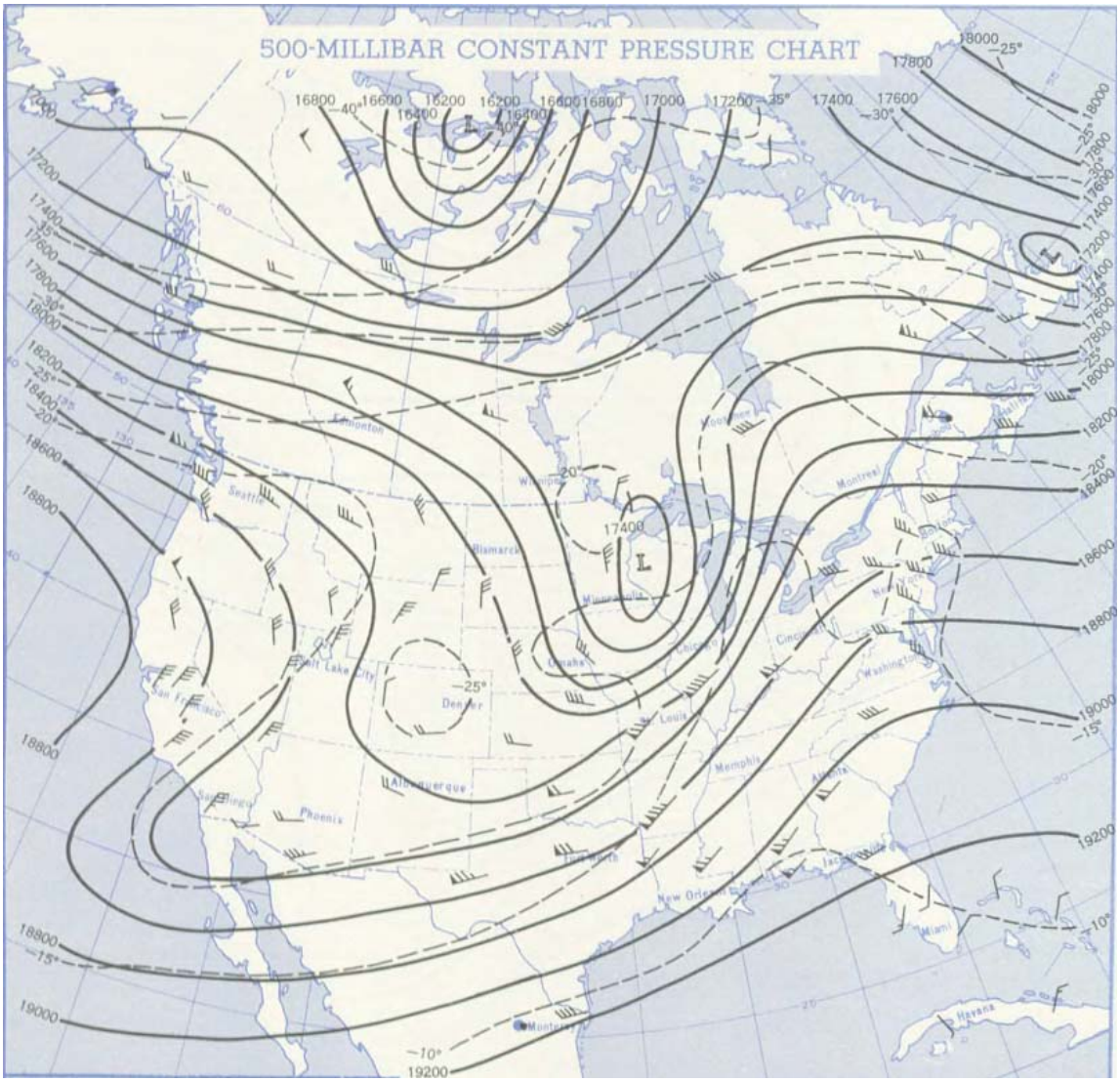


Figure 7: 0400 UTC 4 April 1956 500 hPa chart. Thermal units are in °C and winds are as in Fig. 6b. Courtesy NOAA.

(Holland, Michigan) let classes out early in anticipation of severe weather. Of the roughly 150 people that were interviewed or provided written accounts, about three quarters of them were aware of the possibilities of tornadoes on that day. Many of them recalled hearing about the threat of tornadoes on radio and television or from people they had spoken to that afternoon. A common theme expressed by most of the interviewees was a general belief among the population that "tornadoes don't happen in Michigan," despite knowledge of the devastating tornado at Flint, MI, less than three years prior. Even so, those who had heard about the threat were much more likely to recognize the approach of the tornado and take evasive action than those who had not. It could not be determined if a tornado warning was issued for the Saugatuck to Holland tornado. One of the interviewees stated that he "called the Weather Bureau" after sighting the tornado from Saugatuck. However, no one who was interviewed along its path recalls hearing a tornado warning.

A warning was issued for the Hudsonville to Lakeview tornado as it was moving into Hudsonville. The tornado was sighted south of Hudsonville by observers at a Civil Defense post in Cutlerville, about 7 mi (11 km) south of Grand Rapids. They called the U.S. Weather Bureau office in Grand Rapids and a tornado warning was issued. Several people in Hudsonville

recalled hearing the tornado warning on television and that the announcer specifically mentioned that the tornado was heading for Hudsonville. The reaction of those who heard the warning was either to take shelter immediately or to confirm the tornado visually and then take shelter. Those who had not heard the warning were more likely not to recognize the threat. Many people mistook the tornado for a column of smoke, since there had been several large fires in the area in the preceding years. Even after the tornado was recognized, some people stood and watched it until they saw buildings disintegrating before they took evasive action. People in at least two cars in Hudsonville drove into the tornado while trying to flee (Ostuno, 2007), resulting in two deaths and three serious injuries.

MKC FORECAST#62 ... "TSTM ACTVY IN SRN WIS ECPD TO INTSFY AND MV EWD THIS AFTN WITH SCTD SVR TSTMS AND TORNADOES LIKELY IN AREA ALONG AND 75 TO N AND 50 TO S OF A LN FROM 40 WSW MKE TO LANSING MICH UNTIL 2000C."

Figure 8: NSSFC Tornado Forecast Number 62, issued at 1918 UTC for part of Wisconsin, Illinois, Lake Michigan and Lower Michigan. Three of the four powerful tornadoes in western Michigan that evening occurred in the forecast area between 2230 UTC 3 April and 0130 UTC 4 April. Courtesy of Joe Schaefer, Storm Prediction Center.

