



A Summary of MCEER
Reconnaissance Efforts

MCEER RESPONSE

ADVANCED TECHNOLOGY FOR RAPID TORNADO DAMAGE ASSESSMENT FOLLOWING THE 'SUPER TUESDAY' TORNADO OUTBREAK OF FEBRUARY 2008

Anneley McMillan, Beverley J. Adams, Amber Reynolds, Tanya Brown, Daan Liang and J. Arn Womble

ImageCat Ltd. and Wind Science and Engineering Research Center, Texas Tech University

This field campaign, undertaken in the aftermath of the 2008 'Super Tuesday' tornadoes, was funded by MCEER and Texas Tech University's Wind Science and Engineering Research Center. It presented the team with a unique opportunity to collect geographically located perishable damage data on a per-building level throughout a variety of tornado strengths and environments.

This exploration marks the first tornado event where the VIEWS (Visualizing Impacts of Earthquakes with Satellites) system has been deployed to collect detailed ground survey data for identification and mapping of damage in a wide-ranging area. This use again extends the original aim of the VIEWS system and shows its flexibility for multi-hazard damage detection. Previous studies include the 2003 Bam, Iran earthquake (Adams et al., 2004a), Hurricane Charley and Hurricane Katrina (Adams et al., 2004b, Womble et al. 2006), the Niigata, Japan earthquake in October 2004 (Huyck et al., 2006), the Asian Tsunami of 2004 (Ghosh et al. 2005) and the 2007 California Wildfires (McMillan et al. 2008).

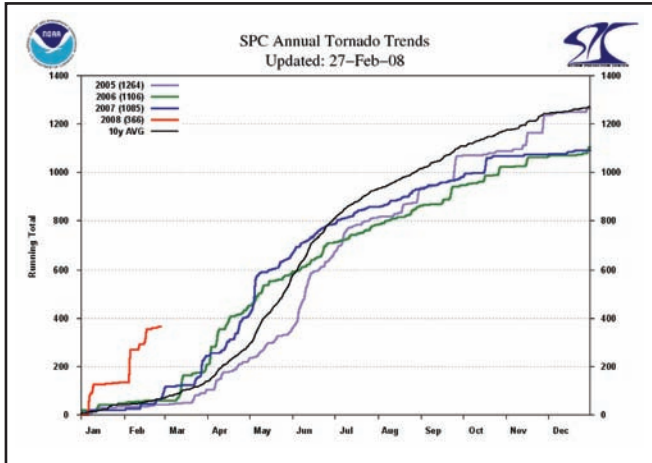
VIEWS was developed by ImageCat through funding from MCEER. The ground-based deployment shows in detail the type of buildings which populate certain areas, the vegetation surroundings, the building materials that survive and other crucial aspects. In some neighborhoods, debris removal, and even rebuilding, had started to occur very soon after the tornado and prior to the arrival of ground-survey teams; it is therefore essential to collect information rapidly to assess the level of damage before this occurs. These quick response deployments occurred within 1 month of the event. It is envisioned that the data collected will form part of a larger research thrust into tornado damage assessment, wind characterization and improving community resilience.

A tornado outbreak struck on the afternoon and evening of February 5 and the early morning of February 6, 2008, impacting the Tennessee Valley and the Mid-south of the U.S. The so-called 'Super Tuesday' tornado outbreak struck many places under cover of darkness. As of February 7, there were 55 reported casualties; 7 in Kentucky, 30 in Tennessee, 4 in Alabama and 14 in Arkansas (NOAA 2008a). There have been 62 confirmed tornadoes, although storm surveys are still ongoing.

This tornado event is unusual in several respects, giving justification for the monitoring of early-2008

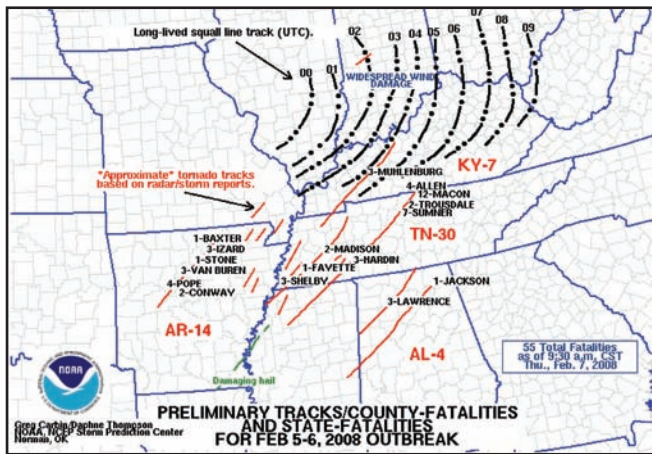
tornado activity using advanced technologies. First, the most recent tornadoes are the first EF-4 tornadoes to hit north Alabama in February. Second, it is already a much more significant year for the frequency of tornadoes than the last few years, and more significant than the long term average. This trend is shown in Figure 1. The tornado outbreak between February 5-10, 2008 was also the deadliest outbreak in the U.S. since May 1985, when 76 were killed in Ohio and Pennsylvania.

Atmospheric conditions in the outbreak region reflected an unstable environment conducive to severe storms with the capacity to produce tornadoes. A powerful low pressure system combined



NOAA 2008b

Figure 1. SPC Annual Tornado Trends



NOAA 2008b

Figure 2. Preliminary Tornado Tracks

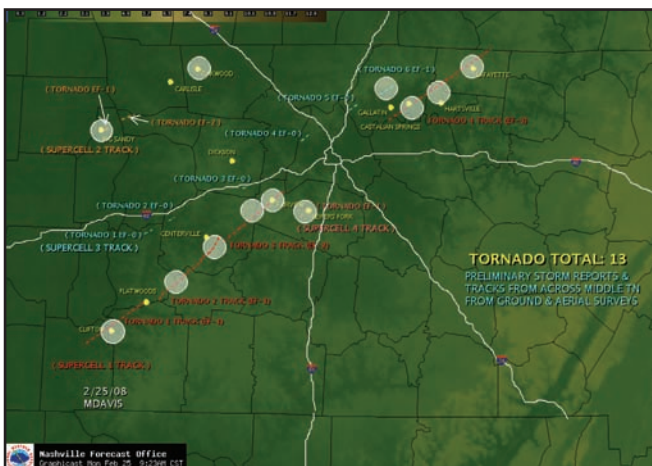


Figure 3. Revised Tornado Tracks for 'Supercells 1 and 2'

with a strong upper level jet stream created a vacuum, which initiated storms. In particular, a split in the jet stream over the middle South created upper level diffluence, providing the sustenance for long-lived supercell thunderstorms (NOAA 2008a).

