170 THE ART OF STORM SURVEYING: LEVERAGING NEW DATASETS TO DOCUMENT THE 12 JUNE 2013 TORNADOES

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1. INTRODUCTION

On the afternoon of 12 June 2013, a lone thunderstorm produced multiple tornadoes along a 40-km path through Wright and Franklin Counties in north-central Iowa. In the days, weeks, and even months that followed, personnel at the National Weather Service (NWS) office in Des Moines utilized multiple sources to construct the most accurate set of tornado tracks possible. Whether it was the findings of the NWS ground survey team, aerial photos from an unmanned aerial vehicle (UAV), high-resolution satellite imagery, or photos/videos posted to social media websites, each played a critical role in this effort. Aiding in the integration of this data was the Damage Assessment Toolkit (DAT), a suite of GIS-based mapping programs that can be used on smartphones, tablets, and PCs. This powerful program not only provides storm surveyors a tool to upload their findings in near real-time to a central server which provides community access to the data, but also allows for the construction of incredibly detailed tornado tracks for disaster response, post-event reviews, and research studies.

2. REVIEW OF THE 12 JUNE 2013 EVENT

The synoptic environment on 12 June 2013 was supportive of severe weather across eastern Iowa. A sharp, negatively tilted 300-hPa shortwave trough across Nebraska and South Dakota rounded a Southern Plains ridge during the morning hours with a 36-ms^{-1} (70-kt) jet impinging from the west, placing eastern Iowa in the left front exit region. Meanwhile, a 1002-hPa surface cyclone lifted northeastward from Kansas and reached western Iowa by mid-morning. Early afternoon forecast soundings in the warm sector depicted 2500 to 3500 J kg^{-1} of surface-based convective available potential energy (CAPE) and weak inhibition with effective bulk-shear values of 18 to 23 ms^{-1} (35-45 kts). The Storm Prediction Center placed the eastern quarter of Iowa under a “Moderate Risk” with their 1200 UTC Day 1 Convective Outlook, upgrading a portion of this area to a “High Risk” with a 15% hatched tornado threat at the 1730 UTC update. Tornado development was expected near the surface low’s triple point and along the warm front draped from west to east across east-central Iowa and west-central Illinois.

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However, the surface low weakened during peak heating and began redeveloping over southern Iowa, with the remnant circulation displaced 200 km to the north of the new mean sea-level pressure minimum. As a result, the anticipated low-level shear and helicity never materialized over eastern Iowa and instead was replaced with broad, weak west-southwest flow. Multiple supercells with vigorously rotating updrafts did initiate along the effective warm front during the afternoon hours, but failed to produce a single tornado in eastern Iowa due to the lack of low-level shear.

Additional thunderstorms formed further west in north-central Iowa near the remnant low circulation. The resultant strong surface vorticity, juxtaposed on 100 to 125 J kg^{-1} of 0–3-km mixed-layer CAPE and near adiabatic 0–1-km lapse rates, produced a favorable environment for vortex stretching and tornadogenesis (Davies 2005). One thunderstorm rooted on a subtle boundary was tornadic, producing seven tornadoes between 2100 UTC and 2200 UTC across northeastern Wright and western Franklin Counties.

The first two tornadoes of the event struck the town of Belmond. Damage from the first tornado, as rated on the Enhanced Fujita (EF) scale, was a high-end EF3 on the north side of town, where several structures were heavily damaged or destroyed. The second tornado touched down on the east side of town, knocking a mesonet weather station off a school roof before tracking off into farm fields. The third tornado formed west of Belmond while the first two tornadoes were still in progress; it rotated anticyclonically during its short life based on satellite scour marks. An EF2 tornado tracked north of the town of Alexander just after 2130 UTC, while three smaller EF0/EF1 tornadoes touched down northwest of Hampton between 2145 UTC and 2200 UTC. A listing and map of these tornadoes is provided in Table 1 and Figure 1.

