A Retrospective Mesoscale Analysis of the Intense Midwest Tornado Outbreak of 21 April 1967

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Abstract

A tornado outbreak of 44 tornadoes, five of which were F4s, killed 58 people and injured 1113 along a narrow axis that included parts of Illinois, Michigan, Missouri, Indiana, and Iowa on 21 April 1967. To the author's knowledge, no formal analysis has been conducted on this historic case, making it a good event to examine so that we may better understand the causes behind the confinement of the storms to a narrow band.

This study used synoptic and mesoscale analyses, along with digital archived data, hand written surface observations, and output from a re-run Eta model to recreate the conditions present on that day. These tools show that several components favorable for severe weather were present as a fast moving short wave trough moved through the area and helped initiate the numerous storms that formed during the outbreak. Not only was the short wave trough moving rapidly, but the environmental conditions ahead of the system evolved quickly. With the combination of the fast moving system, and the rapid evolution of the environment, it was difficult to predict the extent of the outbreak and its extension into Michigan. This aspect of the outbreak made preparation difficult and should a similar outbreak occur in the future, difficulties could again be faced.

1) Introduction

The Midwest tornado outbreak of 21 April 1967 spawned 44 tornadoes which included 5 F4 vortices, killed 58 people, and injured 1113. Five states were affected, Missouri, Iowa, Indiana, Michigan and Illinois, with most of the fatalities in Northern Illinois. Twelve children perished when an F4 tornado struck the Belvidere, IL High School as buses were loading on that fateful Friday afternoon. In Oak Lawn, IL, 33 people were killed when a separate F4 tornado tore through the crowded metropolitan area during rush hour. It is considered the worst tornado outbreak to hit the Chicago metropolitan area in recorded history. Even though this outbreak was historic in magnitude, no analysis had been performed on the event before[1], making it a good case to bring back to life and explore with technology and scientific insight not available in 1967.

Using archived weather observations, synoptic surface and upper air maps, radar images, and output from a re-run of the Eta model, this paper analyzes the outbreak and the conditions leading up to it. Most of the data were obtained from microfilm, or from hand written surface observations. After the analysis of this data, it was noticed that many factors favorable for tornadoes were present on this day, including an area of low pressure that moved from Missouri to Michigan, a cold front that moved southeast from the Northern Plains, and a dry line that was present just ahead of the cold front. Other severe weather indicators, such as Convective Available Potential Energy (CAPE) (Moucrieff & Miller 1976), were also diagnosed with the aid of the re-run Eta model.

[1] This outbreak occurred during the time that Ted Fujita was analyzing the Palm Sunday outbreak. When he was finished, another outbreak had occurred that he analyzed, leaving this outbreak unanalyzed until now.

The various factors supportive of deep moist convection came together along a relatively narrow axis that coincided with the path of the tornadic storms.

2) Data

There were several sources for the data used during the analysis. The upper air and some of the surface observations came from the digital archives of the National Severe Storms Laboratory (NSSL), Storm Prediction Center (SPC), and National Climatic Data Center (NCDC). However, as the surface observations were very sparse, numerous additional surface observations were digitized from hand written surface observation records on Surface Weather Observation Sheets.

The majority of the data came from microfilm archives of NWS products. These included upper air maps for various pressure levels, large scale analyzed surface maps, radar summary charts, 5 minute WSR-57 radar images from the Kansas City and Chicago Weather Bureau network radars, and National Severe Storms Forecast Center (former name of the SPC) convective outlooks, and tornado watches.

Lastly, an Eta model (Black 1994) was created using initial conditions for 0000 UTC 21 April 1967 from the National Centers for Environmental Prediction (NCEP) Climate Reanalysis (Rogers et. all 1996) data were used. Hourly output including point forecast soundings was created. The model differed from the operational Eta model in that the Kain-Fritsch convective parameterization (Kain & Fritsch 1990) was used to help improve the representativeness of sounding profiles within the simulation (Kain 2004).

3) Methodology

Once the data collection was completed, the upper air observations were analyzed according to the SPC guidelines. The historic NWS national surface maps were also analyzed for temperature and dew point in order to better identify the potential locations of mesoscale boundaries. To create digital surface maps, all of the hand written surface observations were entered into a spread sheet data file. The file was used by N-AWIPS/GEMPAK (desJardins et. All 1991) to create station plot maps on which the pressure field was hand analyzed. The times of analysis were narrowed to 1200 UTC 21 April 1967 to 0500 UTC 22 April 1967 to focus on the time of the outbreak.

The tornado watches and outlooks were replotted to see the progression of the watches and the accuracy of the outlook in order to evaluate the forecast. The severity of the watches had to be changed to today's severity scale (Corfidi 1999). The radar summary charts were looked through to help determine individual cell movements which were then compared to the motion of the entire system.