A low pressure system tracked east during the outbreak. The area ahead of the low pressure zone contained very warm moist air from the Gulf of Mexico. South of the low pressure was a cold front, creating a large difference in pressure. Unusually high temperatures for the time of year were observed in the deep South, and crucially, temperatures did not drop considerably during the night, keeping the instability going.

The combination of moisture, a source of lift, instability and wind shear created perfect conditions for tornado formation, focused around Memphis, Tennessee, on the afternoon of the outbreak. Throughout the evening, the system moved further east. The 'Super Tuesday' storm produced numerous tornadoes crossing six states (Mississippi, Arkansas, Tennessee, Alabama, Kentucky, Missouri and Illinois). Figure 2 shows approximate tracks of tornadoes based on radar and storm reports.

The aim of this study was to capture a range of damage states, tracking the variability of the storms as they develop. The deployment required a focus of attention onto a few key areas, to gain maximum detail of the event. In this case, it was decided to focus on two main tornado tracks, examining the variability in force and damage along its length. The first track chosen for this investigation was the large supercell that hit middle Tennessee and Kentucky. In the radar report, it is shown as one long track. Subsequent ground damage reports helped to better characterize where the storm had produced a tornado that made contact with the ground. This is shown in Figure 3.

The tornadoes spawned from this supercell were caught on camera at various times over the course of the evening. Figure 4 shows the storm as it developed. The tornado was still intensifying when it passed over Memphis. Reports indicate an EF-1 level of damage. In Jackson, TN the tornado intensified and produced up to EF-4 level damage. In Nashville, this rare video footage shows the funnel as it has lifted over Davidson County.



Figure 4. Tornadoes spawned from 'Supercell 1' as it moved northeast.

The second track chosen was named as 'Supercell 2'. This again struck Tennessee, hitting the counties of Shelby, Fayette, Madison and Benton. Along the track multiple tornadoes were spawned, estimated at various EF ratings, giving a good breadth of study. This supercell is also mapped in Figure 3.

REMOTE SENSING DATA AND VIEWS

This study provides a unique opportunity to link accurate ground based surveys with remotely sensed data in order to interpret the damage caused

by tornado outbreaks, and to better understand the development of a tornado and the resulting damage produced along its path.

To fully document the aftermath of a natural disaster, especially when considering perishable building damage, quick response from scientists and engineers is necessary. To address this need for quick and accurate data collection, the VIEWS system was utilized. This is a notebook-based system, which integrates GPS-registered digital video footage, digital photographs and observations with high-resolution satellite imagery collected before and after a disaster (see Figure 5). VIEWS was



Figure 5. Deployment of the VIEWS System

previously used in reconnaissance activities following the 2003 Bam, Iran earthquake (Adams et al., 2004a), Hurricane Charley and Hurricane Katrina (Adams et al., 2004b, Womble et al. 2006), the Niigata, Japan earthquake in October 2004 (Huyck et al., 2006), the Asian Tsunami of 2004 (Ghosh et al. 2005) and the 2007 California Wildfires (McMillan et al. 2008). This is the first instance of using the VIEWS system and high-resolution satellite imagery for tornado field reconnaissance. It offered the survey team a unique opportunity to investigate the use of remote sensing for tornado-related damage assessment. It also enabled the survey team to expand the multi-hazard data collection capabilities of the VIEWS system from earthquakes, hurricanes, tsunamis and wildfire to tornadoes.

This is the first instance of using the VIEWS system and high-resolution satellite imagery for tornado field reconnaissance.

The full utility of the VIEWS system is realized when it is used in conjunction with satellite or aerial imagery to gain an overall view and to link what is seen on the ground to what is seen from the air. Satellite imagery allows a geographically extensive analysis, gaining general ideas and observations about the damage caused by an event. However this interpretation needs both calibration from ground observations and a geographically intensive survey including information (such as nonstructural parameters) that cannot generally be inferred from satellite imagery.

VIEWS recorded the structural damage sustained by properties and the surrounding environment. It recorded video footage throughout tornado affected areas, capturing damage levels ranging from unaffected buildings to total levels of destruction. This deployment was unique, as it was the first time the system had been used to record tornado damage. Over 200 km of ground was covered over a 4 day period, giving 15 hours worth of footage.

Technically, the VIEWS system has been upgraded since previous research efforts, and now boasts two video cameras working in unison, to gain concurrent data from a 180 degree view, in a very short space of time. It also utilizes High Definition (HD) video footage, which allows it to capture detailed crisp images with faithful reproduction of colors. This level of detail is unsurpassed by aerial or oblique view data, and is a very useful resource when examining structural components of damage.

As well as structural information, a host of other environmental data were captured, such as examples of tree uprooting in particular alignment formations on a large scale. This information is useful for interpretation of wind speeds and directions, as well as environmental impact.

In some instances where demolition and recovery activities had already commenced, these activities were captured, which is useful for recovery studies in the future. It is envisioned that such perishable data on damage severity and extent could, in the case of future catastrophic events, be used by key decision makers, emergency response personnel, and researchers for planning response and mitigation policies.

In summary, three objectives for the post-tornado reconnaissance mission were identified:

- To collect perishable tornado damage information.
- To explore new VIEWS system functionalities.
- To link ground surveys with satellite and aerial imagery to better interpret the nature of tornadoes and tornado damage.

SATELLITE IMAGERY

As well as high quality ground deployment data, the satellite imagery which these deployments are being undertaken with is also increasing in quality. As well as high resolution QuickBird imagery, this study has allowed us to consider DigitalGlobe WorldView 1 data for the first time. The satellite is more maneuverable than its predecessor QuickBird, which means more rapid collection of imagery. It also has 50 cm resolution as opposed to 60 cm



Image courtesy of Geoeye © 2008

Figure 6. IKONOS data from Highland Middle School in Arkansas, showing the path of one tornado during the outbreak.