Tor #	Start & End Time (UTC)	Rating	Path Length (km)
1	2108 - 2127	EF3	9.98
2	2119 - 2132	EF1	8.05
3	2121 - 2124	EF0	1.83
4	2132 - 2144	EF2	8.37
5	2146 - 2155	EF1	5.60
6	2153 - 2156	EF0	2.06
7	2156 - 2159	EF0	1.77

Table 1: *A listing of the tornadoes that affected north-central Iowa on 12 June 2013, including start and end times, EF rating, and path length.*

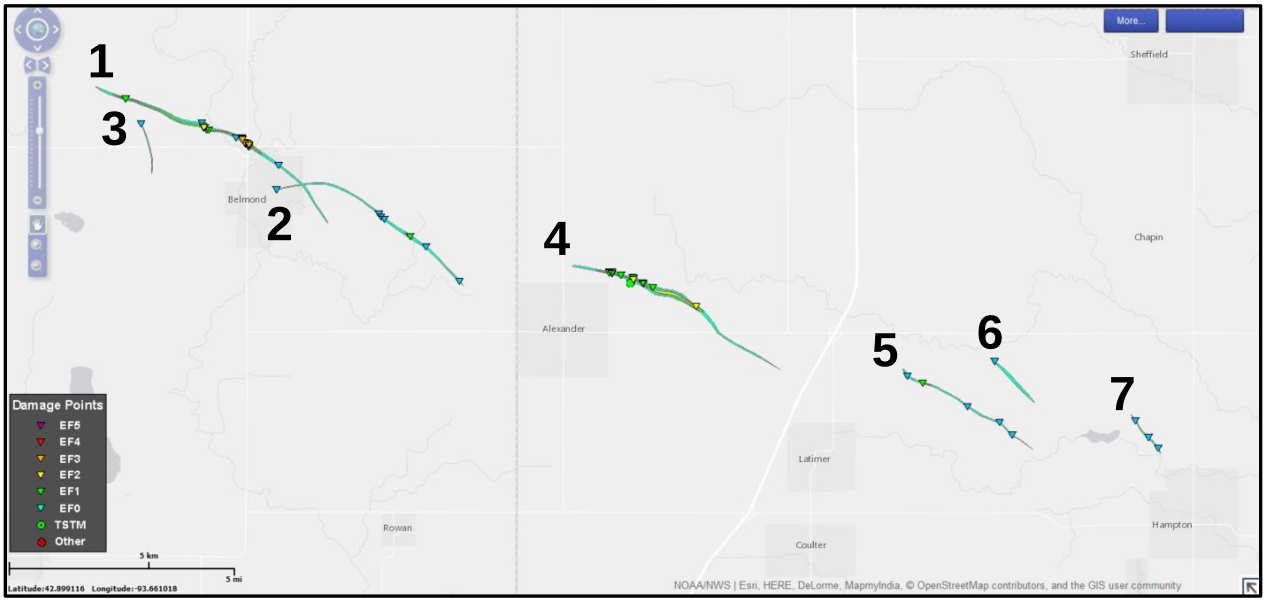

Figure 1: *Map of tornado tracks from 12 June 2013. This map contains the damage points and paths constructed in the DAT. The number next to each track corresponds to the number assigned to the tornadoes in Table 1.*

Photographic evidence suggests that these tornadoes possessed certain landspout characteristics while the parent storm appeared more supercellular in structure. On radar, the cell exhibited a persistent appendage on its southwest flank and a weak echo region under the updraft on its south side. Yet only weak and brief mesocyclones and no tornado vortex signatures (TVS) appeared on radar (more details on the radar data in section 4.1). It is possible that the tornadic circulations were very shallow and rooted under the updraft, as would be expected with landspouts.

3. THE DAMAGE ASSESSMENT TOOLKIT

The DAT consists of a suite of smartphone/tablet apps and a PC software program all linked to a common GIS database accessible via a web browser (Camp et al. 2010). The DAT was developed during the late 2000s and has gradually been incorporated into NWS operational storm surveys during the last few years. The success and cost effectiveness of the DAT has been documented with several high-profile events, including the 27 April 2011 Southeast U.S. and 20 May 2013 Moore, Oklahoma tornado events (Stellman 2011; NWS Service Assessment 2014).

