Utility of UAS for National Weather Service Damage Assessments: A Report for the NOAA Unmanned Aircraft Systems (UAS) Program Office

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Cover Photograph:

Field operation photos provided courtesy of Todd Barron, NWS Huntsville.
Aerial image of damaged house produced by Autonomous Flight Technologies, Inc., a NOAA Weather Ready Nation (WRN) Ambassador, and provided courtesy of NWS Blacksburg.

Executive Summary

This document details the work the National Oceanic and Atmospheric Administration (NOAA) Unmanned Aircraft Systems (UAS) Program in the Office of Oceanic and Atmospheric Research has performed with National Weather Service (NWS) Weather Forecast Offices (WFO) to identify observational requirements for post-hazard damage assessment (PDA), or “damage surveys”, and to determine an approach through which these needs may be addressed by providing unique, affordable imagery with UAS. In addition to providing other viable benefits for NWS WFOs, this technology may be applicable to assessing damage produced from severe thunderstorms, hurricanes, winter storms, and wildfires, as well as various types of ongoing hazards, such as flooding events.

When made available to local NWS offices during the planning stages of a PDA, this data has the capacity to save time and other limited resources by providing upfront information, such as the length and width of a damaged region, locations where the most intense damage has occurred, and potential inbound routes to areas where ground-based survey teams may need to deploy for in-situ examination. It can also provide gap-filling information about damage sites located in overly hazardous or rural areas where there are no accessible roadways, making it difficult or impossible to assess damage via traditional ground-based operations.

Investigation into multiple avenues for making UAS imagery available to local NWS offices has been a key objective of this study. Based on previous work and a review of the steps other government organizations have taken, an outsourced UAS operations approach presents the most viable means of accomplishing this objective. Building upon existing partnerships, and through an identification of common needs with local Emergency Management Agency (EMA) offices, a unified approach to outsourced UAS disaster response efforts is attainable. This route can provide beneficial aerial imagery to NWS and EMA without the cumbersome responsibilities that come with UAS operations, maintenance, and training. With the release of supportive Federal Aviation Administration (FAA) regulations, many communities already possess a wealth of public and commercial operators with whom partnerships can be established for disaster response activities.

A list of lessons learned and best practices has been compiled and continues to evolve from a series of discussions and successfully executed missions performed by civil and public operators from around the country. The latency in activating UAS assets and generating useful aerial imagery are the largest obstacles that must be overcome to effectively use this resource for emergency response and PDA. Advanced planning, preparation, and development of formal protocols with local partners and stakeholders are at the forefront of these best practices and represent a recurring theme.

UAS applications for rapid response missions can assist the NWS and partnering emergency response teams to perform missions more safely, efficiently, and effectively. Together, several

diverse, dedicated groups from around the country have accomplished much in the development of UAS for such applications, yet more work remains.

To a community that is affected by a disaster, all emergencies are “local”. The successful transition of these UAS applications into operations depends heavily on the proactive development of technology, formal protocols, and plans for operational execution. In advance of the next disaster, it is only through these efforts that the NWS and its many local partners may reap the maximum benefit attainable from UAS capabilities during rapid response and damage survey operations.

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1 Introduction

The National Oceanic and Atmospheric Administration (NOAA) Unmanned Aircraft Systems (UAS) Program Office (UASPO), under the Office of Oceanic and Atmospheric Research, is dedicated to assisting all NOAA Line Offices and associated collaborators in identifying opportunities to expand and transition UAS observational capabilities into routine operations to benefit the organization's objectives and society at large. In pursuit of this goal, the UASPO prioritizes research goals with NOAA leadership and coordinates the capture of NOAA's observational requirements to provide environmental intelligence to end users and data partners in support of a Weather-Ready Nation (NOAA 2016a) to help mitigate threats to lives and the economy, especially during and after high-impact events.

The National Centers for Environmental Information (NCEI) is the "Nation's Scorekeeper" in terms of addressing severe weather and climate events in their historical perspective. According to the NCEI, as of September 2016, there were 12 weather or climate disaster events during the year that resulted in losses exceeding $1 billion each across the U.S. (Figure 1). This total includes four flooding events and eight severe storm events. Overall, these disasters led to the deaths of 68 people and posed significant economic impacts on the areas affected. From 1980–2015, the annual average, adjusted for inflation, for these types of billion-dollar catastrophes is around five events per year, and the annual average for the most recent five years in that span (2011–2015) is just under 11 events per year, indicating an overall increase in frequency. The all-time annual record from 1980 for most events in the U.S. is 16 weather- or climate-related billion-dollar disasters. However, the years 2012 and 2016 are close behind in this ranking, yielding totals of 11 and 12 billion-dollar events, respectively (NOAA 2016b).