The Portage Point to Grand Traverse Bay tornado occurred outside the NSSFC forecast area. None of the eyewitnesses recalled hearing a warning for this tornado, but some had heard news reports of the tornado hitting Hudsonville and northwest Grand Rapids shortly before this tornado struck.

None of the eyewitnesses to the Bangor to Lowell tornado heard a tornado warning, but several had heard mention of tornadoes during the evening news. A warning may have been issued for this tornado; since one of the interviewees remembers a police patrol car speeding up to a checkpoint in a tornado-damaged neighborhood in northwest Grand Rapids and announcing that another tornado was coming.

c. Descriptions of four tornadoes

1.) The Saugatuck to Holland tornado

The first tornado to strike western Michigan on 3 April 1956 began at the Lake Michigan shore near the town of Saugatuck at about 2240 UTC. This tornado injured seven people as it destroyed four homes and did significant damage to several other buildings (Fig. 9). The tornado damage path began at Camp Gray, a Presbyterian summer camp built on the sand dunes overlooking Lake Michigan, where several buildings sustained heavy damage. The path continued north-northeast to the popular summer resort area of Oval Beach, where the beach house was destroyed. The tornado then flattened the historic 97-year-old Saugatuck Lighthouse. All of these buildings were deserted at the time. The tornado crossed the Kalamazoo River and did minor damage at the David Bennett estate (point 4 in Fig. 9), where an eyewitness recalled seeing the debris cloud approaching, including a screen door floating high in the air. Five people suffered minor injuries as the tornado continued northeast and leveled two homes in rapid succession. Several farms received varying degrees of damage and another home was destroyed before the tornado damage path ended, just as it was about to move into a residential area on the southern outskirts of Holland, Michigan (Fig. 10). The funnel cloud was observed moving over the southeast part of Holland and dissipated near the town of Zeeland, where debris was seen

falling from the sky. The F4 rating is based on the descriptions and photographs of the Saugatuck Lighthouse and three homes that were destroyed completely (see Subsection *d*.). As of 2008, NCDC listed this tornado as the same that hit Hudsonville and Standale.

2.) The Hudsonville to Lakeview tornado

This tornado, the strongest and deadliest on record in western Lower Michigan, began in an open field about 3 mi (5 km) southwest of Hudsonville, about 30 min after the first tornado ended. It was the one of three tornadoes in Lower Michigan that evening to produce significant damage over a path > 50 mi (80 km).Given the differences in time and distance, it is possible that this tornado was spawned by a different thunderstorm than the one that produced the Saugatuck to Holland tornado.

The first damage occurred at a farm where a barn was rated F1. The tornado intensified very quickly. Less than 3 mi (< 5 km) into the path, the first fatality occurred in what appeared to be F5 damage to several homes (see Subsection *d*.). In about 30 min, a total of 13 people were killed across the western and northern outskirts of Hudsonville, with another four fatalities in the northwest suburbs of Grand Rapids, where the tornado left a patchwork of F1 to F5 damage across residential areas of Walker and Comstock Park (see Subsection *d*.).

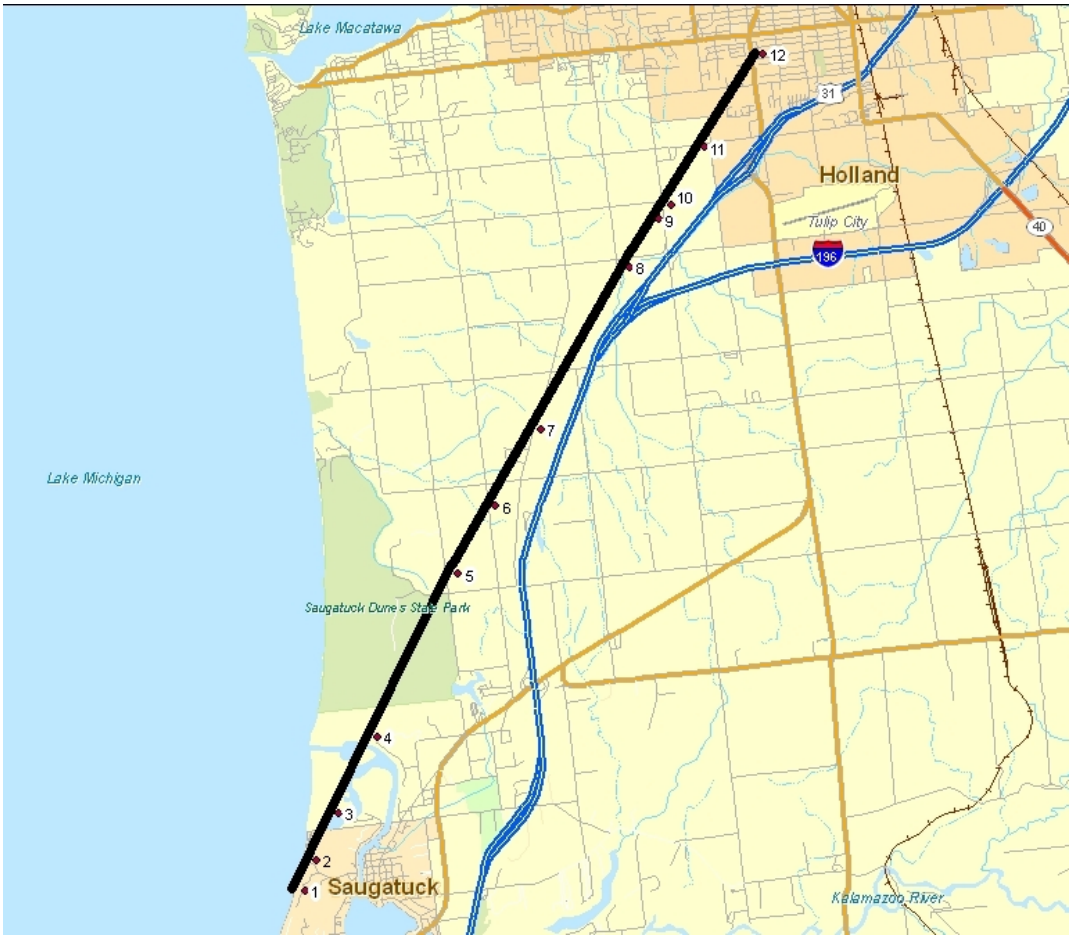


Figure 9: The path of the Saugatuck to Holland tornado, with locations of damaged or destroyed buildings numbered: 1. Damage to several wooden cabins and a concrete block building at a summer camp. 2. A wooden beach house destroyed. 3. The Saugatuck Lighthouse and three outbuildings destroyed. 4. A small cabin destroyed. 5. A two story frame home destroyed. 6. Roof damage to a frame home. 7. A frame home destroyed. 8. Barn unroofed. 9. and 10. Barn destroyed. 11. One story brick home destroyed. 12. Windows blown out of a two story concrete retail building.