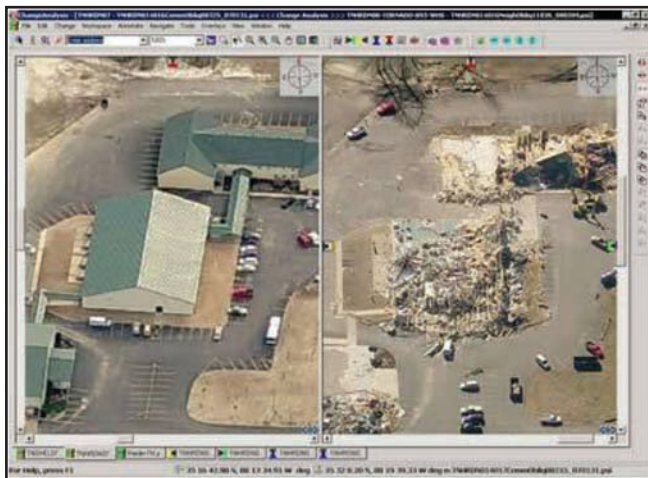


Image courtesy of Pictometry International © 2008

Figure 7. Example of Pictometry data showing before and after footage of one property destroyed by the tornado.

panchromatic on QuickBird. Worldview 1 imagery is panchromatic only, but the soon-to-be-launched Worldview 2 will include both panchromatic and multispectral imaging capabilities. IKONOS data was also available for some tracks, as shown in Figure 6. Satellite imagery was available for certain areas that were focused on, as well as Pictometry data for gaining oblique imagery of sites. Using these angles in conjunction will be a useful toolkit for detailed damage assessment. Figure 7 shows an example of the Pictometry data. This type of data will be utilized in this research project in conjunction with ground surveys.

STUDY SITES

The study site chosen includes portions of the two main storm tracks, 'Supercells 1 and 2', which passed through middle Tennessee on February 5-6. Figure 8 shows the general path that these storms took. The long track supercell storm marked 'Supercell 1' on Figure 8 tracked from Oxford, Mississippi through Tennessee to Kentucky, over 200 miles. Considering Figure 3, the NOAA report has this supercell spawning four different tornadoes. Examining the damage reports, the level of damage reached was EF-0 to EF-1 in Mississippi, an EF-2 to EF-3 in Hickman and Williamson Counties in Tennessee, and an EF-3 to EF-4 in Sumner, Trousdale and Macon Counties in Tennessee. Thus, the tornadoes spawned by 'Supercell 1' increased in strength as the storm moved northeast across Tennessee.

'Supercell 2' passed through Shelby County, TN causing EF-2 level damage, EF-0 through Tipton County and EF-3 in Fayette County, TN. The supercell then moved north, spawning a tornado which

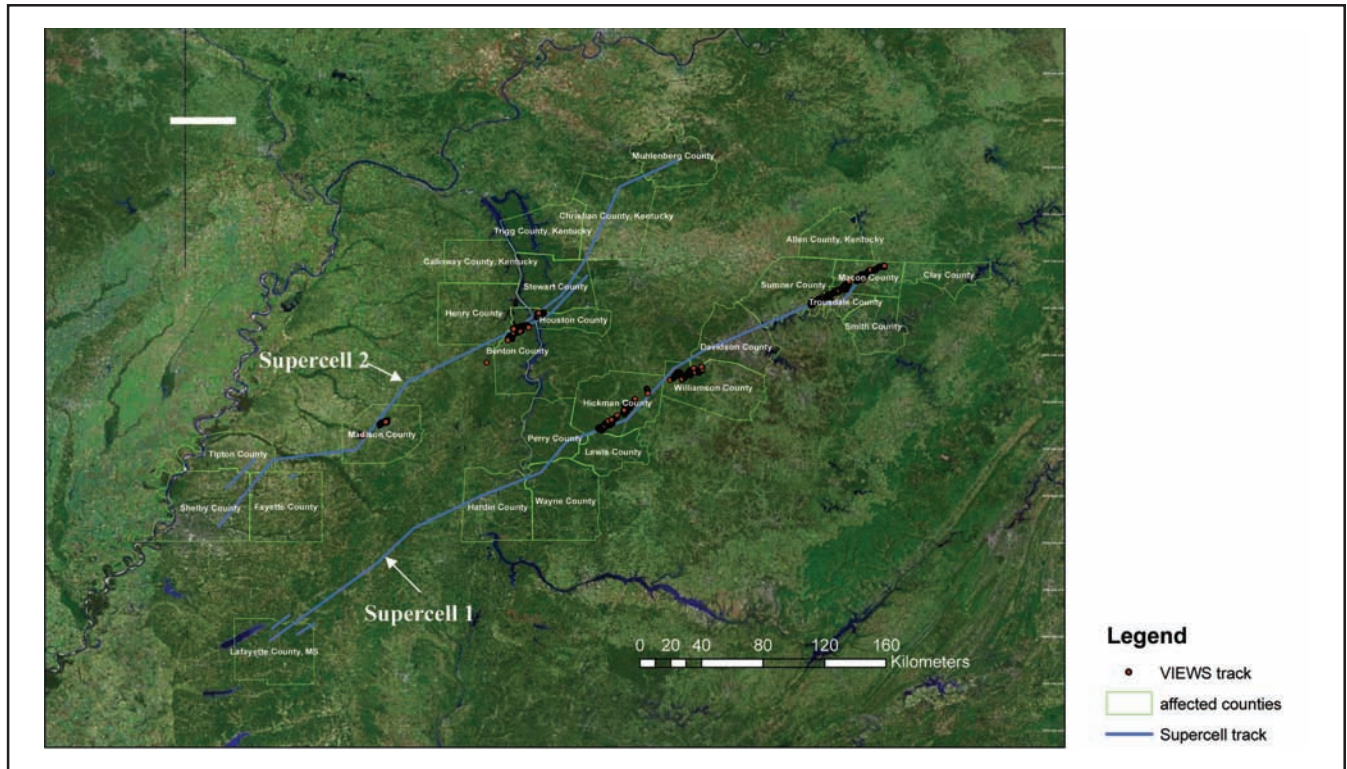
created heavy damage in Madison County (EF-4), before moving northeast again. More tornado damage was noted in Benton County, however weaker than Madison County, before the storm dissipated.