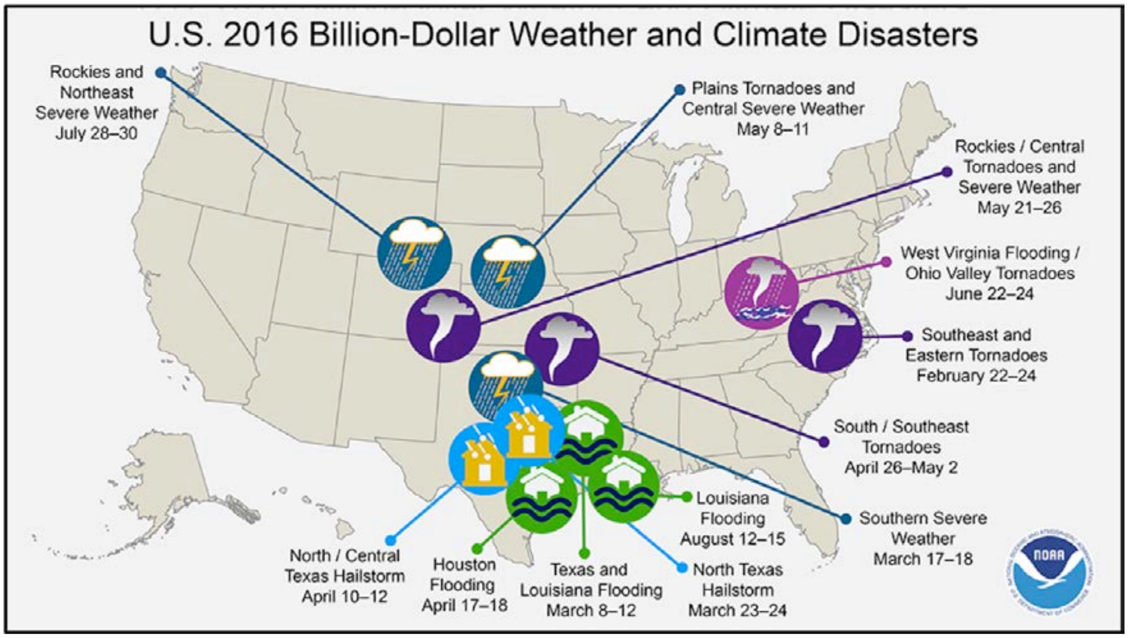

Figure 1. This map depicts 12 weather- or climate-related disasters that affected the U.S. between January and September 2016, costing the nation at least one billion dollars each (NOAA 2016b).

With this knowledge, the NOAA UASPO has engaged in conversation about observational needs with forecasters and managers from several of the 122 National Weather Service (NWS) Weather Forecast Offices (WFO) around the country (approximately 45 representatives from 20 WFOs, to date). As each of these offices has responsibilities to serve a large domain within its county warning area (CWA; Figure 2), the goal for these discussions was to determine needs at the WFO level and generate a focused list of observational requirements UAS technology may be able to address. From these discussions, the two most recurring requests were support for:
1) aerial imagery for post-hazard damage assessment (PDA; aka: “damage surveys”) and
2) increased density and frequency of thermodynamic and kinematic atmospheric observations in the lower atmosphere. Of these, the desire for airborne imagery to assist with PDA operations was noted as the most mentioned observational requirement[1]. This report provides details regarding the background, analysis, and a potential framework through which NWS WFOs across much of the country may routinely obtain access to UAS-based imagery for the purpose of performing safer, more efficient, and more thorough damage surveys while ultimately reducing the operational footprint of deployed NWS personnel and potentially saving on operational costs during post-disaster functions.