Figure 10: The Saugatuck to Holland tornado seen shortly before the damage path ended, as it was moving into a residential section of Holland, MI. Photo credit: Don Brink.

Rural areas to the northeast of Grand Rapids also were hit hard, with lost livestock on many farms. There were no serious injuries north of Grand Rapids, but significant damage to homes and outbuildings continued. At least one home was blown completely off the foundation as the tornado skimmed the western outskirts of the town of Rockford, about 20 mi (32 km) northeast of Grand Rapids (Fig. 11). The tornado continued on for a total track length of 52 mi (84 km), finally ending about 2 mi (3 km) south of the town of Lakeview, around 0050 UTC 4 April.

3.) The Portage Point to Grand Traverse Bay tornado

Similar to the Saugatuck to Holland event, the damage path from this tornado began very close to the Lake Michigan shore, and was apparently continuous. However, there was a slight turn to the right about halfway along the path from east of Honor, MI to the Lake Ann area. The F4 rating appears to be justified based on the total destruction of at least two homes in Benzie County. The remains of one of them can be seen in Fig. 12, where the lone fatality from this tornado occurred. The NCDC and Tornado Project databases each list two fatalities for this tornado, with the latter describing a couple being killed when the second floor of their house was torn off. However, an eyewitness stated that she and her infant son were visiting the couple when the tornado struck and that they were all on the first floor. The house was demolished and her aunt was killed while her son and uncle were seriously injured. Local newspaper articles corroborate this. Several injuries occurred in the small towns of Lake Ann and Cedar Run in northeast Benzie County, where at least two homes were destroyed completely. The tornado did relatively minor damage to a few farms in Leelanau County before it moved offshore and dissipated over Grand Traverse Bay.

Figure 11: A car sits in the foundation of a home near Rockford, MI, after being hit by the Hudsonville to Lakeview tornado. No injuries resulted as the house was vacant at the time. At least two other homes in this area were destroyed and several others had extensive damage. There is no indication how or if this home was secured to it foundation, therefore winds in the F4 range cannot be inferred. Photo credit: Jack Erickson.

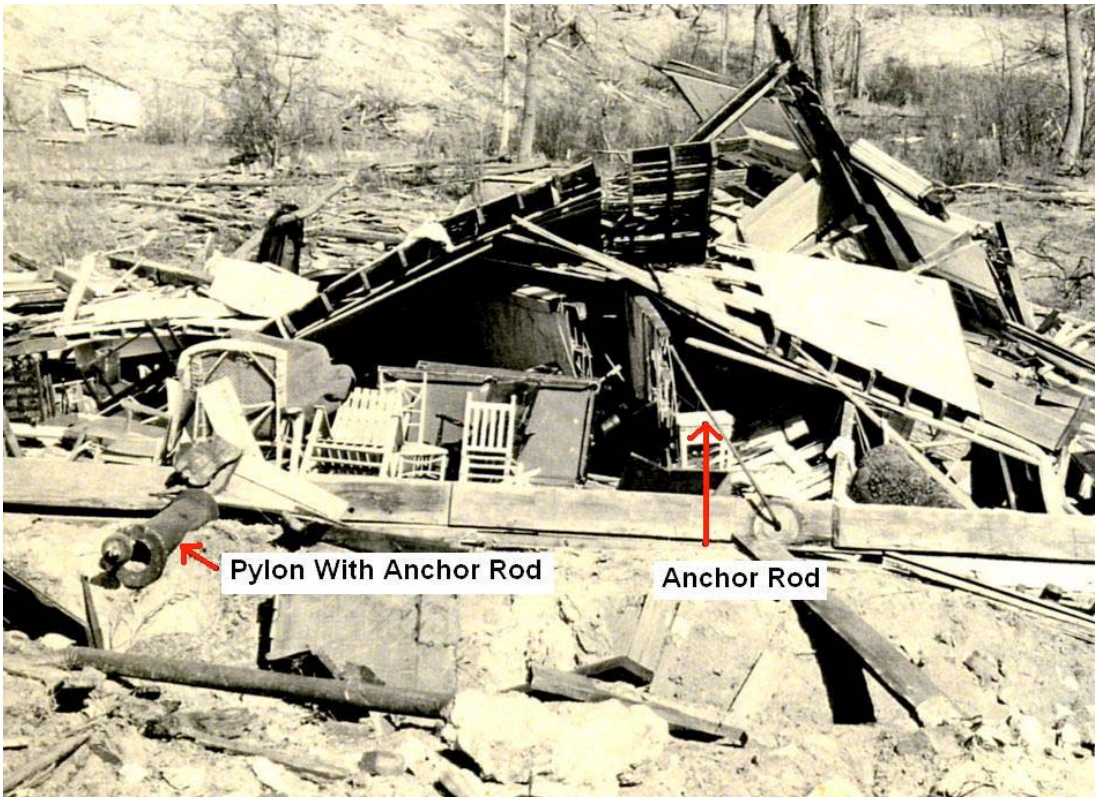
4.) The Bangor to Lowell tornado

This long-track tornado began while the two killer tornadoes to the north were in progress. Damage began on the southern outskirts of the town of Bangor in Van Buren County, and was most impressive along the Van Buren and Allegan County border, where one farm home was leveled and several small summer cottages near a lake were swept away. A factory and the road commission building in the town of Allegan lost large sections of their roofs and at least a dozen farms suffered major livestock losses. Similar to the Portage Point to Grand Traverse Bay tornado, the damage path turned to the right near its halfway point (Fig. 1). The damage appeared to be less intense in this area than elsewhere along the path, with downed trees, but no structural damage (Fig. 4). This may indicate a break in the tornado path in this area, with the lighter damage resulting from the rear flank downdraft.

However, this scenario could not be determined conclusively. The path turned more northward and intensified in Barry County and Kent County, where several farms suffered heavy damage before the tornado ended in the vicinity of Lowell.