The rerun Eta model provided a better picture of the evolution of the meteorological aspects of the day. Screen captures were taken of displays of:

- the 500 mb heights, winds, temperatures and isotachs
- the mean sea level pressure (PMSL), 1000-500 mb thickness and boundary layer winds
- the 500 mb isotachs, 850-700 mb upward vertical motion (UVV), lowest 180 mb lifted index (LI), and 850 mb winds (severe composite 2)
- the surface based CAPE (SBCAPE), helicity (Lilly 1986), and energy-helicity index (EHI)

- the significant tornado parameter (Thompson et. all 2003) which consists of normalized values of 0-1 km SRH, 0-6 km shear vector magnitude, and CAPE and LCL levels from the values of the lowest mean 100 hPa parcel (sig tor)
- the SBCAPE, 0-1 km shear, lowest 1500 m mean relative humidity (RH) and the 10-6 m above ground level (AGL) shear vector (sig tor 1)
- the 0-3 km storm relative helicity (SRH), CAPE, and 10 m - 6 km above ground level (AGL) shear vector (supercell composite)

from 1200 UTC 21 April 1967 to 0600 UTC 22 April 1967. The model also provided forecast soundings and hodographs for Columbia, MO (COU), Rockford, IL (RFD), Chicago O'Hare, IL (ORD), and Flint, MI (FNT). Selected observed soundings were modified with afternoon surface observations in order to validate the accuracy of the numerical simulation and some hodographs were also modified with the observed storm motion and speed to see the changes in storm relative parameters such as SRH.

4) Results

a) Synoptic overview

A strong 500 mb short wave trough with a corresponding surface low moved northeastward at approximately 45 mph from Missouri to Michigan between 1200 UTC 21 April 1967 to 0000 UTC 22 April 1967 (see figures 1 & 2). These features provided a large-scale environment conducive to moist convection. Many of the storms that day developed along or on this surface low and progressed away from the front. Additional storms formed downstream within a region of weak warm temperature advection ahead of the surface cyclone.

b) Mesoscale analysis

While still a work in progress, a series of initial mesoanalysis (Fujita 1963) were performed for the period from 1200 UTC 21 April to 0600 UTC 22 April (not shown). Based on the 1900 UTC analysis and Kansas City Radar, a dry line ahead of the cold front contributed to the formation of several bands of strong storms including supercells with those along the dry line at an angle to the cold front (see figure 3). The storms moved off the dry line into the warm sector and were responsible for many of the tornadoes across Southern Iowa and Northern Missouri.

By 2100 UTC, surface and radar analyses combined with the Eta simulation indicate that warm advection ahead of a strengthening low level jet contributed to rapid sever thunderstorm development over portions of Northern Illinois. As the supercells formed along the boundary in Illinois, moved over Lake Michigan, and crossed into Michigan, they met up with this warmer, moist air right at the edge of the lake and were able to strengthen and produce tornadoes not far from the lake shore.

c) Model output

Use of observed soundings to validate the model simulation were complicated by the sparse upper air observing network in space and time and the narrow rapidly evolving character of the outbreak. An observed sounding from COU at 1200 UTC 21 April 1967 modified with the station's 2100 UTC 21 April 1967 surface observation was compared to the model sounding at 2100 UTC. While the soundings were not identical, they had similar low level temperature and moisture profiles (see figure 4). Severe weather related parameters were also of comparable magnitude supporting the use of the model environment as a path to gain insights into the evolution of the actual environment during the outbreak.

From the model simulated soundings and hodographs at ORD, it was shown that the environment changed rapidly. The hodographs showed an evolution from a wind profile not indicative of tornadoes at 1800 UTC 21 April 1967 to a curved hodograph which is more supportive of tornadic development at 2300 UTC 21 April 1967 (see figure 5).

Regional plots of the simulation focused on the Northern Plains and showed plots of SBCAPE, helicity, and EHI, sig tor 1, supercell composite, and severe composite 2, focusing on 2300 UTC 21 April 1967, the time which corresponds the mesoscale analysis (see figure 6). The regions of higher CAPE, helicity, EHI, 0-1 km shear, 10 m - 6 km AGL shear, and 0-3 km SRH all coincided with the location of the surface low at that time. This illustrated that the environment had at least several different characteristics favorable for severe weather in one place, allowing for the supercells and tornadoes to form.

d) Modern parameters

Comparison with results from recent tornado environment parameter studies was made to compare this historic event to more recent, better observed outbreaks (Thompson et. all 2003). From the plotting of the different SBCAPE, SRH, and significant tornado parameters on the graph of SBCAPE versus 0-1 km SRH, and the box plot of sig tor, the evolution of these values were seen. There was a large jump in the sig tor from 3.6 to 7.0 in the hour between 2100 UTC and 2200 UTC which illustrates once again how quickly the environment changed during this outbreak. The values from the 1967 case compared favorably with today's environmental parameters from more recent tornado events. In the graph, all the values fell into the category suggesting conditions are favorable for supercells or tornadoes. While the CAPE never went above 1800 J/kg, the SRH was 356 m^2/s^2.

e) Forecasting difficulty

This was a very fast moving system and therefore difficult to forecast. When comparing the storm reports (see figure 7) to the convective outlook issued that day along with a watch summary (see figure 8) it is noticed that both did a fairly good job at predicting where severe weather would occur that day. The general thunderstorm area on the outlook covered the outbreak area, with a moderate risk for severe weather centered over an area of Illinois, Indiana, and Missouri. However, the outlook placed a somewhat greater emphasis on severe weather in the Southern Plains where a more "classic" tornado environment was in place, while the majority of the tornadoes occurred in Illinois. The majority of the tornado watches issued was issued with plenty of lead time. However, the watch issued over Michigan was put out after the first reports of tornados came in. The rapid movement of the system and the rapidly changing environment made the situation difficult to forecast the rapid expansion of severe weather into Michigan.