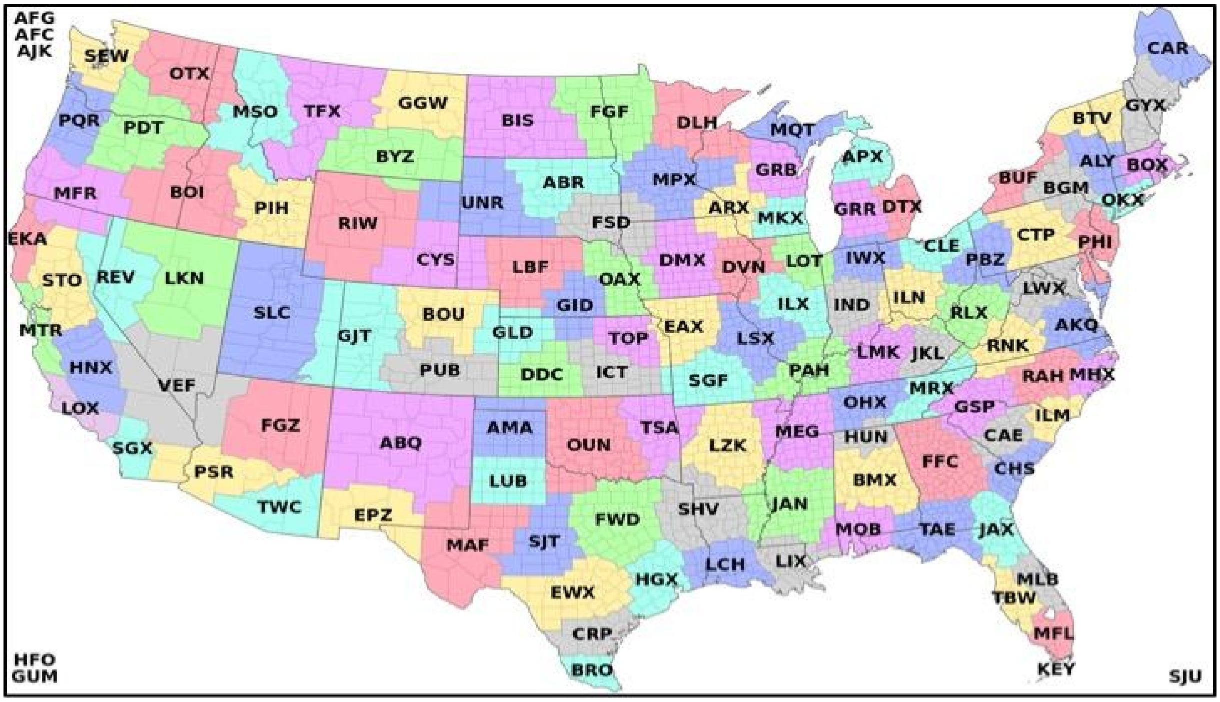

Figure 2. The NWS has 122 local WFOs, each with its own CWA of responsibility. Here, the Alaskan, Pacific, and Puerto Rican WFOs are represented by abbreviations only.

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[1] *This information was collected through personal interviews conducted in-person, via telephone, and through email correspondence with NWS personnel from 20 WFOs, to date. Citations and references for many of these of discussions are included in this study, yet a more comprehensive list may be furnished upon request.*

2 Background

NOAA has successfully tested and applied small UAS capabilities in a variety of applications. Other government agencies have also been successful in introducing this technology to existing workflows. NWS WFOs are yet another group within the larger NOAA agency with observational gaps that may be addressed with UAS, particularly, with regard to PDA missions.

2.1 Recent Applications of Small UAS

Use of small UAS for disaster or “rapid response” operations is a relatively new concept, particularly in the civilian sector (DeBusk 2009), but its utility to quickly deliver sought after information has been proven in multiple test cases. For example, during the summers of 2013–2015, Operation Arctic Shield made use of small fixed-wing UAS that were deployed from the U.S. Coast Guard Cutter *Healy* to provide real-time, high-resolution imagery for ice mapping, simulated oil spill events, and search and rescue (SAR) test operations (Jacobs et al. 2016). In May 2015, UAS capabilities were deployed for a real-world event, providing high-resolution imagery in the wake of the Refugio Oil Spill incident along the coastline of Santa Barbara, CA (Jacobs 2016). More recently, UAS were used in a wildfire response effort in the Grand Bay National Estuarine Research Reserve (GBNERR) in February 2016. The latter effort was made possible through a pre-existing relationship between the GBNERR and NOAA’s Northern Gulf Institute (NGI), which provided operational support to facilitate the capture and delivery of actionable data while the fire event was still occurring (Pitchford et al. 2016; NOAA Unmanned Aircraft Systems, *n.d.*).