SUPERCELL 1

NOAA storm reports determined that four individual tornadoes occurred along a path extending from Clifton in Wayne County, TN to northeast of Lafayette in Macon County. The first two tornadoes have been rated as either EF-0 or EF-1. A third tornado touched down near the end of the previous tornado track east of Centerville, and passed through Fairview, in northwest Williamson County, before lifting near the Williamson/Davidson County line. This tornado has been rated as either EF-1 or EF-2.

HICKMAN AND WILLIAMSON COUNTIES

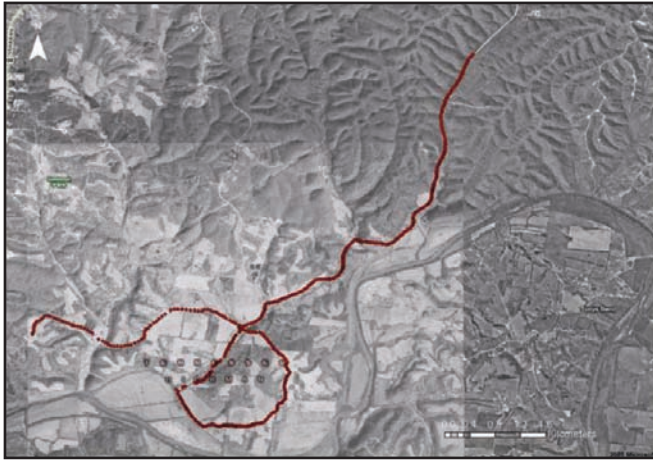
The first tornado touched down over northeast Hardin County, moved near Clifton, lifting near Flatwoods in northern Wayne County. A second tornado touched down in extreme southeast Perry



Aerial imagery © Ask.com 2008

Figure 8. Two preliminary supercell tracks, affected counties and VIEWS footage collected.

Table 1. Roads surveyed in Hickman County



Track H1



Track H2

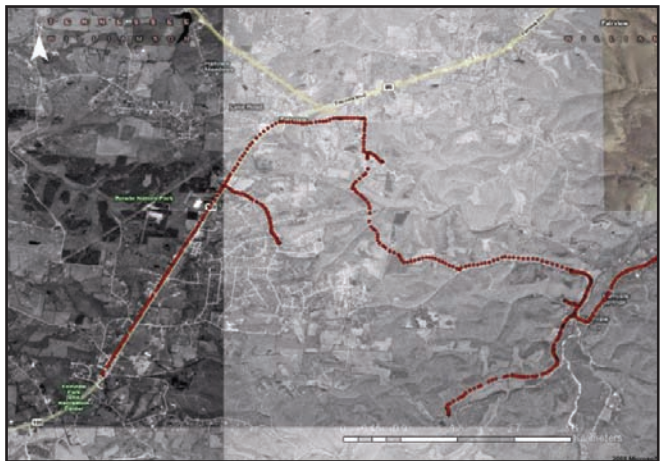


Track H3

Table 2. Roads surveyed in Williamson County



Track W1



Track W2

County, TN, a few miles northeast of the end of the previous tornado track. This tornado remained on the ground as the storm moved across north-west Lewis County and into Hickman County. The tornado struck the Brushy community, then turned toward the left just east of Centerville before dissipating. The first area of 'Supercell 1' to be surveyed by VIEWS footage was Hickman and Williamson counties, where damage was generally found to be at the EF 0-1 level. Figure 9 shows the track of the VIEWS footage that was collected. Tables 1 and 2 show the GPS tracks in more detail.



Figure 9. Overview map of Hickman and Williamson Counties, with collected VIEWS routes. Arrow shows general path of storm.



Figure 10. VIEWS track recorded through Sumner, Trousdale and Macon Counties, as well as Worldview and QuickBird satellite imagery from just after the tornado.

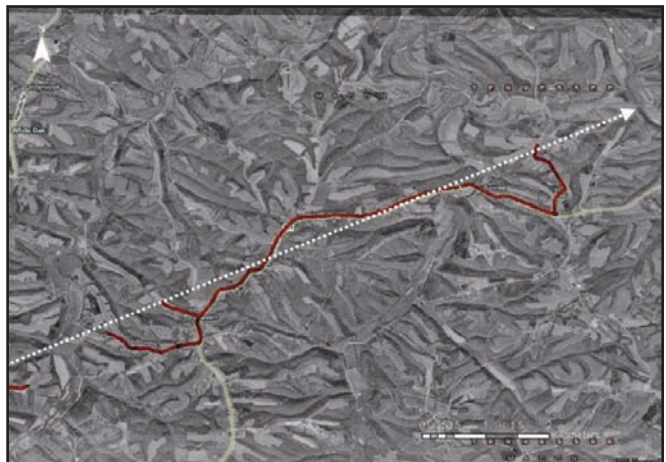
SUMNER, TROUSDALE AND MACON COUNTIES

NOAA reports that the supercell thunderstorm continued to move northeast, across Nashville, before spawning a fourth tornado, which dropped down on the south side of Gallatin, near the Cumberland River. This tornado moved through Castalian Springs, extreme northwestern Trousdale County, across Macon County, striking the northwest side of Lafayette, before moving into Kentucky, where it finally lifted northeast of Tompkinsville. The path length of this tornado was approximately 51 miles. Much of the damage along this path was rated EF-2, although some areas received EF-3 damage. This long track tornado had winds in the 110 to 140 mph range and caused damage three quarters of a mile wide (NOAA 2008c). Figure 10 shows an overview of Sumner, Trousdale, and Macon Counties, with the GPS routes plotted, and available satellite coverage. Table 3 shows a section of the GPS track in more detail.

Table 3. Roads surveyed in Macon County



Track M1



Track M2

SUPERCELL 2

Supercell 2 produced a tornado which touched down in Shelby County, causing estimated EF-2 damage, and EF-0 damage in southeast Tipton County before dissipating. Storm reports suggested that this path of the tornado produced generally moderate effects, where some roofs were partially removed, as well as windows being blown out. Tree damage was evident.

The supercell also caused some estimated EF-3 damage across Fayette County as it pushed northeast. This tornado uprooted a number of large trees and broke power lines. The path length of this tornado was estimated at 2 miles, with a maximum width of 500 feet. A preliminary National Weather Service storm report estimates 3 second wind gusts in the region of 140 mph (NOAA 2008d). The winds for all storm surveys considered were estimated using the Enhanced Fujita Scale's Damage Indicators (see Table 4). All EF levels are interpreted according to the damage description observed by building type. An example of this damage description scale is shown in Table 7. Occasionally other factors influence the estimate such as construction quality, or proximity to other damage (Salem pers. comm. 2008).