5) Conclusion

The outbreak that occurred on 21 April 1967 formed as a result of a combination of many factors. The synoptic and mesoscale analyses revealed a fast moving short wave trough and its surface low. The storms of that day formed along and ahead of the cold front and the coupled dry line associated with the surface low. The analyses also revealed that this was a fast moving system which moved from Missouri to Michigan in a short period of time.

From the rerun Eta model, the presence of various severe weather parameters, such as high CAPE and SRH, were found in the area of the fast moving short wave trough and its associated surface low. The storms formed along the edge of the boundary and were confined to the narrow area where the severe parameters and the boundary were all collocated.

The model soundings illustrated the rapid environmental evolution. The changes in the ORD soundings and hodographs occurred quickly, showing how the environment changed into one favorable for tornadic development. The rapid environmental change was also another indicator of how fast the system was moving.

The modern parameter space figures plotted the CAPE, sig tor, and 0-1 km SRH from the model data. These showed that not only did those values change over time, but that in modern terms, the environment for the day of the outbreak was considered to be one favorable for supercell and tornado development.

Even though the environment rapidly evolved and the system moved quickly, the outlook and watches issued that day were fairly accurate as the watches gave good lead time and the outlook predicted the possibility for severe weather over most of the affected region. However, both had difficulties with Michigan. The outlook did not include this state in the chance for severe weather, and the watch that was issued was put out after tornadoes were in progress. The rapidly changing environment made forecasting difficult, which contributed to the difficulty in warning the people in the path of these storms.

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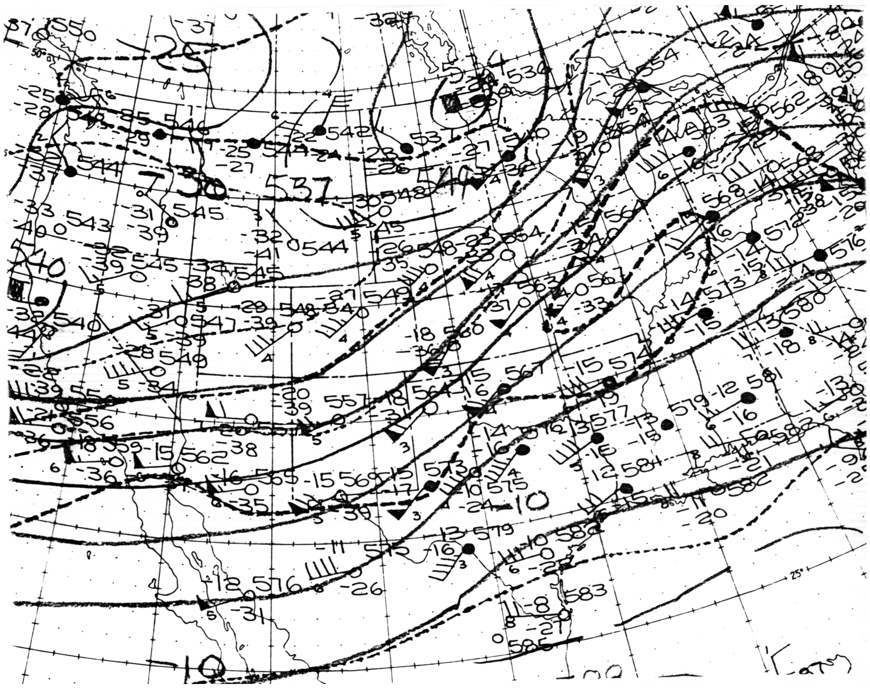


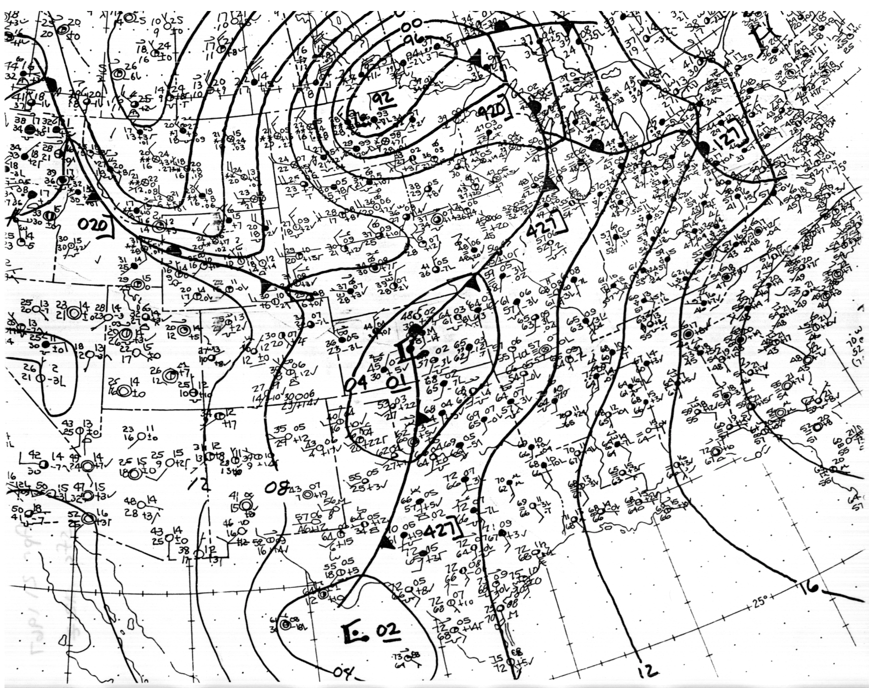


Fig. 1 The top image is the 500 mb heights temperatures and winds and the bottom image is the surface sea level pressure with fronts at 1200 UTC 21 April 1967.