Figure 12: The remains of the Hugh Parks residence in Benzie County, MI where one fatality occurred. Photo credit: Al Chapman.

(a)



(b)

Figure 13: The remains of the Saugatuck Lighthouse. (a) The foundation. Six of the twelve cast iron pylons can be seen, labeled with numbers. Pylons labeled 4 and 6 still are attached to the foundation by their anchor rods. Other locations where the anchor rods still are attached to the brick and mortar foundation are indicated with arrows. (b) The main mass of debris of the destroyed lighthouse. Note the iron anchor rods still attached to the wooden beam. Photo credits: Norm Deam.

d. Fujita and enhanced Fujita (EF) scale ratings of the tornadoes

Several hundred photos and about a dozen home movies of the damage were used to reconsider the original F scale ratings and estimate EF scale ratings (McDonald et al. 2006) of the four tornadoes.

The Saugatuck to Holland tornado completely destroyed at least four homes, with "before and after" photos of two of them available. The Saugatuck lighthouse was used as a summer home by a professor of architecture, who described it as a well-constructed frame building, similar in structural integrity to historic homes of the colonial period. The lighthouse had weathered the hurricane-force winds of the Great Lakes storms of 1913 and 1940, and was secured to the ground. A dozen iron pylons, three on each exterior wall, housed iron rods that were bolted to wooden beams at the base of the lighthouse. The rods were connected to brick and mortar masonry that formed the foundation. The tornado blew the lighthouse off the foundation, either snapping or pulling out all twelve rods. Some of the rods and pylons can be seen in Figs. 13a and 13b. The lighthouse was carried about 60 ft (18 m) to the north and landed upside down; the lighthouse tower was found buried in the sand with the rest of the structure on top of it. Other pieces of the structure were scattered for at least 200 ft (61 m) to the north-northeast. A two story frame home was demolished about 3 mi (5 km) northeast of the lighthouse (Fig. 14). The destruction of the anchored lighthouse indicates an F4 rating.

Two more homes were destroyed completely along the path of this tornado. An EF-4 rating would be appropriate there as well, using the "one- or two-family residence" as a damage indicator (McDonald et al. 2006).

The vast majority of the available photographic evidence was for the Hudsonville to Lakeview tornado, listed as an F5 (F4) in the NCDC (Tornado Project) data. Photos taken from an airplane a few days after the tornado show at least three homes completely destroyed and swept from their foundations on New Holland Street in Hudsonville, where the first fatality occurred (Fig. 15a). Fig. 15b shows one of the homes two years before, and Fig. 15c shows part of the foundation of the home after the tornado. There is no evidence that the home was secured to the foundation. Similar damage to homes and buildings occurred at several points along the path through Hudsonville and into the northwest suburbs of Grand Rapids. Fig. 16a is an aerial photo of tornado damage in a suburb northwest of Grand Rapids. Apparent damage was rated F5 for two homes and F4 for two others.

Damage was widespread in the Standale area, as several businesses and homes were leveled and almost completely swept away, including a new manufacturing plant. The remains of this building are seen in Fig. 17a and 17b, with only one corner left standing. An EF-4 rating would seem appropriate for this damage, using the "large isolated retail building" damage indicator.

The tornado carried several cars for long distances. The most reliable reports of that nature come from Hudsonville, where cars were photographed after having been carried or rolled far from their points of origin. One auto, with four people inside, was said by eyewitnesses to have been lifted about 30 ft (9 m) in the air before it came to rest in an open field. Two people in the car were killed. One of the survivors was interviewed, and said the car was carried more than 100 m (109 yards), indicating F5 damage (Fujita, 1971). At least two other cars were carried by the tornado for even greater distances (Fig. 18). The Portage Point to Grand Traverse Bay tornado demolished at least four homes for which photographs of the remains exist. The damage appears consistent with the official F4 rating and would indicate EF-4 damage if the homes were well-constructed.

The Portage Point to Grand Traverse Bay tornado demolished at least four homes for which photographs of the remains exist. The damage appears consistent with the official F4 rating and would indicate EF-4 damage if the homes were well-constructed.

The Bangor to Lowell tornado officially is rated F3 and the Tornado Project describes it as a "minimal F3". Most of the damage photos show damage consistent with an F2 or EF-2 rating. However, apparent F4 damage was done to a farm home in northern Van Buren County (Fig. 19) with no walls left standing. Without any indication of the structural integrity of the home, a rating of F3 and EF-3 appears reasonable.

(a)

(b)

Figure 14: The James Boyce house in Allegan County, MI. (a) The house circa 1935. (b) The remains of the house after the tornado. Photos courtesy of James Boyce.

(a)

(b)

(c)

Figure 15: (a) Aerial photo of damage on New Holland Street in Hudsonville, MI. Four empty foundations mark the locations of homes that were swept away. The foundation of the Willard Brower home is labeled 2. Photo credit: Pete Ludema. (b) The Willard Brower home in 1954. Photo courtesy of Maxine Baker. (c) The foundation of the Willard Brower home. Photo courtesy of the Gary Byker Library.

(a)

(b)

(c)

Figure 16: Damage in Walker, Michigan. (a) Aerial photo, with possible F5 damage at the homes labeled 1 and 2, and F4 damage at home 3. Note the debris streaks from the houses extending to the left (northeast). Photo courtesy of Richard Tuttle. (b) The remains of the home labeled "1" in Fig 16 a. This was a two story wood frame home. Although the home foundation does not appear to be "swept clean," it is believed that most of the debris seen here originated elsewhere. The cinder blocks of the foundation may indicate that the home was not securely attached to the foundation. Photo courtesy of Richard Tuttle. (c) The home labeled "2" in Fig 16b. Other than being described as a duplex, little is known of the structural integrity. Photo courtesy of Richard Tuttle.

(a)

(b)

Figure 17: The remains of the O'Dell Manufacturing Company building in Standale. (a) The building extended to near where the crane is. Perspective is looking northeast. Photo credit: Lou Nichols. (b) The O'Dell building seen from the air after much of the debris, including steel beams, had been removed. Perspective is looking south. Photo credit: Pete Ludema.