The apps and PC program are designed to be used in the field by the NWS survey team. From within the app, the surveyors can photograph, geotag, rate, and add detailed notes about every damage point encountered. The list of EF-Scale damage indicators (DIs) and associated degrees of damage (DODs), along with lower, expected, and upper bound wind speeds, are built into the DAT program for convenience. Once entered, this information is sent to the central GIS server via a cellular or wireless connection. If no service is available, the information can be stored locally until such a time that it can be uploaded.

Meteorologists at the forecast office can view and work with the data sent from the survey team in near real-time via an interactive map in a web browser (Fig. 2). This greatly expedites the release of information to the media, state and local emergency management, and FEMA, since a team at the office can draft a report while the survey is still in progress. One can draw tracks and take measurements of the length and width of the tornado track within the DAT web interface. The finished tracks can be exported in GIS-friendly formats including shapefiles and KML files.

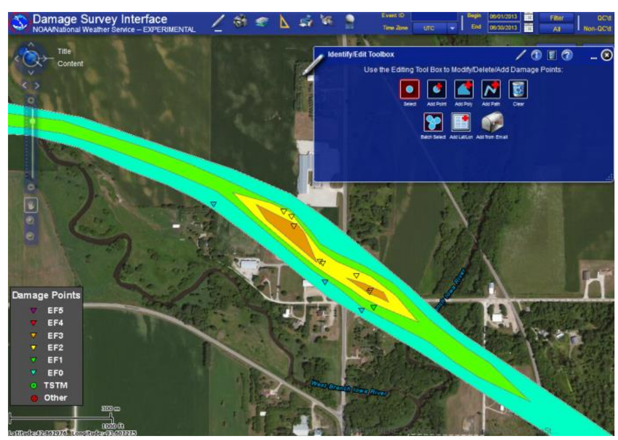

Figure 2: *The web browser interface of the DAT. Different action buttons are accessible on the top bar, which open floating pop-up windows with various tools (example shown on upper right side of the map). The map encompasses the remainder of the screen. A track with different EF-Scale contours is shown.*

4. DOCUMENTING THE TORNADOES

The following is a summary of the methods used to document the 12 June 2013 tornadoes.

4.1 *Radar Data*

Due to the unusual, hybrid nature of the storm, radar data from the KDMX WSR-88D radar proved to be of limited value in narrowing down the locations of any possible tornadoes. During the course of the event, the storm was located at a distance of approximately 120 km north of the radar with a subsequent 0.5° beam height of about 2 km. Neither the radar-based algorithm nor a subjective analysis of the radar data revealed any TVSs. Broad, weak mesocyclones were noted at intermittent times during the event (again, via both the radar algorithm and a subjective analysis).

There was one exception where a stronger mesocyclone appeared around the formation time of the fourth tornado (and was offset by over 3 km from the ground track). This couplet was cyclonically divergent and transient, quickly dissipating within three radar volume scans. A reduction in the correlation coefficient (CC) dual-pol radar product appeared behind this couplet at the same time with reflectivity values within this lower CC region ranging from 10 to 50 dBZ. This may have been a plume of debris being lofted into the radar beam, though from which tornado is still in question. This CC depression also behaved like a debris plume, quickly rising to a height of 5 km before widening and settling back down to the ground in the next two volume scans.

4.2 *Ground Survey*

The day following the event, two meteorologists from the NWS in Des Moines surveyed the area impacted by the storm. With the help of local county officials, the team initially concluded that there had been six tornadoes. One tornado on this list was based on an eyewitness report and later discredited; videos taken at the purported time never showed a tornado in that location. The damage around Belmond was originally thought to be the result of one continuous tornado—which will be shown disproven by evidence presented in the next sections.

A ground survey is the oldest method of analyzing a tornado's intensity. It is nonetheless the only way to ascertain reliable EF ratings as the rating process requires assessing the quality of damaged structures. No other method of surveying can currently replace this aspect of a ground survey. A ground survey may be conducted remotely by having emergency mangers and law enforcement officials thoroughly photograph the damage and send the photos to the NWS for evaluation. This has been utilized with varying degrees of success with weaker tornadoes in the NWS Des Moines County Warning Area (CWA).