Table 4. EF-Scale wind speed ranges derived from Fujita-Scale wind speed ranges

F Scale	Windspeed (mph)	EF Scale	Windspeed (mph)
F0	45-78	EF0	65-85
F1	79-117	EF1	86-110
F2	118-161	EF2	111-135
F3	162-209	EF3	136-165
F4	210-261	EF4	166-200
F5	262-317	EF5	>200

Note: All speeds are 3-second gusts at 33 ft height in open-country exposure.

WISE 2006

The storm subsequently passed northeast and spawned 3 tornado segments in Madison County, and one in Carroll County. The first segment caused EF-3 damage with winds of 160 mph (NOAA 2008d). This tornado was up to 3/4 of a mile wide and 5 miles in length. Numerous homes, a church and an Interstate 40 rest area were damaged. Eight semi-tractor trailers were blown off Interstate 40 during the tornado's passage.

The second segment caused extensive damage at Union University and buildings near the U.S. highway 45 bypass. The National Weather Service rated this tornado segment as EF-4 damage with winds of 170 mph (NOAA 2008d). The path was up to 125 yards wide and 11 miles long. In addition, EF-3 damage was noted 5 miles east southeast of Fairview.

NOAA reports that a third segment indicated a brief EF-2 tornado touchdown in Spring Creek along highway 152, approximately 1/4 of a mile west of highway 70 (NOAA 2008d). One home suffered total roof loss and partial failure of the front exterior wall. Three additional homes received extensive roof damage. Large trees were snapped and uprooted. Winds were estimated at 125 mph with a maximum width of 150 yards.

A fourth and final EF-0 tornado touchdown occurred one mile west southwest of Cedar Grove in Carroll County along Roger Frye Road. Trees were downed and snapped in a small wooded area. Maximum wind speed was 65 mph with a width of 25 yards.

Having lifted again, the storm continued to move northeast, before producing a tornado in northern Benton County, which caused damage between Big Sandy, Faxon, and Granny's Branch. Preliminary reports suggest an EF rating of 2-3 at this point.

MADISON COUNTY

The first VIEWS footage from this supercell was recorded in Jackson (Madison County, TN) where EF-4 damage was recorded. Figure 11 shows a general overview map of the Madison County area, with the GPS tracks recorded, along with available satellite coverage. Table 5 shows the GPS tracks in more detail.

Use of the VIEWS system allowed the team to track the general direction of the tornado in this area. Classifying building damage to infer tornado

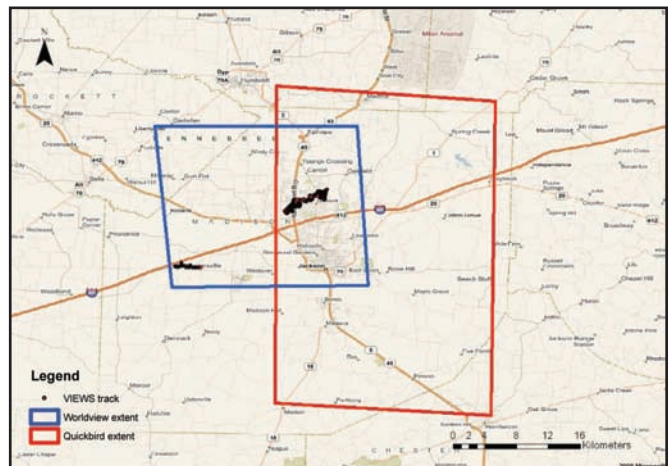


Figure 11. VIEWS track recorded through Madison County, as well as Worldview and QuickBird satellite imagery from just after the tornado.

Table 5. Roads surveyed in Madison County



Track MD1



Track MD2

width will be a future direction for research based on the collected data. The video footage confirmed the storm reports that there was variable damage in Madison County, with the worst hit area being Union University. This contained some EF-4 damage, which will be expanded upon later in the report.

BENTON AND HOUSTON COUNTIES

The second track from this supercell was recorded around northeast Benton County, pushing into Houston County. The level of damage seen here was generally EF-1. Figure 12 shows the overview map of these counties, while Table 6 shows the GPS tracks in more detail. Figures 13-15 show photos typical of the damage observed.

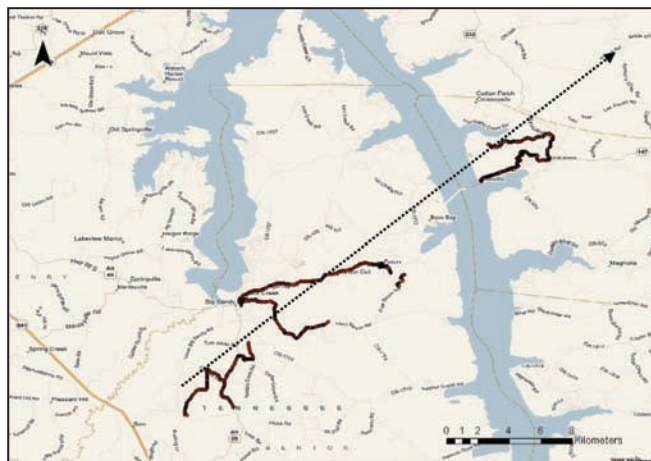


Figure 12. VIEWS tracks in Benton and Houston County. Black arrow marks rough track of tornado.



Figure 13. Older construction with damage to roof covering and windows. An overhanging porch has also been removed (Faxton, TN, Benton County).

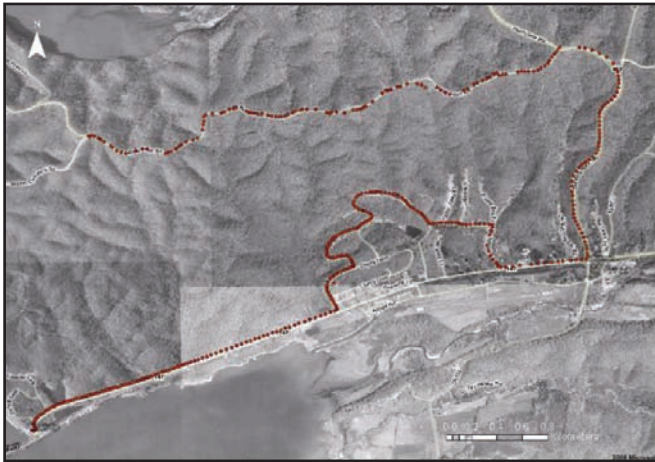


Figure 14. An example of likely substandard construction with higher degree of damage than surrounding structures in Faxton, TN (Benton County).