Figure 18: This car came to rest more than 100 m from the road from which it was swept. Another car (marked with arrow) in this photo may have been carried an even greater distance. Photo courtesy of Al Vanderbeek.

e. Possibility of other tornadoes

Only three tornadoes were recorded officially in Michigan on 3 April 1956. They were rated F3, F4 and F5. Research from late 2005 and early 2006 determined that the F5 tornado was actually a combination of two tornadoes (Fig. 1). It is possible, and perhaps likely, that undocumented weaker tornadoes occurred on this day. In the course of researching this event, the only indication of any damage that could be attributed to such a tornado was a photo and eyewitness account of damage to an outbuilding that occurred in Kent County, roughly halfway between the paths of the Hudsonville to Lakeview and the Bangor to Lowell tornadoes. The photo shows what appears to be F0 damage, which could have been caused either by a weak tornado or downburst winds.

f. Debris fallout

Newspapers and eyewitnesses provided many descriptions of debris being carried long distances by the tornadoes, almost all of them by the Hudsonville to Lakeview tornado. The Saugatuck to Holland tornado carried a letter 60 mi (97 km) from a demolished house, according to one of the survivors. Light debris from the Bangor to Lowell tornado was found about 15 mi (24 km) northeast of the end of the damage path. No reports of debris lofting were noted from the northernmost tornado, possibly because it moved over a more sparsely populated area than the other tornadoes and because it ended over Lake Michigan. Among the numerous reports of debris falling from the F5 tornado include a well-documented case of a fur coat being carried from a destroyed home in Hudsonville to a farm field in Rockford, a distance of more than 25 mi (40 km).

Figure 19: The remains of the Ray Imig home near Bloomingdale, Michigan. Although the house was leveled, several trees surrounding the house had limbs removed, but remained standing. Photo credit: Harold Burleson.

Letters, a truck title, and other papers from this same home were carried as far as Saginaw, about 80 mi (129 km) away. Clothing from a destroyed department store in Standale was found almost 50 mi (80 km) to the northeast. Several farms in northern Kent County were littered with debris carried from Hudsonville and Standale, to the extent that a farmer described the trees around his house as being "decorated like it was Christmas" with clothing and other debris. The fields had to be "passed over" to collect the debris before they could be plowed that spring.

g. Evidence of multiple suction vortices

Several eyewitnesses described seeing more than one funnel as the Hudsonville to Lakeview F5 tornado was in its formative stages south of Hudsonville. Most of them describe two or three separate funnels that appeared to merge into one large funnel as the tornado began moving into Hudsonville. As this tornado passed across the northwest suburbs of Grand Rapids, one eyewitness described seeing a "finger" move horizontally out from the side of the main funnel, in what appears to be a reference to a suction vortex.

Remarkably, there is also photographic evidence of suction vortices with this tornado, including a movie film (Fig. 20). Movie film evidence of suction vortices first was compiled during the 3 April 1974 "Super Outbreak" (Grazulis, 1993, p. 65). This film clip predates that event by exactly 18 years. At least two photographs of the F5 tornado faintly show evidence of suction vortices as well. Fig. 21 was taken about 2 mi (3 km) south of the tornado as it was moving through the northern section of Hudsonville, where eight people were killed. The light colored streak near the bottom of the funnel may be a suction vortex. What appears to be a suction vortex in Fig. 22 extends to near the ground, while the rest of the visible funnel remains aloft.

The Saugatuck to Holland tornado was photographed near the end of its life cycle and appears as a single, very narrow rope-like funnel. Eyewitnesses near the beginning of its path describe a large debris cloud surrounding a single large funnel. No photos of the other two tornadoes that day are available, and no eyewitness describes more than one funnel.

h. Details on the fatalities

Eighteen people were killed by the four tornadoes. Thirteen fatalities occurred in the Hudsonville area, and four were in the suburbs northwest of Grand Rapids. One was southeast of the town of Honor, in rural Benzie County. The ages of the victims ranged from 17 months to 89 years, the gender breakdown being ten female and eight male. Nine were killed in their homes, but not in basements; four were killed out in the open; three died in cars fleeing the tornado; and two fatalities occurred in basements. The latter were both young children who suffocated under debris.

Figure 20: These three still frames from an 8 mm home movie of the F5 Hudsonville to Lakeview tornado show the formation of a suction vortex on the left (west) side of the main funnel. The tornado was moving through the northwest suburbs of Grand Rapids at the time. Photo credit: Eugene Dohm.

(a)

(b)

Figure 21: The Hudsonville to Lakeview tornado: (a) Moving through the northern outskirts of Hudsonville on 3 April 1956. Photo credit: Myrtle Coats. (b) See next page. Moving through Comstock Park, MI, and exhibiting suction vortices. Photo credit: *Grand Rapids Herald*.

The majority of the fatal injuries were skull fractures, the cause of death of at least twelve of the victims, including all three of the fatalities in cars and most of those in homes. Other primary causes of death included crushing injuries and severe lacerations. There was one coronary occlusion. All but one of the victims died within three hours of sustaining their injuries. An 81-year-old male survived one week before succumbing.

i. Discrepancies with the NCDC database

Eyewitness and photographic evidence, as well as archival newspaper accounts, indicate that the path of damage currently listed as one tornado from Saugatuck to Trufant, MI, actually is composed of two separate tornado paths. The first contained F4 damage and had a length of 9 mi, while the second had a path length of 52 mi (84 km) apparently with F5 damage in Hudsonville and the northwest suburbs of Grand Rapids.

The F4 tornado that passed west of Traverse City moved into Grand Traverse Bay about 12 mi (20 km) further north than plotted in the NCDC database. This more northward path was noted in a newspaper map at the time, and it is corroborated by several eyewitnesses.

The F5 tornado was responsible for 17 fatalities, one fewer than listed by NCDC. There was one fatality with the F4 tornado that moved through Benzie County, one fewer than shown by NCDC.

ACKNOWLEDGMENTS

The author would like to thank John Klaassen and Dave Dahl of Hudsonville Emergency Services and Scott Corbin of the Allegan County Emergency Management Agency for their time and dedication in finding and recording numerous eyewitness accounts, as well as assisting in the anniversary events. Several local libraries and historical societies provided

valuable archival material. Jack Sheridan of the Saugatuck/Douglas Historical Society, Ron Mokma of the Graafschap Heritage Center, George Lessens of WZZM-TV Grand Rapids, and reporters Keith Essenburg of the Grand Rapids Press and Roel Garcia of the Holland Sentinel, were especially helpful in the gathering of eyewitness accounts and photographs. See Appendix A for a list of sources used in this study. T. J. Turnage, Science and Operations Officer at NWS GRR, provided a review of the manuscript. Three EJSSM reviewers helped improve the quality and completeness of the paper. Finally, acknowledgment is due to the dozens of eyewitnesses who graciously provided first person accounts and photographic material for this project.