A ground survey may encounter situations where a tornado does not strike a DI, which can be common in rural areas. In these instances, while the strength of a tornado cannot be assessed, the tornado can be rated an EF0. A tornado's strength may also exceed the upper limits of weaker DIs. For example, farm outbuildings are typically destroyed by tornadoes of EF1 to EF2 intensity. It is not possible to know if a tornado's winds were higher unless stronger DIs are nearby. In this instance, the tornado is rated as high as the DIs will allow. The traditional ground survey is also often limited by time and available road networks, which is where newer surveying methods fill in these gaps.

4.3 *Unmanned Aerial Vehicle*

A local television station meteorologist accompanied the NWS ground survey team and piloted his personal remote-controlled quadcopter over several sections of the tornado tracks. The UAV flew a few hundred feet above the ground within a mile of the launch point. The onboard camera captured images in predefined intervals while the surveyors on the ground watched a live feed from the camera. The aerial photos from the UAV revealed intricacies in the damage paths that not even the satellite imagery could resolve. In one instance, the survey team rated an area of tree damage as tornadic; however, the aerial imagery revealed these winds to be linear in nature with the tornadic circulation quite evident over 100 m to the north (Fig. 3).

Figure 3: *Aerial photo captured by the UAV of the track of the fourth tornado. The tornado track is on the left side of the photo and denoted by white arrows. Field debris streaks indicative of linear winds are highlighted by the dashed back arrows oriented in the same direction as the winds (Photo courtesy of Adam Frederick).*

While the usage of the UAV on this survey was limited to just a few locations, it nevertheless demonstrated its usefulness in locating the footprint of a tornado. A quadcopter, camera, monitor, and other needed supplies range in cost from one to two thousand dollars, but provide an on-demand and accurate aerial surveying method for the NWS without involving the civil air patrol or capturing satellite imagery. A UAV is limited by its short flying time and would require extensive training for NWS staff to operate. The legality of operating UAVs over private property has also been called into question in recent years (American Bar Association 2014).

4.4 *Satellite Imagery*

Tornado tracks and damage patterns have been photographed by satellites since the early 2000s (NASA 2014). However, limitations in imagery resolution, processing time, and network bandwidth likely made it unfeasible to use in an operational NWS survey. The first documented case of satellite imagery being used by the NWS to map out tornado tracks was with the 27 April 2011 tornado outbreak across the Southeast U.S. (Carcione 2011). Normalized difference vegetation index (NDVI) imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS, resolution of 250 m) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER, resolution of 15 m) were used to locate the tornado tracks, which worked well given the dense vegetation of the region and the significant tornado path lengths and widths (Molthan et al. 2014). This imagery was made possible by a collaborative effort between the NWS Southern Region and the NASA SPoRT program (Carcione 2011).

Unfortunately, the above satellite products are inadequate for nearly all of Iowa's tornado events because:

- A high percentage of Iowa's land use is for agricultural purposes (ISU 2014). Tornadoes over these areas tend to produce a weak or undetectable change in the NDVI (Molthan et al. 2014).
- The vast majority of Iowa tornadoes are weak (≤ EF2). Approximately 96% of all Iowa tornadoes from 1980 to 2013 were rated EF0-EF2 (SPC 2014). The MODIS and ASTER data showed a notable decrease in skill with tornadoes of these intensities (Molthan et al. 2014).
- Most tornadoes in Iowa are brief and narrow. The average **maximum** path width of Iowa tornadoes from 2000 to 2013 was less than 100 m (SPC 2014). The tornadoes were often narrower throughout much of their life.

At the beginning of 2013, the NWS partnered with the United States Geological Survey (USGS) to provide satellite imagery to its local forecast offices under a program titled "Emergency Satellite Support." The USGS has available data from a number of different satellites, including the Worldview-2 and Quickbird-2 imaging platforms, both capable of capturing reconnaissance photos with a resolution around 0.5 m (Satellite Imaging Corporation 2014). This resolution makes them ideal to locate tornado tracks across Iowa, where subtle field scouring or crop damage may be the only evidence of a tornado's existence.