As of spring 2017, the NWS WFO in Fairbanks, AK, has tested small UAS in two consecutive years in the River Watch Program for non-rapid response applications (Kontar et al. 2015; Plumb and Saiet 2017; NOAA OR&R, n.d.). Here, UAS are used to routinely obtain information about the location and timing of the annual warm season ice break up on the Yukon River to improve forecasts of potential flood events, locally and downstream. This concept was developed during NOAA’s Optimal Unmanned Aircraft Systems River Observing Strategy Workshop (Moorhead et al. 2012) and NOAA UAS Program 2nd UAS Arctic and River Forecast Workshop (Zarzar et al. 2014), which were necessary precursors to the successful execution of these missions.

More recently, following the series of recent hurricane disasters that severely impacted the southeastern United States during the late summer and early autumn of 2017, the Federal Aviation Administration (FAA) granted over 100 authorizations to use UAS to aid in disaster response, including damage assessment and recovery efforts. FAA Administrator Michael Huerta praised these initiatives, referring to this activity as a “landmark in the evolution of drone usage in this country” (Unmanned Aerial Online, 2017).

Furthermore, the Department of the Interior (DOI) has developed a detailed roadmap outlining how UAS will be integrated to accomplish a variety of routine missions for the agency (Cress et al. 2015). This plan involves a hybrid approach, in which the DOI is investing funds to purchase several UAS platforms to operate internally, as well as pay for outsourced operational services provided by trained, commercial UAS operators located around the country (Department of the Interior 2015). The former approach refers to a Government Owned Government Operated (GOGO) operational model, while the latter describes a Contractor Owned Contractor Operated (COCO) model. Both aspects of the DOI hybrid approach to implementation will be a focus of study for this report, with greater emphasis on the latter component.

2.2 Scope of Analysis

Following a weather-related disaster, such as a tornado, local NWS WFOs identify potential areas requiring PDA surveys using a combination of archived data (e.g., radar-derived products) and local storm reports that filter in from the public through local Emergency Management Agency (EMA) offices and emergency first responders (T. Barron, C. Darden, E. Hicks, and B. Davis, Personal interview, April 22, 2016). With little more information than this to proceed, the PDA operation may begin as soon as the associated hazard has departed the area of responsibility and the danger has subsided (Cherokee Nation Technologies 2016). The survey objectives include identification of the location and spatial dimensions of the damaged area, encompassing the beginning/end points of the damage, the length, the width, and the perimeter; locations of the most intense damage; specific cause of the damage (e.g., tornado, straight-line winds, etc.); and the rating of the damage, if it is deemed to have been produced by a tornado (C. Darden and D. Nadler, Personal interview, November 13, 2014).

Meeting these objectives using traditional, ground-based survey methods can often be difficult for a variety of reasons. Roadways for accessing affected areas may be blocked or otherwise impassable, and even cleared thoroughfares may not provide adequate reach to allow the survey team to determine the full spatial scope of a damaged area. In these cases, a significant amount of time and fuel may be expended, as NWS survey teams must drive around long stretches of “potential” damage in rural regions in search of the beginning/end points and the perimeter of the affected area, which may ultimately be discovered to reside over the horizon and away from even the best of available roadways (Cherokee Nation Technologies 2015; C. Darden and J. Russell, Personal interview, August 10, 2015).

Often times, these teams are also required to walk extensive lengths of damage paths through dense, tangled vegetation and hazardous shards of debris, which may pose a safety issue. Yet, despite the benefits of an in-situ examination, it can be difficult to accurately capture and document some areas of damage from a ground-based perspective (Morales and Sporer 2016; Association for Unmanned Vehicle Systems International 2016). During such events, staffing is a large challenge, as the attending NWS WFO often requires additional personnel and resources, including “overtime pay” compensation, to accomplish these PDA missions, which compounds existing daily tasks and obligations essential for the operation of a typical WFO (Cherokee Nation Technologies 2015; R. Morales and M. Sporer, Telephone interview, June 2, 2015; J.

Medlin and D. Butts, Personal interview, March 5, 2016; J. Weaver, J. Jurecka, and M. Samuelson, Telephone interview, April 6, 2017; Weaver 2017).