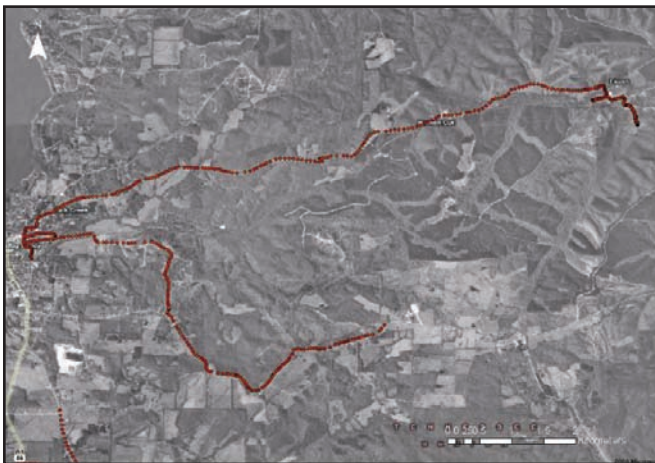
Table 6. Roads surveyed in Benton and Houston Counties



Track B1



Track B2



Track B3



Figure 15. An example of damage consistent with EF-0 rating near McKinnon, TN (Houston County). From Table 7, loss of awnings and siding is expected for DOD 2, with an expected wind speed of 79 mph. The image was taken looking west with Tennessee River in the background.

Table 7. Damage Indicators for Single-Family Residence, giving Expected, Lower Bound, and Upper Bound Wind Speeds for each Degree of Damage

DOD*	Damage Description	EXP	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed, except small interior rooms	152	127	178
9	All walls	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	165	220

Note: The appropriate wind speeds are used to determine the EF-Scale rating from Table 4.

*DOD is degree of damage, EXP is expected damage, LB is lower bound and UB is upper bound

PRELIMINARY DAMAGE ASSESSMENT

SUPERCCELL 1

Along the central portion of the 'Supercell 1' track, the VIEWS system was deployed in Hickman and Williamson Counties along 'Tornado 2' track and 'Tornado 3' track, southwest of Nashville. 'Tornado 2' and 'Tornado 3' are shown along the 'Supercell 1' track in Figure 3. Along this area of the storm track, the damage was quite variable, and in most cases was not extensive (see Figures 16-19). Based upon ground observations gathered with VIEWS, this portion of the storm track would be rated EF-0 or EF-1. The types of damage generally seen in this area include small trees snapped and uprooted, some small debris impacts to structures, and shingles removed from roofs. Some older and poorly maintained storage, barn, and shed buildings were collapsed or destroyed, which is thought to be more a function of the quality of construction rather than the strength of the storm. (Note that the EF Scale accounts for variation in damaging windspeeds due to construction quality (WISE, 2006)). The damage paths resulting from tornadoes in this area were quite narrow, and in many cases the storm path was difficult to locate because the damage was minor.

As 'Supercell 1' moved out of Williamson County and towards Nashville, the 'Tornado 3' causing destruction near Fairview lifted, and no tornadoes were reported on the ground in Davidson County as the storm progressed toward the northeast. Along the northern portion of the 'Supercell 1' track, the VIEWS system was deployed in Sumner, Trousdale, and Macon Counties, northeast of Nashville, to collect data along 'Tornado 4' track, which is shown in Figure 3. Judging by the damage observed along this portion of the storm track, 'Supercell 1' strengthened as it progressed toward the northeast, and produced the strongest tornado in this region. Directly along the tornado path, damage was extensive - with still larger trees uprooted and snapped and with more significant damage to homes and structures. This level of damage is shown in Figure 18(a). Along the center

of the path, numerous structures were destroyed, either by the structure being shifted from its foundation, by the collapse of major walls, or by the uplift of roof assemblies. Figure 18(b) shows a house which had been flipped onto its side. Further away from the center of the track, broken tree limbs, shingle removal, and broken windows were common. One interesting feature seen in this area was the uprooting of numerous trees, which had been blown over in alignment patterns parallel to the tornado wind direction, showing the cyclonic swirl effect as shown in figure 18(c). Based upon the team's preliminary observations, the highest damage level experienced along this particular tornado track appeared to be borderline EF-3 to EF-4.



Figure 16. A log home with minor roof damage in Hickman County.



Figure 17. Snapped trees and minor residential damage in NE Macon County. The tornado appears to have weakened in this region, when comparing level of damage seen here in contrast to that seen in Lafayette.



(a)



(b)



(c)

Figure 18. (a) Damage in the worst hit region of Macon County; (b) Overturned house in Macon County; (c) uprooted trees showing alignment patterns.



Figure 19. An example of minor roof damage in Hickman County. The degree of damage is somewhat uncertain in this case because construction efforts were already started.

SUPERCCELL 2

Along the ‘Supercell 2’ track, the VIEWS system was deployed in Madison County, in Jackson, TN and the surrounding areas. The most extensive damage recorded along this portion of ‘Supercell 2’ was observed on the campus of Union University in Jackson. Several residence halls were destroyed or severely damaged. A number of photos from this area are shown in Figures 20-23. A large number of vehicles were damaged, moved, or even flipped over on the campus. While the residence halls suffered extensive damage, the academic halls suffered minor damage, which was mostly cosmetic, with the exception of one building which had damage to the gable roof structure. Based on the severity of the damage to the engineered structures in this area,



Photo taken Friday, February 8, 2008

Figure 20. Residence halls in southwest portion of Union University campus.



Figure 21. Cars pushed or rolled multiple times in residence hall parking lots.



Figure 22. Minor damage to windows and roof shingles at Jennings academic hall. Residence halls in previous pictures are in the background.

the team rated this storm as an EF-4 tornado. As this tornado progressed, the strength decreased, with the most severe damage located at Union University and in a neighborhood just on the other side of US 45 bypass, northeast of the university. By the time the tornado reached the western side of the city to the west of US 45, most of the damage observed was minimal, with some tree damage, shingles removed, and debris impacts, but little structural damage.