The NWS in Des Moines took advantage of this new program following the 12 June 2013 tornadoes. The office requested satellite data the day following the event (13 June), with the imagery captured on 17 June and made available to the office the following day. The Worldview-2 platform was the highest-resolution satellite used to map out the area (resolution of 0.46 m), with passes made by three other satellites. Panchromatic and multispectral images were available in GeoTIFF and jpeg formats. The jpeg files were used for the survey because the GeoTIFF file sizes were significantly larger yet did not add any apparent image quality improvements compared to the jpeg files.

Six of the seven known tornadoes produced discernable tracks in the high resolution satellite data. The original ground survey tracks for three of these six tornadoes were substantially modified based on the satellite findings. Most notably, satellite data revealed that the track of the first Belmond tornado actually began 4 km further northwest (and thus eight minutes sooner) than previously thought (Fig. 4). The data also indicated that a tornado track east of Belmond (originally thought by the ground survey team to be an extension of the first tornado, but discredited by social media) extended all the way back to the east side of town, validating several claims that two tornadoes had struck the town. In fact, the imagery showed these two tornado paths crossing in a field next to the town airport, a detail that the ground survey team would not have been able to determine without some form of aerial-based data (the UAV was not used in this location). Scour patterns resolved by the satellite of the third tornado indicate that it likely rotated anti-cyclonically.

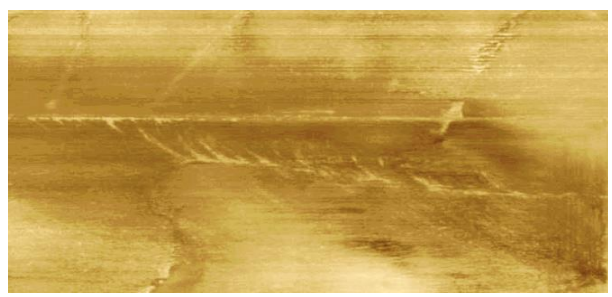

Figure 4: *Scour marks and field damage (dark area on either side of the scouring) from the first tornado show up clearly on satellite imagery northwest of Belmond. This image is enhanced to show the track more clearly. The photo above is a section of track that was extended based on this new dataset.*

It should be noted though that no new tracks were located via satellite imagery. In this case, all seven tornadoes were known to have existed and their approximate locations known before the satellite data were analyzed. This underscores the true utility of this dataset as a means to fine-tune tornado tracks. While it is certainly possible to locate previously undocumented tornado tracks via the satellite data, in the vast majority of cases the tornado's existence is known in advance.

Yet satellite data are far from perfect. As was alluded to earlier in this section, not all of the tornadoes produced a discernable satellite track. No track was found for the sixth tornado, which was well-photographed from multiple angles near Hampton and on the ground for three minutes. Other tornadoes produced partial satellite tracks, with ground survey or photographic evidence indicating that the tornadoes existed for longer than the satellite track would indicate. This limitation was also noted by Molthan et al. (2014) with respect to the MODIS and ASTER data used on 27 April 2011.

Other drawbacks to satellite imagery include a dependence on satellite availability and a lack of cloud cover. These two limitations may result in a one-to-three-week delay in acquiring the data. Debris can be cleaned up and scour marks washed away in this timeframe. Also, both natural and anthropogenic features can be mistaken for tornado tracks. A non-exhaustive list of these features include: old railroad lines, dried streambeds, ridgelines, and farm equipment trails. A careful comparison between pre- and post-event imagery is required to determine if the feature in question existed beforehand.

4.5 *Social Media*

The power of social media websites for severe weather documentation is rapidly growing thanks to the proliferation of digital cameras, smartphones, and expanding high-speed internet access across rural areas. Videos and photos are not only uploaded by storm chasers, but in many cases by local residents. This is especially true for brief tornadoes (very common in Iowa) or days when the forecasted severe weather threat is low. On 12 June 2013, the tornado threat was believed to be further east. All of the photos and videos analyzed afterwards by the NWS were taken by local residents. At least fifteen videos and dozens of photos were shared online of the tornadoes. Six of the seven tornadoes were photographed, with multiple people witnessing the seventh tornado (its existence also confirmed by the ground survey).