Early access to information about a damaged area from an aerial viewpoint, especially during the planning stages of a PDA mission, can assist WFOs in allocating NWS resources and personnel. Aerial imagery overlaid onto a map and annotated can help identify the perimeter of an affected region and locate blocked roadways, precluding the need to drive around difficult, or impossible, to access areas where damage may not have occurred. Localized regions and significant structures where the worst damage exists may also become evident, which can help the survey team prioritize the mission by focusing efforts and distributing resources to areas of greatest need (Swirka 2017; M. Conder, B. Haynie, and G. Swirka, Email interview, June 12, 2017; Cherokee Nation Technologies 2015, 2016).

Additionally, the ability to observe an affected location from the aerial viewpoint provides a broader perspective and more contextual information to identify continuous damage paths (Figure 3; NWS Blacksburg and Mid-Atlantic Aviation Partnership 2015). Identification of convergent or “cross-over” tree-fall patterns, indicative of tornadic circulations, as opposed to divergent “fanned out” tree-fall patterns, characteristic of straight-line winds (Figure 4), are crucial in the determination of a tornado track, and aerial imagery greatly facilitates this task (C. Darden and D. Nadler, Personal interview, November 13, 2014; R. Morales and M. Sporer, Telephone interview, June 2, 2015; C. Entremont, E. Carpenter, D. Cox, and M. Ryan, March 23, 2016). Furthermore, archiving these imagery datasets allows for their incorporation into future PDA training sessions for new employees (M. Sporer, Email interview, August 30, 2017).

The primary objectives of this study are to explore the utility of UAS for providing quick access to actionable information to enhance damage surveys for thoroughness and to identify optimal implementation approaches to improve the efficiency of PDAs (Cherokee Nation Technologies 2015, 2016). Potential benefits exist but are limited with the use of UAS for *supplementary* PDA applications; rather, the most efficient methods and protocols for employing this capability must be identified and implemented to maximize advantages. Various implementation options for UAS use by NWS were explored in a parallel Aviation Business Case report, which indicated the potential for a significant reduction in operational footprint by NWS personnel for PDA missions when aerial imagery was provided in advance (NOAA 2017). Through all of this, the employment of rapid response UAS operations to support NWS PDA efforts can save a substantial amount of time and resources, with added potential benefits for the safety of survey crew members.

Figure 3. An aerial viewpoint (bottom) can provide a broader perspective and more contextual information to determine the scope and cause for certain types of storm damage, such as this weak tornado damage path, than may be visible from the ground (top). Images provided courtesy of NWS Blacksburg.

Figure 4. Straight-line wind damage is often characterized by a fanned out tree-fall pattern (top), whereas, a convergent or “cross-over” tree-fall pattern is often indicative of a tornadic circulation (bottom). Images provided, courtesy of NWS WFOs in Duluth, MN, and Huntsville, AL, respectively.

3 Explored Concepts for Operations

The identification of observational requirements is the first step to determining the potential benefits of UAS for a given objective, while the next steps are to select a proper platform/sensor payload combination and develop a feasible concept of operations (CONOPS) through which this capability can be tested. A multitude of small UAS platforms and payload options exist with capabilities to capture quality aerial imagery for disaster response applications (DeBusk 2009; Everaerts 2008); however, the challenge for PDA applications lies in developing a proper CONOPS and protocol for implementation. Therefore, after the NWS PDA objective requirements were identified (see Section 2.2), most of the work performed by the UASPO has been determining the best UAS implementation approach to obtain aerial data to meet those objectives.

Three primary NWS options for UAS implementation were explored for this study. While logistical feasibility was one aspect used to vet each approach, estimated costs were also heavily interrogated. For more information, an in-depth cost-comparison analysis of these same options is provided in the complementary Aviation Business Case report (NOAA 2017). For purposes of the present study, however, only a high level overview of the logistics and relative costs of these options is provided.

3.1 Option A: NWS WFO GOGO UAS Assets

Providing every NWS WFO with its own UAS, a GOGO approached dubbed "Option A" for this study, initially appeared to be the simplest solution. With this implementation, the platform would be within close reach whenever random weather-related disasters struck, meaning that PDA survey teams could pack up and deploy the unit as needed. Upon further investigation, it was found that this seemingly straightforward solution is not the optimal approach to UAS implementation for NWS WFOs (Morales and Sporer 2016), presenting more problems than solutions. This conclusion is based on the top two constraints affecting most WFOs, which rapid response UAS capabilities are intended to address in the first place: operational budgets and time limitations (NOAA 2017).