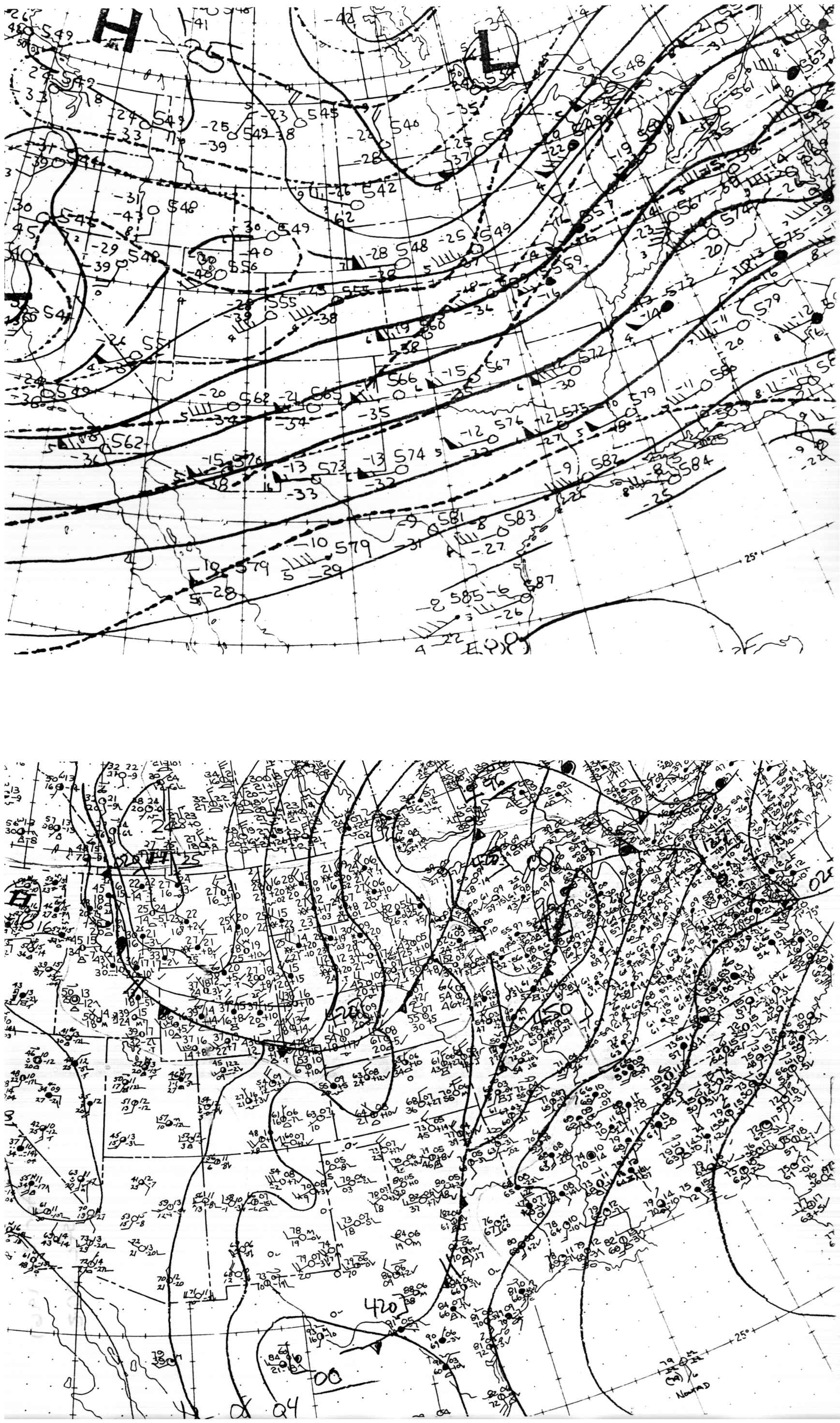


Fig. 2 The top image is the 500 mb heights temperatures and winds and the bottom image is the surface sea level pressure with fronts at 0000 UTC 22 April 1967.