Figure 24 shows two properties in Jackson, TN, where the tornado passed through at around a level EF-3. Figure 24(a) shows structural damage on the upper floors, and a broken window on the



Figure 23. Worst damage to residence halls on Union University campus. Taken at approximately the center of campus looking west.

ground floor. This building is observed to have a wood-framed upper story structure, whereas the lower story is covered with brick veneer cladding (likely atop conventional wood-stud framing). Figure 24(b) shows that the wood frame part of this building again collapses, whereas the brick built structure remains more intact. It is possible to start to investigate the trends and correlations between building materials and structural integrity once a classified database is created from the VIEWS footage. Figure 24(c) shows another interesting case where the building was lifted from its foundations and moved a considerable distance, without losing structural integrity. It is thought the building used to be parallel



(a)



(b)



(c)



(d)

Figure 24. (a) and (b) VIEWS footage showing two partially devastated buildings recorded in Jackson showing increased building damage in wood frame construction than brick; (c) House blown from its foundations; (d) Missiles imbedded in roof.

with the hedge. Lastly, Figure 24(d) shows evidence of high velocity missiles where relatively large posts of wood were seen to penetrate roof material.

The central portion of the 'Supercell 2' track moved through Benton and Houston Counties, along the Tennessee River, northeast of the Jackson area. The tornado spawned in this area touched down northeast of Big Sandy in Benton County, then crossed the Tennessee River causing more severe damage on the immediate eastern side of the river. The damage observed on the western side of the river was relatively minor, with some tree branches snapped, and damage to a few homes. However, some of the homes had suffered significant damage, but this was likely due to substandard construction. As the storm crossed the Tennessee River, (nearly 2 miles wide at this point), the winds near the ground appear to have strengthened over the open expanse of the water, due to the open fetch afforded by the river and the lack of trees to slow wind speeds near the ground. The VIEWS system documented more severe damage to more substantial structures on the eastern side of the river, than was observed on the western side of the river. The damage observed on the western side of the river is considered high EF-0 or low EF-1 damage, while the damage level on the eastern side of the river is more likely high EF-1 damage.

GENERAL OBSERVATIONS

After surveying tree and structural damage along both the 'Supercell 1' and 'Supercell 2' tracks, some general statements regarding the patterns of damage can be made.

- Trees and structures directly below the tornado vortex suffered much more damage than those located a short distance away, indicating that the level of damage decreases rapidly with distance from the center of the tornado's path.
- The large number of deteriorating storage buildings and barns generated a large amount of debris, and at times it was difficult to determine whether the storm was responsible for the damage, or if the structure was in that condition prior to the storm's passage.

- Those homes with double-paned windows (see Figure 25) often had the outer "sacrificial" pane broken by debris impacts, while the inner pane remained undamaged, reducing the chance for internal pressurization which often leads to roof uplift and further damage to the structure.
- The walls of structures with a brick veneer exterior finish performed better than those with wood board and vinyl finishes. Numerous log-cabin style homes were observed in the region, and because of the thickness of the wall material, no debris punctures were observed in these structures.
- Shingle removal was common on homes located even a large distance from the storm track.
- Improperly and/or poorly anchored mobile homes were flipped and destroyed, leaving twisted undercarriages. These structures were often carried some distance from their original location.



Photo courtesy of Larry Tanner

Figure 25. An example of a double-paned glass window in a residence hall of Union University. The exterior pane on the left side has broken, whereas the panes on the right side appear to be intact. The amount of damage to blinds would be expected to be higher if only one pane of glass was used with these windows.

GOOGLE EARTH VISUALIZATION

A major aim of this research is to create data-sets which are easy to use, and easy to disseminate to end users. A goal is to give the user a sense of a 'Virtual Disaster Tour.'

This concept will be developed using one of the most widely used pieces of geographic software at the present time, Google Earth. Figure 26 shows the geographically extensive mode of the API, with tornado tracks and damage states recorded as vector

layers. Satellite coverage can also be overlain. Figure 27 shows the geographically intensive mode, where GPS points can be clicked, and damage photos along with attributes appear. Other derived layers that could be added are tornado width and damage state layers, as well as storm reports, news articles etc. These disparate sources can be combined together to give a coherent overview of the disaster to the end user.