Increased access and declining purchase prices for several viable UAS platforms (Federal Aviation Administration [FAA] 2016a) have made it tempting to invest in ownership of these assets, but there are a host of less obvious underlying costs that would soon follow for local NWS offices. Operational and maintenance requirements (FAA 2016b) required to keep the UAS in an optimal working condition are among the least of these, although they are very important. Routine maintenance is crucial, since these platforms must always be in a ready-to-go status for PDA operations.

A greater drawback, with respect to UAS operational time and budget concerns, is the amount of time required by designated office staff to learn how to operate a platform then safely maintain proficiency through regular, weekly practice (Department of the Interior 2015; Lusk and Monday

2017; North Carolina Department of Transportation 2017; Avion Solutions Inc. 2017). With additional costs above $20,000 per year for a typical WFO to maintain two trained UAS operators, excluding initial qualification costs, this was the primary cost driver for UAS implementation Option A for NWS applications (NOAA 2017).

Directly related to this cost factor are the personnel time obligations. Having successfully implemented a UAS program within its agency, the Department of Interior has developed requirements stipulating 10–20% of employees' time (4–8 hours per week, nominally) for its UAS operators must be allotted toward maintaining currency and proficiency (Department of the Interior 2015). With streamlined NWS operations, PDA deployments present major staffing challenges, there is little time to spare for additional tasks (Cherokee Nation Technologies 2015). However, assuming a steady state for some offices, it may be feasible at the onset of implementation to select a few individuals from each WFO to fill these UAS operator roles. Yet, with rotating shifts, annual leave, and the persistent inter-office relocation of staff throughout the country (NWS-National Weather Service Employees Organization 2001; NWS 2016), this approach poses an ever-growing logistical challenge, making it difficult to determine at any future point how many UAS-trained WFO staff may be available on short notice for UAS survey operations. Furthermore, through this UAS implementation option these recurring costs would persist, regardless of the necessity for PDA operations (NOAA 2017).

3.2 Option B: NWS Regionally Shared GOGO UAS Assets

Despite decreased purchase prices available for several potential UAS platforms, the total net cost could be substantial when taking into consideration the 122 NWS WFOs in operation, and it may be unreasonable to assume that just one UAS unit per office would be sufficient for most PDA missions. Because of this, the "Option B" approach was developed to explore a "shared and shipped" GOGO approach for the reduction of initial costs (P. Wolf, Email interview, June 10, 2015). The need for simultaneous UAS-assisted PDA efforts for all WFOs within a NWS Region is unlikely; therefore, this approach requires the purchase of fewer units than the one-per-WFO UAS Option A in Section 3.1. In this implementation, various hub locations across each of the larger NWS Regions (Figure 5) would house a finite number of UAS platforms. Offices expecting hazardous weather in their CWA would have UAS assets shipped to them in advance for use in subsequent damage surveys.

While this tactic seems reasonable, resulting in a reduction in costs for platform purchases and fewer units to maintain, UAS Option B also presents similar shortcomings to those noted for Option A. Primarily, this option does not remedy the time and logistical constraints that would be required of NWS WFOs to maintain a subset of trained, practiced UAS operators (NOAA 2017; Department of the Interior 2015). It was also found that recurring shipping costs offset the initial savings afforded by "Option B". Given enough time, this UAS implementation would actually cost more to maintain.