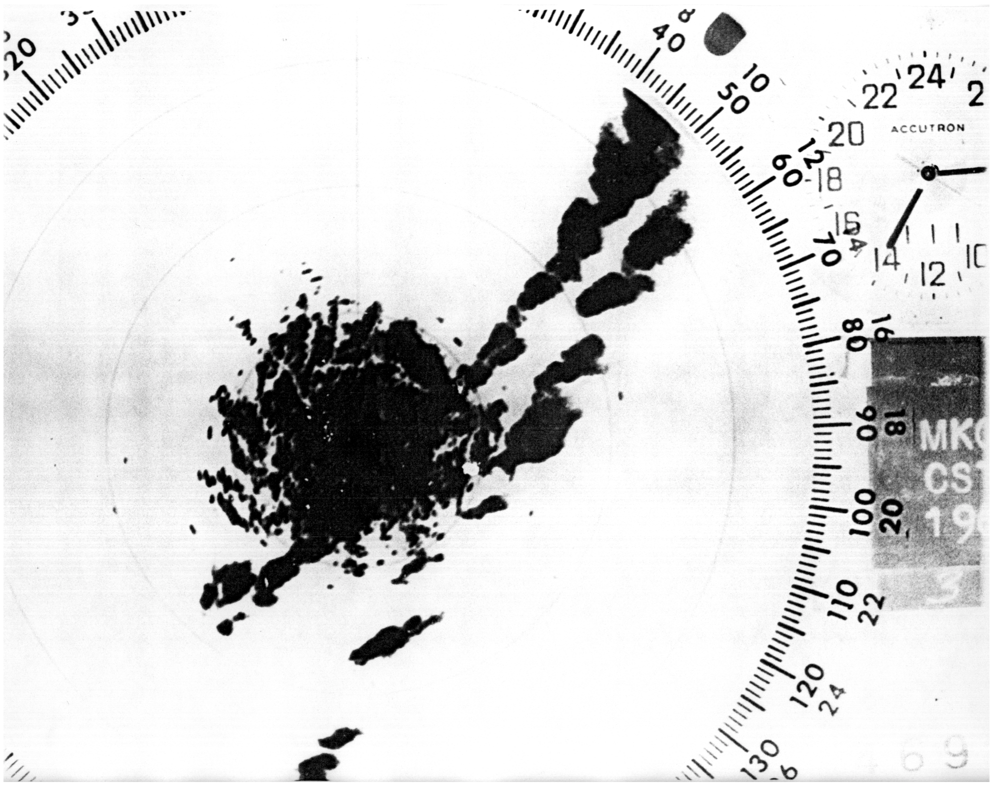


Fig. 3 WSR-57 radar image from Kansas City, MO from 2015 UTC 21 April 1967
Note the line of thunderstorms behind another line of more scattered thunderstorms

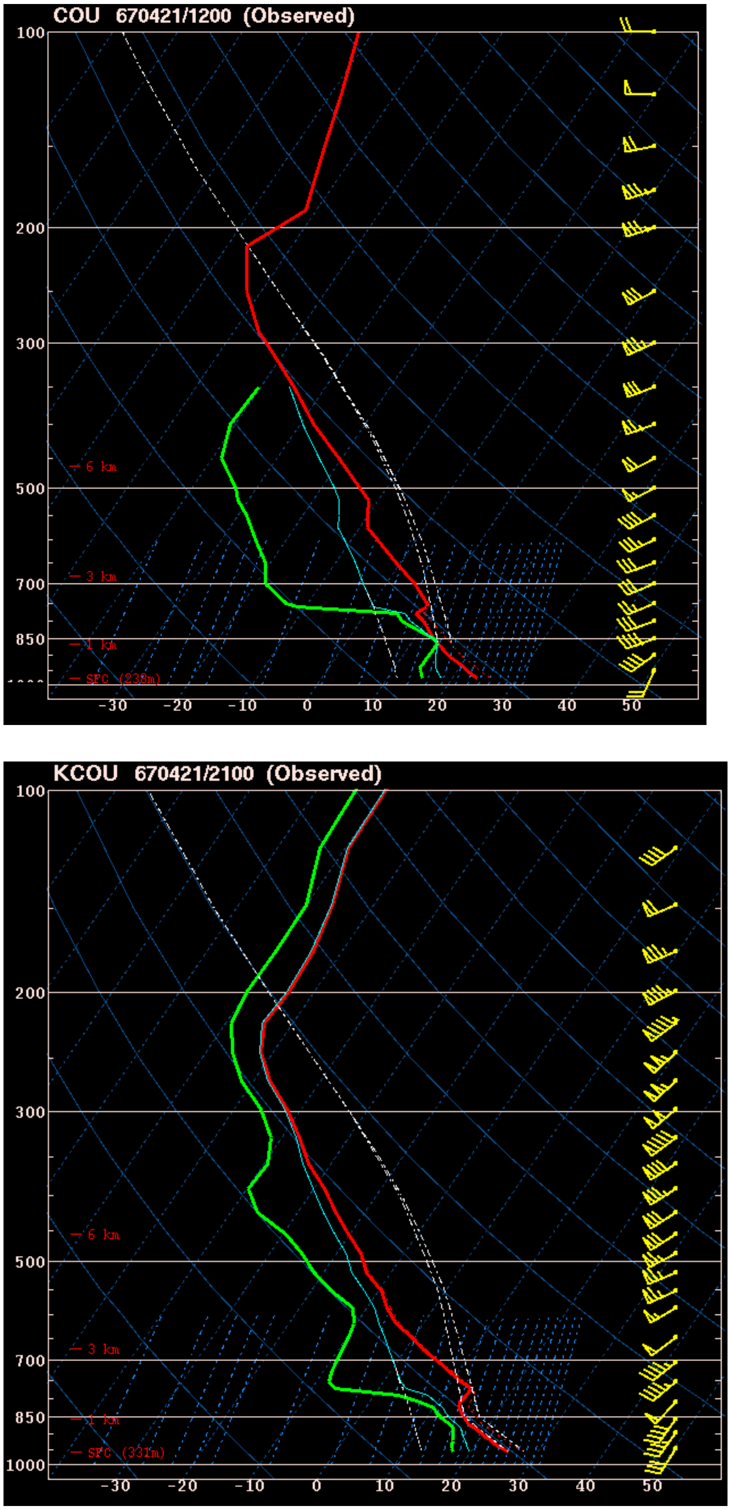
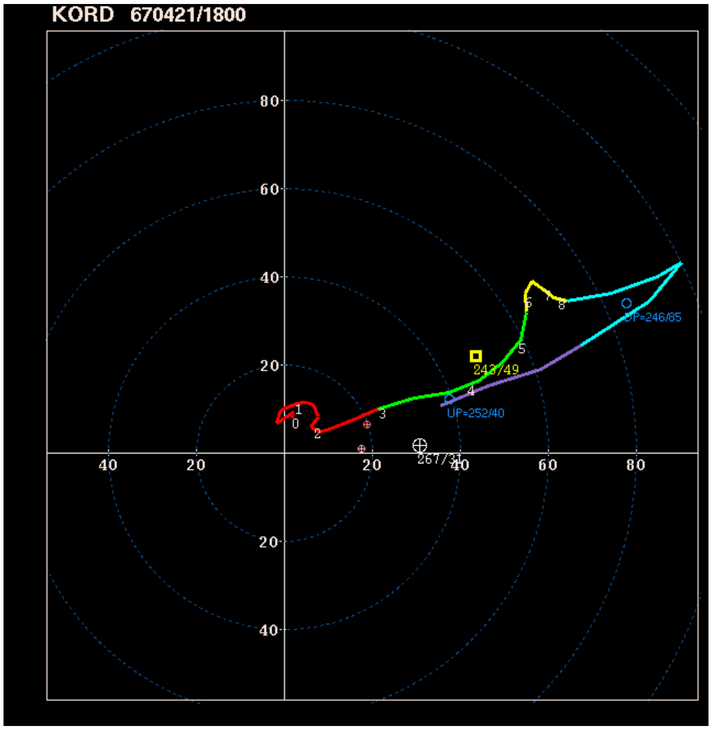