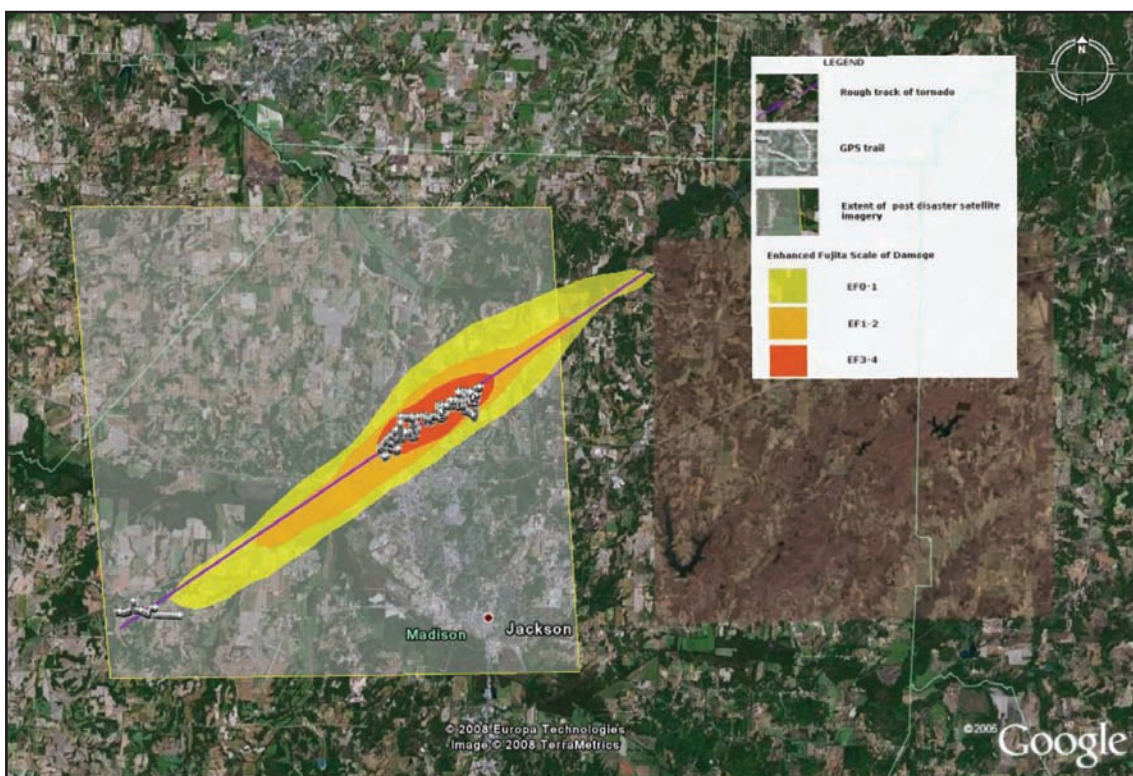


Figure 26. Prototype Google Earth API showing overview vector layers of tornado track, optical satellite imagery extent for post-disaster view, and rough map of EF rating zones (mock up, not real data).

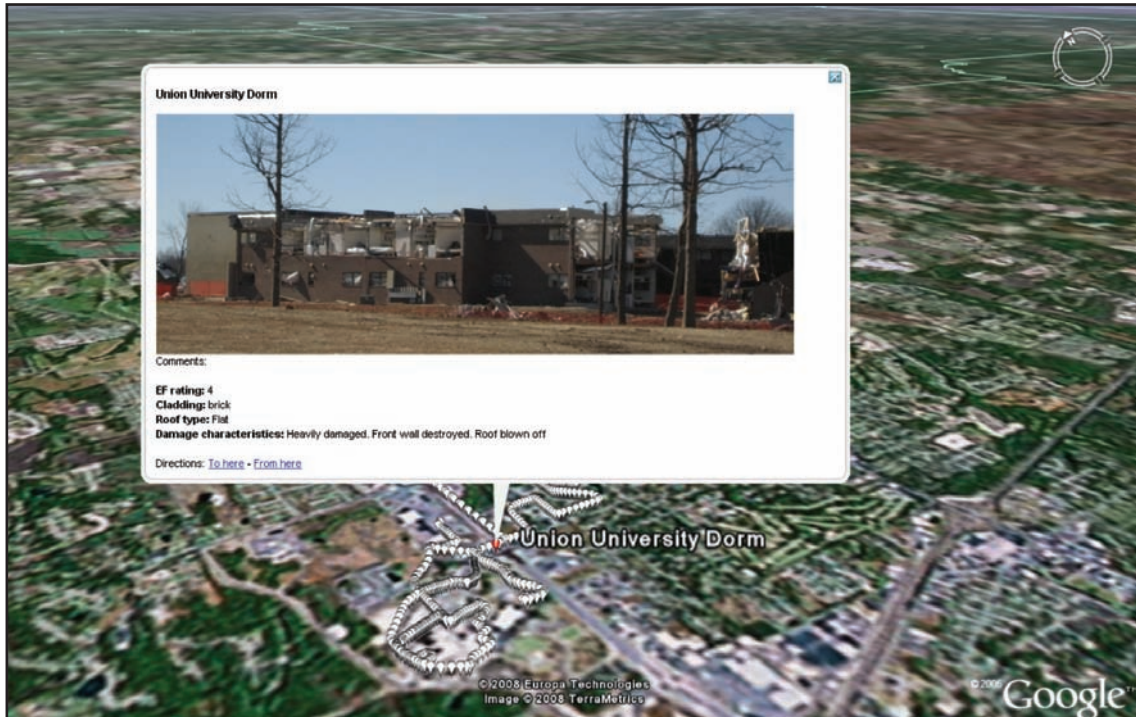


Figure 27. Prototype Google Earth API showing damage to structure and attributes for GPS point. The finished Google Overlay will be available to download from <http://mceer.buffalo.edu/research/Reconnaissance/tornado02-08/default.asp>.

FUTURE RESEARCH

This data collection documents the first time that a consistent damage survey has been undertaken using VIEWS for tornado damage. It allows civil and structural engineers to examine in detail structural damage states, and the tornado's effects on building materials. This should allow an investigation into building types and resultant damage, which will lead to increased understanding of resilient structures and mitigation strategies.

Secondly, it is a useful benchmark for assessing perishable damage before recovery takes place. The data could be used as a baseline for examining restoration or demolition of houses, and monitoring the success of recovery activities to improve tornado resilience. As well as structural damage, the environmental data collected would also be useful in terms of wind patterns and regimes. It is thought that the behavior of the tornado can be inferred by the

marks it leaves on the landscape, such as tree alignment patterns. The damage to buildings and surrounding areas can also be used to guide estimates of tornado width and strength at different points. Utilizing both VIEWS and aerial/satellite imagery, a further potential research direction to follow from this collection would be to examine what characteristics of tornado damage are detectable on satellite and aerial imagery, and what characteristics need VIEWS ground deployment, in order to classify and estimate damage states.

In terms of dissemination, the development of Google Applications is a very current and user friendly method of delivery. This is believed to be the first time a detailed virtual damage tour has been produced for tornadoes using this software, and will undoubtedly be a useful tool for researchers.

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MCEER RESPONSE

Anneley McMillan and Beverley J. Adams

*ImageCat Ltd.
Communications House
63 Woodfield Lane
Ashted KT21 2BT
United Kingdom*

**Amber Reynolds, Tanya Brown, Daan Liang and
J. Arn Womble**

*Wind Science and Engineering Research (WISE)
Center
Texas Tech University
Box 41023
Lubbock, Texas 79409*

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FOR MORE INFORMATION

MCEER

University at Buffalo, State University of New York
Red Jacket Quadrangle
Buffalo, NY 14261

Phone: (716) 645-3391

Fax: (716) 645-3399

E-mail: mceer@mceermail.buffalo.edu

Web Site: <http://mceer.buffalo.edu>

STAFF

Editor: **Jane Stoyle**

Illustration/Photography: **David Pierro**

Layout/Composition: **Michelle Zuppa**

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University at Buffalo *The State University of New York*



University at Buffalo
State University of New York
Red Jacket Quadrangle
Buffalo, NY 14261