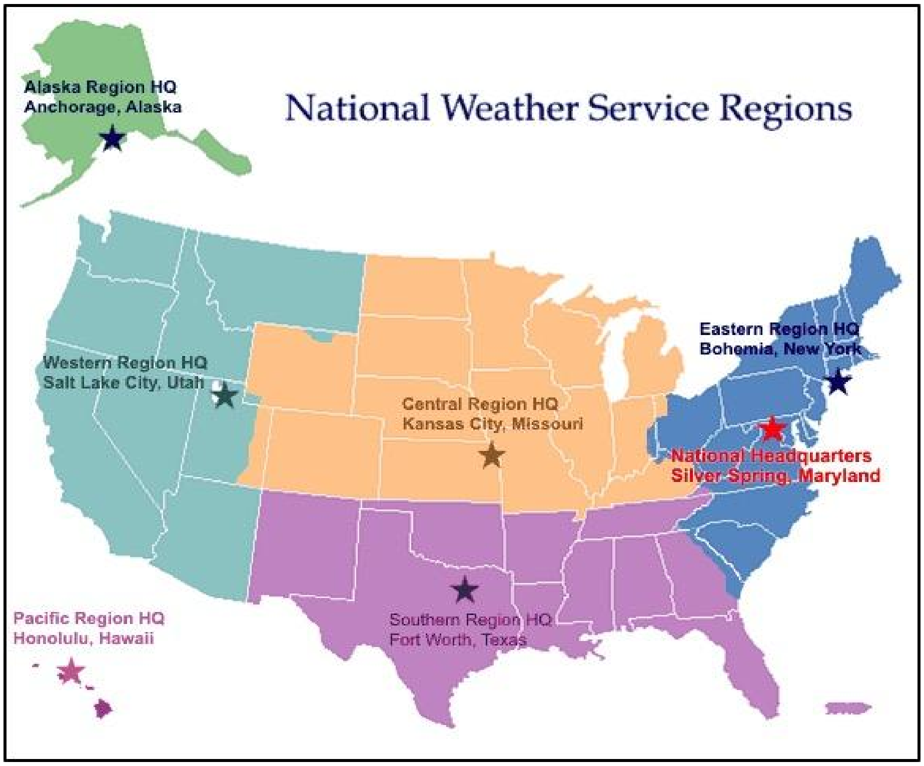

Figure 5. The NWS is divided into six regional domains across the U.S.; four are spread out to cover the continental states, while the Alaska and Pacific Regions make up the other two.

3.3 Option C: Outsourced UAS Operations

Both GOGO options presented in Sections 3.1 and 3.2 rely solely on NWS employees for UAS maintenance and operations. By contrast, UAS "Option C" closely resembles the second component of the DOI approach to operational UAS integration (see Section 2.1; Cress et al. 2015). This concept hinges on the ability to outsource operations to experienced professionals residing locally, either in the commercial sectors (i.e., COCO approach), or with operational support from other public entities. The results provided by the corresponding Aviation Business Case revealed this implementation to be the most cost-efficient UAS option for obtaining aerial imagery for NWS PDA operations (NOAA 2017). Out of all options considered, Option C yielded the greatest reduction to the operational footprint of PDA-deployed NWS personnel (71% reduction for the representative case in that analysis), and it provided the greatest amount of cost flexibility. Unlike the recurring costs and personnel time requirements associated with each of the GOGO options, if there are no disasters or PDA missions requiring the need for aerial imagery, then there are no costs associated with this approach to implementation.

One of the primary logistical differences for Option C is that it is more strategic than the others, requiring a higher level of customization through the development of community partnerships and up front planning at the local scale (Cherokee Nation Technologies 2015, 2016). However, this is not a drawback, as the upfront investment in planning can provide tremendous benefit in the end, including mutually beneficial coordination with local Emergency Management Agency offices and other first responders (Sullivan 2016; Morales 2016; Cherokee Nation Technologies 2016). Since the objective is to quickly obtain aerial imagery to direct and complement ground-based PDA surveys (J. Weaver, J. Jurecka, and M. Samuelson, Telephone interview, April 6, 2017), the method for acquiring this data is not of significant consequence, as long as the imagery may be reliably secured from a dependable source at a minimal cost to time and financial resources. Growing access to this burgeoning capability in the civil sector, and the advent of new, flexible regulations have paved the way for a multitude of new operators to spring forth all over the country (FAA 2016a). Many of these operations are small enough that, when a COCO operation is needed, the cost to purchase aerial imagery from an operational UAS group through a "data buy" is small enough (Association for Unmanned Vehicle Systems International 2016; T. Fernandez, Telephone interview, October 30, 2015) to fit within a government credit card simplified acquisition request (see Appendix A).

3.3.1 Public Operators

On the public service side, many fire departments and law enforcement offices have already invested in this technology and remain practiced through routine duties and operations (C. Kessler, Telephone interview, March 15, 2016). This was made possible, in part, by the FAA making available the use of blanket area public safety Certificates of Waiver or Authorization, which allows for easier access to airspace for qualified individuals that plan to use UAS in the line of duty to serve the public (International Association of Fire Chiefs, n.d.). During and following a natural disaster, these groups of first responders are typically on site where damage has resulted, in advance of many NWS survey operations (Cherokee Nation Technologies 2015, 2016; K. Roberts, Personal interview, April 22, 2016). Forging partnerships with some of these entities may provide an avenue for all groups to share the benefits of disaster response UAS imagery.