Fig. 4 The top is an observed sounding from 1200 UTC 21 April 1967 at COU modified with the station's observations from 2100 UTC. The bottom sounding is the model's sounding from COU at 2100 UTC.



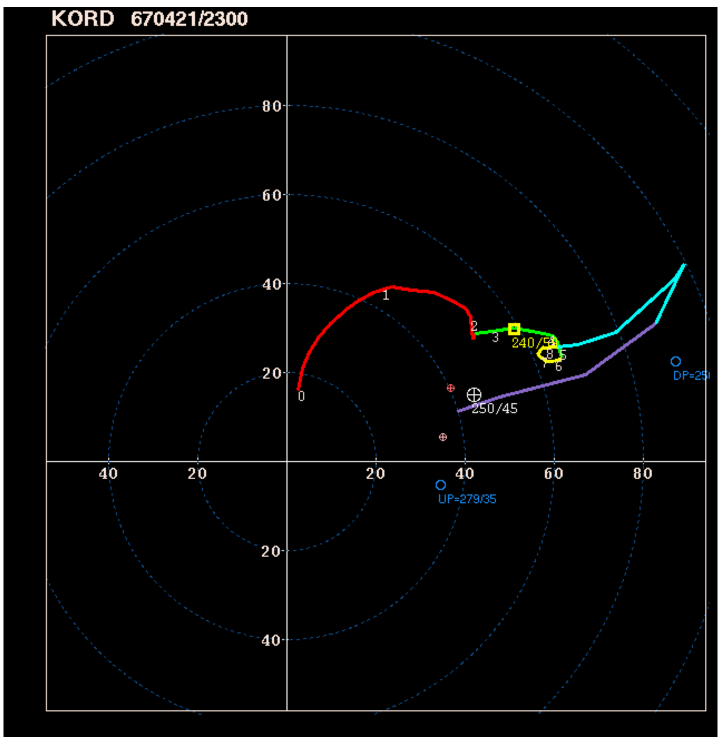


Fig. 5 The top image is the model hodograph from 1800 UTC while the bottom image is the model hodograph from 2300 UTC. Note the amount they have changed in only a few hours.