Several videos shot in and around Belmond clearly showed two tornadoes present at separate times on the east side of town, a change from the ground survey results that had initially presumed one continuous track. While most people in Belmond were focused on these two tornadoes, a third, brief tornado formed west of town that was photographed by one resident and shared with a local storm chasing group on Facebook. These are the only known photos of this tornado and helped locate a track in the satellite data. Numerous photos and videos were taken of the sixth tornado northwest of Hampton and are the only evidence of its existence. The multiple photo angles allowed for the triangulation of this tornado to produce an approximate track with an error of less than 800 m.

Despite the wealth of new information that can be gleaned online, locating all of these photos and videos sometimes requires extensive legwork and creative search techniques. With video sharing sites like YouTube, one may have to use various keyword combinations to locate all possible videos. If the video title does not contain the location or date in it, the video may be almost impossible to find. On social media sites such as Facebook, if the photos and videos are not shared with popular weather groups or directly with the NWS, the likelihood of them being found by the NWS drastically decreases. The same holds true for Twitter if no hashtags are used in the tweet or the tweet is not sent directly to the NWS. Having to search the many different social media sites, as well as local media web pages (many of which have viewer-submitted galleries), takes additional time.

In the case of the 12 June 2013 tornadoes, new photos and videos were being found months after the event. Originally, the photos and videos of the sixth tornado were thought to be the fourth tornado, which had touched down further to the northwest. It was only after triangulating the tornado's exact position in October 2013 did it become obvious this was a new tornado. The photos of the third tornado west of Belmond were not found by the NWS until February 2014.

The legitimacy of a tornado/severe weather photo or video shared on social media needs to be validated by comparing it to other reports and radar data. The general public can occasionally mistake other meteorological phenomena for a tornado or inaccurately list their location/time. With the 12 June 2013 event, many video captions stated that they were of the "Belmond tornado." In reality, many of these videos were of the latter tornadoes near the towns of Alexander or Hampton. It required a careful review of each video to determine which tornado the person was viewing.

5. SUMMARY

A hybrid supercell/landspout environment over north-central Iowa on the afternoon of 12 June 2013 allowed one thunderstorm to produce seven tornadoes over a short time and spatial scale. This event provided an opportunity for the NWS in Des Moines to employ several pioneering storm surveying techniques in addition to a traditional ground survey to accurately map out all known tornado tracks. How these datasets were used for each tornado is summarized in Table 2. The DAT software was used exclusively to assemble the final, highly detailed, and GIS-ready tornado tracks.

Social media photos/videos are now routinely used at the NWS in Des Moines to search for tornadoes after an event and augment ground surveys. All tornado tracks in the Des Moines NWS CWA are now mapped out in the DAT, even if a ground survey is not conducted. Satellite imagery has been captured for multiple tornado events in 2014 and continues to prove its value in locating and adjusting tornado tracks in other events. The 12 June 2013 event showed that while one surveying method alone will likely be inadequate to appropriately document a tornado, a combination of the aforementioned datasets and techniques will yield the highest-quality tornado tracks possible.

Tor #	Ground Survey	UAV	Satellite Imagery	Social Media
1	✔	✔	✔	✔
2	✔	✔ (light)	✔	✔
3			✔	✔
4	✔	✔	✔	✔
5	✔	*	✔ (light)	✔
6				✔
7	✔	*	✔ (light)	✔ (light)

Table 2: *A listing of data sources that contributed to the final tracks for each tornado for the 12 June 2013 event. Lighter-colored checkmarks under the UAV, satellite imagery, and social media columns indicate that while information was found via these methods for a tornado, this information did not result in any changes to the ground-surveyed track or timing of the tornado. (*) Note that the UAV did not accompany the survey team for the fifth and seventh tornadoes.*

6. ACKNOLEDGMENTS

The author would like to thank Adam Frederick for allowing the NWS to utilize his UAV during the 12 June 2013 storm survey.

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