APPENDIX A: List of sources

Walker Historical Commission
Plainfield Township Historical Society
Allegan County Historical Society
Then and Now Historical Society of Dorr, MI
Almira Township Historical Society
Manistee County Historical Museum
Benzie Area Historical Museum
Leelanau Historical Museum
Flat River Community Library
Allegan Public Library
Van Buren District Library
The Gerald R. Ford Presidential Library

REFERENCES

Fujita, T.T., 1971: Proposed characterization of tornadoes and hurricanes by area and intensity. Univ. of Chicago Satellite and Mesometeorology Research Project, Research Paper 91, 42 pp.

Grazulis, T.P., 1993: *Significant Tornadoes 1680-1991*. Environmental Films, St. Johnsbury, VT, 1326 pp.

Hanks, H. H., and G. M. Neubrand, 1956: Tornadoes of April 2 and 3, 1956. *Mon. Wea. Rev.*, **84**: 155-162.

McDonald, J. R., K. C. Mehta, and S. Mani, 2006: A recommendation for an enhanced Fujita scale (EF-Scale), revision 2. Wind Science and Engineering, Texas Tech. Univ., Lubbock, TX, 111 pp. [Available at http://www.wind.ttu.edu/EFScale.pdf]

Ostuno, E.J., 2007: Life and death decisions in the path of a violent tornado. *Wea. and Soc. Watch*, **2**:**1,** 2,11. [Available at http://www.sip.ucar.edu/news/pdf/WSW_October_2007.pdf]

———, 2008: *Paths of Destruction, the Story of West Michigan's Worst Natural Disaster: The Tornadoes of April 3, 1956*. Grand Rapids Historical Society Press, 126 pp.

REVIEWER COMMENTS

[Authors' responses in *blue italics.*]

REVIEWER A (Gregory W. Carbin):

Initial Review:

Recommendation: Accept with Minor Revisions

General Comments: Overall, the paper presents an interesting case in forensic meteorology and its use in describing an historic event. This reviewer would prefer the inclusion of a bit more meteorology in the paper. There should also be some mention of the watch/warning process that was used in 1956 and the degree to which the word was out about the impending storms. This information is completely absent in the presentation but should be considered seriously for inclusion.

The paper could be confusing to a reader with little or no geographic knowledge of Lower Michigan. Many place names are mentioned in the manuscript, but there are no maps showing the reader where these locations are. Also, the author changes the names used for the tornadoes and describes the discovery of alternative track information for one of the tornadoes. These findings are described somewhat inconsistently which could further lead to confusion for the reader.

This is a valid point and this information was added. See section 4a for a description of the meteorological conditions and section 4b for a discussion of the watch/warning process and public awareness and reactions to the tornado threat that day.

Substantive comments:

Ultimately, the NCDC Storm Events database probably should be referred to throughout. However, there should not be differences between SPC and NCDC. Use one or the other.

I used the NCDC Storm Events database.

The author makes a reassessment of the F-scale for the other tornadoes but leaves the reader hanging here (no F-scale rating mentioned for the Saugatuck to Holland tornado in section 4d).

I added a discussion of the F-scale rating for the Saugatuck to Holland tornado in section 4 d.

[Minor comments omitted...]

Second review:

The manuscript generally is acceptable for publication if the author can address the formatting issues and correct the grammatical mistakes highlighted throughout the document.

REVIEWER B (Charles A. Doswell III):

Initial Review:

Recommendation: Accept with Major Revisions

General Comments: I think this is a good topic and the effort expended has produced good results. However, there are several aspects of this presentation that need improvement. Hence, I believe the paper is potentially publishable, but the aggregate implications of my comments amount to what could involve a major effort, depending on the author's capabilities to add content. I certainly want to encourage the author

to consider making changes along the lines I've recommended, as I believe this paper can be a valuable contribution to the literature (and EJSSM).

Substantive comments:

Presumably, this was only an edited selection of eyewitness accounts. Or were they included in their entirety? How were the eyewitness accounts recorded? On tape or as paper transcripts, or what? What was the character of the interviews? What questions were asked? Were the same questions asked of all the witnesses? Were transcripts of these interviews made? Have the videotaped accounts been published or documented anywhere?

I added specifics of the eyewitness accounts and interviews in the introduction and in section 2a.

It probably would be appropriate to list all the sources for this study, perhaps in an appendix or in a table.

I added an appendix listing the sources.

In my experience, newspaper accounts say whose property was affected by the tornado but typically don't give the location of that property. How were locations determined for events described in newspaper accounts?

The newspaper accounts usually mentioned township names and/or street names of the property affected. I was able to use eyewitnesses and plat maps from the mid-1950s to identify the specific locations.

How do you know the recorded times [on a series of photos of the Hudsonville to Lakeview tornado] are accurate?

The three photos in the series (added as Fig. 3) shows the times marked as 7:05 pm, 7:06 pm and 7:08 pm. I am assuming that since they were marked to the minute, they were accurate. Of course, it is possible this precision could have been false, but the time does correspond well with the times that eyewitnesses in this area said the tornado came through.

Is there a centralized archive for the materials collected during this investigation? If someone wanted to do another study, would the information be available?

The archive is about 5 GB of disk space, thanks to several home movie videos, video interviews and many dozens of high resolution photos. I currently have no plans to host it anywhere in its entirety, although the Grand Rapids Public Library has offered to archive much of the material.

The information here [about the individual tornadoes] included in the text can be moved into a table that would incorporate the information about all the tornadoes.

Great suggestion. A table was created to list the specifics of the four tornadoes, as well as to develop a standard naming convention as suggested by Reviewer A.

It would be valuable to show in a figure just where the known damage points are located along the track, so readers could judge for themselves how continuous the damage was along the track.

I added Fig. 9 showing points of damage for the Holland to Saugatuck tornado damage path in its entirety. The path was only nine miles long. The other tornado damage paths were all over 50 miles, so it would be impractical to make similarly detailed maps for them. I added a map (Fig. 4) of a section of the Bangor to Lowell tornado damage path. It is possible that there was a break in the tornado damage path here and that the light damage noted in this area was caused by downbursts. It is also possible that no structural damage was noted since this was a sparsely populated area and there were no buildings to be impacted directly by the tornado.