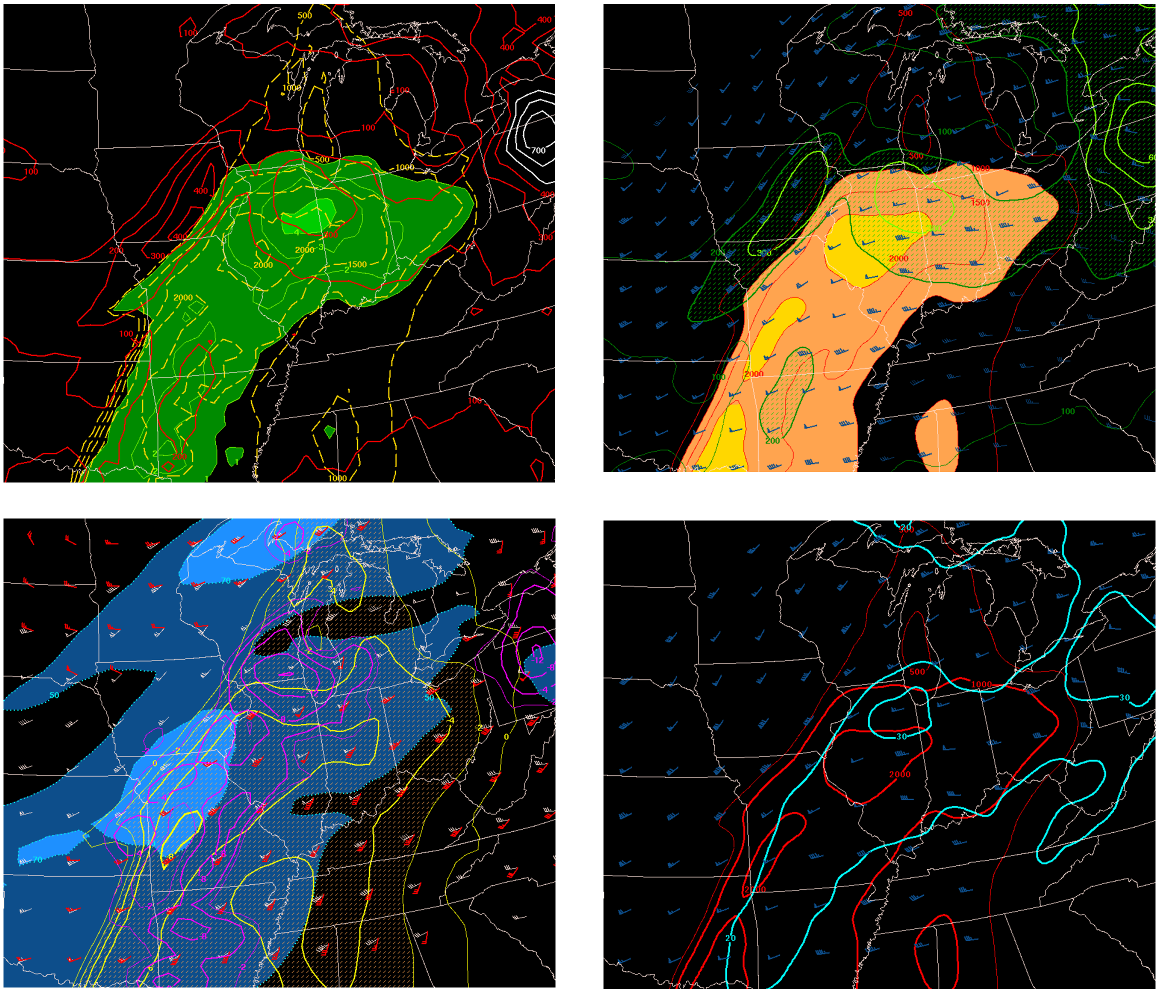


Fig. 6 The top left image is a regional capture of SBCAPE, Helicity and EHI. The top right image is of supercell composite which is composed of 0-3 km SRH (green), CAPE (yellow and orange) and 10 m – 6 km AGL shear vector. The bottom left image is of severe composite 2 which is composed of 500 mb isotachs (blue), UVV and 850 mb winds (red) and lowest 180 mb lifted index (yellow). The bottom right image is of significant tornado 1 which is composed of SBCAPE (red), 0-1 km shear (light blue), 10 m – 6 km AGL shear vector (dark blue), and lowest 1500 m relative humidity (green).