With some exterior walls still standing, this looks like F3 damage, depending on the width and location of the tornado track relative to this building [the O'Dell manufacturing building in Standale]. Was it hit dead on, or are the exterior walls still standing on the margins of the track? Or is it possible to tell?

I added Fig. 17, better showing the extent of damage to this building. As far as I can tell the building took a direct hit from the tornado. A grocery store of across the street (to the right in Fig. 17b) was destroyed completely.

Was it built to withstand marginal hurricane force winds – 75 mph – or was it engineered to a higher standard? Most frame homes in the plains are built according to a code requiring no structural damage in an 80 mph wind, so the bottom end of "hurricane force" winds is not much of a standard.

I changed the text to say that the lighthouse had survived the storms of 1913 and 1940, which are believed to have produce at least marginal hurricane force winds, although I have been unable to confirm this with actual observations near Lake Michigan.

What evidence supports the statement that it "lifted up" the lighthouse?

I changed the text to delete the word "lift" since it could have just blown it over. It landed upside down with the top underneath the main mass of debris.

Without any indication of the structural integrity of the cottages, it's not evident to me that the best rating is a compromise of F/EF-3.

I was not referring not to the cottages, but the one farm house that was destroyed. I clarified this and added some photos of the farm house in section 4d. Unfortunately, they don't show much detail, but from what I was told by the person who took the photos, this was a two story wooden frame home, similar to the homes seen destroyed in Figs. 14 and 15.

It seems very unlikely to me that only F3+ tornadoes would occur in an outbreak. That is, it seems very likely to me that there were many more brief, weak tornadoes that were not reported. In the present era, most such tornadoes are recorded, but in the mid-1950s, it's likely that they were overlooked, as apparently they did little or no damage.

I would generally agree with this, but no evidence was found of weaker tornadoes except for the one instance mentioned. Other weaker tornadoes were recorded in northern Indiana: http://www.crh.noaa.gov/images/iwx/IWX_Tors/annualmaps/1956.pdf

At face value, this [multivortex documentation precedent] isn't true. I have a photograph of a multivortex tornado taken in 1957. What Fujita did was call attention to the existence of multivortex tornadoes, but photographic evidence of them predates Fujita's analysis of those on 3 April 1974.

I changed the text in section 4 g. to clarify this and mention that this is the earliest known movie film sequence of a multiple suction vortex tornado. I also added a link in section 2d to the video clip.

Was there some point to be made with all these details about the fatalities? Perhaps if none is intended, this could be summarized in tabular form in an Appendix.

I put this in a separate section (4h). One reason for looking at details on the fatalities would be to mitigate fatalities in the future, i.e., we know that it isn't safe to take shelter under a highway overpass, because people have done that and died. Information on fatalities has been included in studies of several historic tornadoes. See [Brown et al. 2002] for one example.

This whole section [on discrepancies with the NWS and Tornado Project] repeats what was has already been said. It adds nothing and can be deleted in its entirety without loss.

I deleted some of the earlier references to avoid repetition. I kept the section since it summarizes the findings.

This information [about the methodology of how damage paths were analyzed] should have been mentioned earlier and plots of the known damage points, if available, should be shown within this manuscript.

I created a methodology section and moved the information here so it appears earlier. I also added Fig. 4 to illustrate how the damage paths were analyzed.

[Minor comments omitted...]

Second review:

Remaining comments are minor….

REVIEWER C (Thomas P. Grazulis):

Initial Review:

Recommendation: Accept with Major Revisions

SUMMARY

The submitted paper was obviously a great amount of admirable work, and illustrates some good points. It is an excellent primer for anyone attempting to research an old outbreak. However, the recommendation is # 4, that it be resubmitted with revisions. I would not call the revisions either major or minor … neither word fits. They are significant revisions in figures and the justification for the F5 rating.

SCIENTIFIC CONTENT

Any effort at tornado documentation, even within a day of the event, will have a limited amount of true science in it. There will always be more speculation than science. Such is the nature of the beast. However, an effort should be made to include as much scientific information as possible.

As written, the paper seems better suited for a local historical publication, which was apparently completed as a companion effort. The paper lacks any real insight into the meteorology of the event. It needs more about the weather and climatology.

Section "k" refers to the "need to gather meteorological details." The importance is mentioned but none are presented. Some manner of weather map should be in the paper. Also, some discussion of any uniqueness in the situation would be good. If this was the worst outbreak in the area, what combination of meteorological ingredients was behind it? If the setup was not unique, but the outbreak location was unique, then that finding should be noted.

This suggestion also was made by Reviewer A. I added a section on the meteorology (4a) and included surface maps and a 500 mb chart. I briefly discussed how rare it is for tornadoes to occur along the Lake Michigan shore in early spring and some of the ingredients that contributed to this happening during this event.

QUALITY OF PRESENTATION

The "quality of figures" needs improvement, and not just with the inclusion of weather maps. \

I added several new figures, annotated and changed others and deleted a few. Hopefully, these figures are more effective than the previous ones at illustrating the text.

The fact that there are errors in the SPC data base is an important point. But there are thousands of errors in the SPC data base. Few of them are climatologically significant. Some visual and/or quantitative indication should be presented showing the climatological importance of the 1956 data base errors. That errors were found brings forth a big "so what?" A path map, or side-by-side path maps, should be used to show the old official paths along and the updated new paths. Then the reader can judge the impact of the errors on any risk analysis. Calculation of the risk of intense tornadoes in that region might or might not be significantly affected by the revised data. Side-by-side maps would provide some perspective. Add to that a path area calculation of the old and the revised tracks and a percent increase in risk could be estimated, thus adding even more perspective.

A small difference in the death toll and an inaccurate path is bothersome…very irritating…and may say something about the documenter and his work. However, if the official path area is only a few percent different from revised path area, it is climatologically insignificant. The data base should be corrected. But if it is not corrected (the most likely outcome) the size of the error becomes important. This is a unique opportunity.

I changed Fig. 1 to a side by side comparison of the old and new paths. I did not do an area calculation since I don't feel comfortable with the accuracy of the mean widths of the tornado paths (I had listed them in the earlier version, but deleted them in this version). I could do this if you feel the potential error in assuming the mean path widths to be correct is not substantial.

Fig. 1 could also include the debris locations.

I thought about adding debris locations to Fig.1 but the map would be too cluttered. I could do a separate map for this if you feel it would be a worthwhile addition.