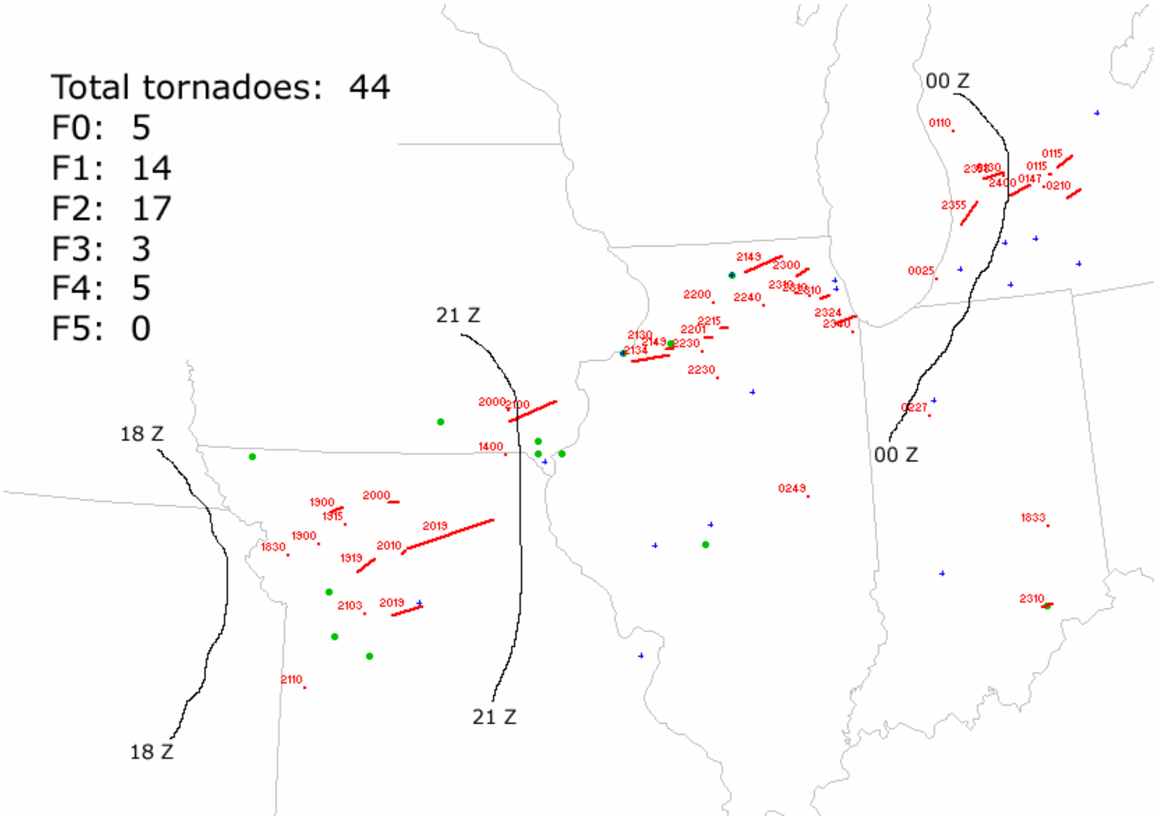


Fig. 7 A storm report summary from 0000 UTC 21 April 1967 to 0600 UTC 22 April 1967 with tornado tracks in red, hail in green and wind in blue. Isochrones have been added as well as a breakdown of the F scale of the tornadoes during the outbreak.

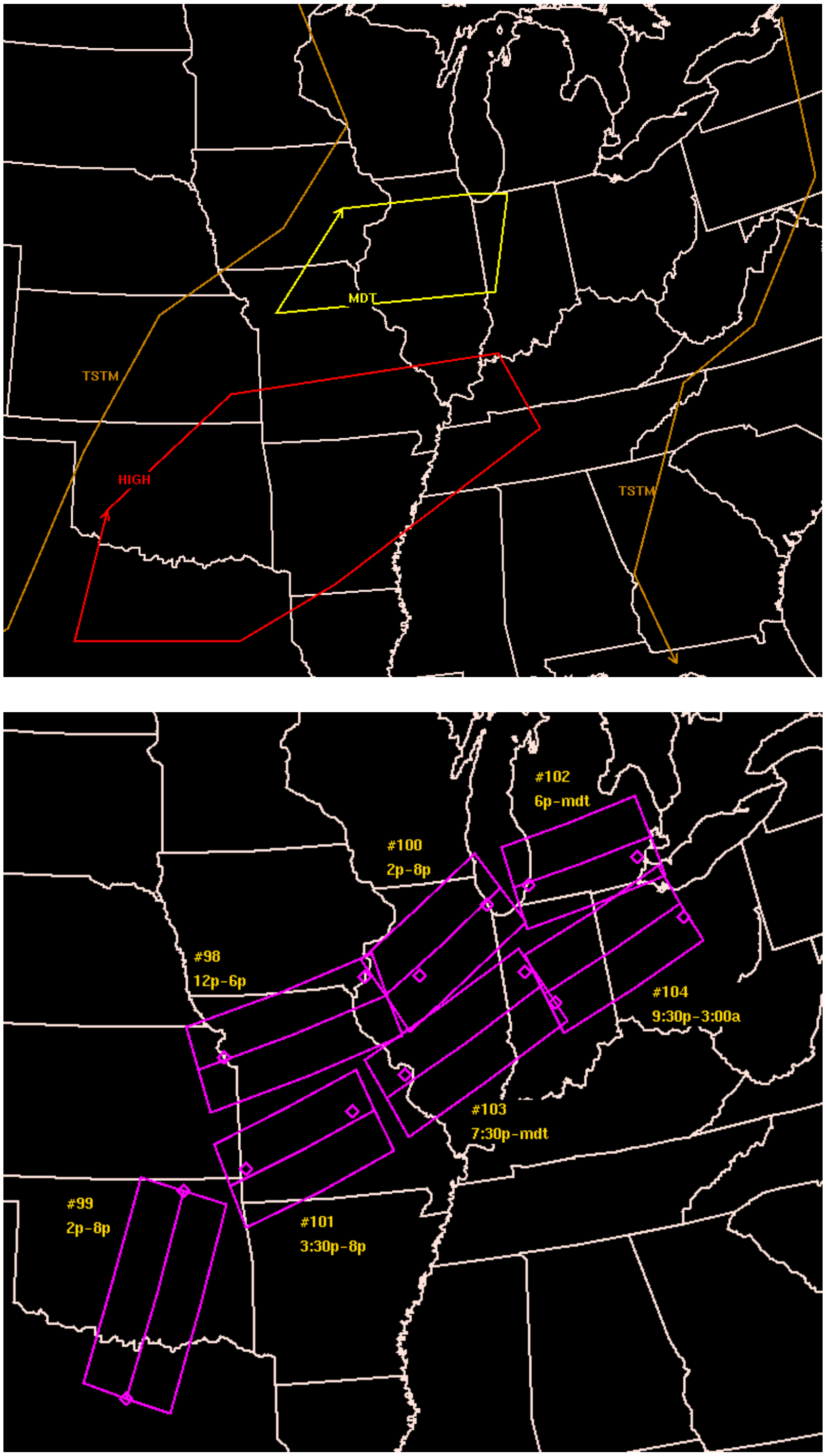


Fig. 8 The top image is the convective outlook issued for 21 April 1967. The brown lines indicate a general thunderstorm potential, with a yellow box indicating a moderate risk for severe weather, and a red box indicating high risk for severe weather. The bottom image is a tornado watch summary and shows all of the watches issued that day with their number and the time period they were in effect.