Some of the details in the paper such as the organization of photos into subfolders, the ownership of photos by relatives, and the age of responders are of absolutely no value in this paper. There is room for tightening of the text in order to make room for meteorological details.

The paper is primarily intended for people planning to investigate historic weather events, and data management will play a big role in such a study. I better organized the paper by adding a methodology section and included this info there, tightened the text and added the meteorological section. I think the details in demographics and other topics may be useful to someone doing a similar study.

The number of photographs was remarkable. Suggesting that they were "relatively rare" was misleading. Professor Fujita did a similar search for photographs of the 1965 Palm Sunday outbreak with less success. This 1956 outbreak was apparently one of the most photographed outbreaks of the decade, and even included a multiple vortex motion picture. "Rare" is not the right word here.

Good point, and I had originally used the word "rare" in there meaning, "relatively rare compared to the damage photos". I changed the text to indicate this and deleted the word "rare".

The main event is firmly called "the F5" right at the start of the paper. Except perhaps for some events in the 1965 Palm Sunday outbreak, any F5 rating prior to 1971 is pure speculation, as the F-Scale did not exist. The F5 rating should not be stated as if it was rated by a trained on-site person. The tornado was given that rating at a time when engineering principles were not part of the rating process. The person who applied the rating may have been only an inexperienced temporary summer employee, an undergraduate student working 18 years after the storm, using only the library resources of the state historical library in Lansing. I now have even less confidence in his or her work than I did during the time of the NRC work that gave birth to the book "Significant Tornadoes." That original rater, working for NSSFC in the mid 1970's, added the note about the two deaths on the second floor. I could find no convincing evidence to discount that comment made on the original NSSFC (unpublished) rating form used at the time. It was

apparently erroneous, calling into question comments made about other Michigan events. The ratings of the 1950's and 1960's have a history, and it is not one of consistency and accuracy.

A better case for the F5 rating should be made. Starting the paper by accepting the dubious "official" rating is hardly a rigorous "forensic" investigation. It was noted in the text of *Significant Tornadoes* that is was probably F5. It was a difficult call, since Fujita's DAPPL data base had it as F4, and this reviewer had to make a tough choice in 1982, before submitting a decision to the Nuclear Regulatory Commission.

I added several photos showing houses swept away and cars carried at least 100 meters. Does this prove F5? Perhaps not, since these houses could very well have been just sitting on concrete blocks. Having said that, I would also say that the damage is as impressive as any photos I have seen of the damage from the 1953 Flint tornado.

Research done by Texas Tech wind engineers who studied the slab homes at Jarrell, Texas in 1997 was one of the reasons that the EF-scale exists. Slab construction homes may never get a "5" rating again. The slab home in Figure 6 strongly recalls the Jarrell situation. Removal of tiles may not entirely be a high wind phenomenon. The original condition of the tiles is unknown. The reliability of the source for tile information is unknown. It's an interesting anecdote, but should not be part of a ratings effort. A better photograph showing F5 damage should be included, or the rating should be put in question as part of the "conclusions" in the paper. I recall some aerial photographs that showed empty foundations, but they were not compelling enough for me to award an F5 rating. Perhaps the author found better ones. The car carried for 100 yards cannot be used as the basis for an F5 rating. Newspaper reports of cars being carried have turned out to be reports of parts of cars, cars without engines, or cars that were rolled, not carried. The report must be discounted unless accurately documented.

I added several more photos showing damage from Hudsonville and northwest Grand Rapids and deleted the slab home photo. The car being carried more than 100 meters was well-documented (one of the passengers survived and was interviewed) and a photo was included of it and other cars.

A tiny home sitting on cinder blocks, as in Figure 4, would not have inspired an F4 rating in The Tornado Project's rating system. Every effort to include the best evidence for each rating should be included in a serious forensic study of this detail, even if reproduction is difficult.

A final note on the goals of The Tornado Project seems appropriate. Its work was not to re-do official paths of post-1950 outbreaks. The official paths were accepted unless they were obviously incorrect. The official description of this event included times and locations, as if someone actually made an effort. Little time was spent to refine paths that would have minimal risk analysis impact. Studies like this are all the more valuable, given the errors in accurate-sounding descriptions. Our goals were to bring the NSSFC (now SPC) data base into agreement with Professor Fujita's DAPPL data base and to examine carefully and rank outbreaks prior to 1950, for which there was no organized data base. A number of times the author seems to wonder why The Tornado Project published what it did. A phone call or e-mail could have cleared up those questions.

I look forward to reading a revised manuscript with more meteorology and more F5 evidence.

Second review:

SUMMARY

The content of the revised paper is a considerable improvement over the original submission. It is an excellent primer for anyone attempting to research an old outbreak. The recommendation is that it be accepted with a revision. That revision is noted below. While the content is fine, it is expressed in about three times the number of words that it could be. Many of the details, while not incorrect, are of no interest or use to anyone who will ever read this paper. The paper could be severely edited and condensed by the editor.

SCIENTIFIC CONTENT

The new sections on the meteorology of the event are interesting and informative. The new figures that involve meteorology, or refer to the Fujita Scale rating problems and path maps are welcome additions. The suggestions made by this reviewer were handled very well.

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QUALITY OF PRESENTATION

With meteorology out of the way, I will address the writing quality and target audience issue. Except for a minor necessary correction in wording, the paper could be published as is, as long as length is not an issue. It would be informative and not misleading. At times, however, it seems as if the author is speaking to the general public in narrative style more suited to a non-technical, very casual stage presentation, certainly not to a technology-savvy professional meteorologist. The entire introduction and methodology section could be condensed into just a few paragraphs without losing content.

For instance, the section [formerly] 3b on "data management" should be deleted entirely. This is only slightly above the level of telling someone that the words were typed on a computer word processing system. I assume that this was directed to the novice who might be thinking about his or her first historical study. As with many other details, if the novice researcher does not know what can be done with a VHS tape, then they have no business considering such a study. I personally don't care how the VHS tape was handled. I do care in seeing examples and conclusions. The words just don't need to be there. If space is no object, then leave it in. [Editor's note: I agree that the specific descriptions that Tom mentions here probably are too superfluous or tangential to keep in the manuscript.] In 4d, the idea that the 16 mm film was shot from the roof of a house was interesting. That it was digitized, converted to mpg, and posted adds more narrative words that are not needed. The mere presence of the link says it all. The paper is drowning in that type of writing. One mention of the word "microfilm" is sufficient.

[Minor comments omitted...]