Additionally, several groups of public operators in the university system now have permission to fly UAS in the National Airspace System (NAS) for education and research (Govan 2016). In certain communities, a strong partnership between NWS WFOs and local universities already exists, simplifying the formation of a mutually beneficial alliance for operating UAS and obtaining aerial imagery of damage in the wake of a disaster (NWS Blacksburg and Mid-Atlantic Aviation Partnership 2015; J. O'Neil-Dunne, Phone interview, April 21, 2017; P. Sisson, A. Nash, and S. Whittier, Videoconference interview, May 24, 2017).

3.3.2 Commercial Operators

In another part of the civilian sector, a more prevalent resource for this initiative resides in the commercial service realm's expanding group of UAS operators. Beginning in early 2015, *Section 333* exemptions under the *FAA Modernization and Reform Act of 2012* (United States Congress 2012) allowed thousands of businesses around the U.S. to legally operate UAS within the NAS as part of regular professional operations (Figure 6). This massive collection of operators represents a growing industry in the U.S., each one vetted by the FAA (FAA 2016a). The professional livelihoods of these organizations rely on their ability to train, maintain proficiency, and keep up with the latest developments in the seemingly endless march of advancing UAS and geographic information system (GIS) technology. It is often the case that these organizations have retained the services of professional GIS experts and invested in advanced computational and software resources capable of swiftly converting "raw" aerial images into more useful maps and models that can better inform PDA operations (P. Owen and J. Sullivan, Personal interview, August 6, 2015; J. May, P. Stoutamire, and M. Sporer, Telephone interview, March 11, 2016).

Effective 29 August 2016, a new set of FAA UAS regulations, *Part 107*, is helping ensure the safe integration of more UAS into the NAS while aiding growth of the use of this technology in the commercial industry (FAA 2016c). As a result, these new rules are expected to foster a significant increase in the creation of commercial UAS engineering and operational jobs, making the use of this capability more commonplace among the majority of communities around the nation (FAA 2016a).

Figure 6. Map displaying the locations of FAA Section 333 exemption holders within the continental U.S. prior to 29 August 2016 (sUAS News–The Business of Drones, n.d.) when the new FAA Part 107 rules for commercial use of small UAS went into effect; however, the number of commercial operators continues to grow (FAA, n.d.).

Based on the common needs and requirements captured from several NWS WFOs through this investigation, as well as the info provided by in the Aviation Business Case (NOAA 2017), the outsourced COCO UAS operations, "Option C", boasts the greatest promise of efficiently addressing NWS PDA objectives while offering a minimum potential for negative impact. Regarded as a "data buy", the imagery and associated products provided to the end user become the property of those individuals and/or organizations after completion of the operations and processing.

Using a data buy approach to obtain aerial imagery for PDA missions, there are no FAA regulations or air space coordination issues for NWS to contend with, and none of the associated burdens exist with maintaining a local UAS operations program. The responsibility of operational issues and maintenance lies exclusively with the designated UAS operations team (T. Fernandez, Telephone interview, October 30, 2015). Most importantly, there are no additional time requirements needed for training or the preservation of remote piloting skills, nor is there a need to purchase and learn how to run expensive GIS software to process some of the more beneficial, higher level imagery products (J. May and P. Stoutamire, Videoconference interview, May 06, 2016). This lets NWS personnel focus on existing priorities and survey planning, allowing the UAS capability to act as a force multiplier *ahead* of the survey mission, rather than causing a division of limited labor assets *during* the mission.

3.3.3 Community Partnerships and EMA Coordinated Operations

As indicated in Section 3.3, the primary efforts needed to implement the Option C data buy approach would occur up front, in the form of discussions, planning, and agreements between the NWS WFOs and local community partners, well ahead of actual natural disaster scenarios. Moreover, other potential stakeholders exist in nearly every community with common observational needs in the wake of a disaster that may also benefit from this option (Cherokee Nation Technologies 2015). Most notably, local EMA offices and first responders have similar needs for information, yet their immediate concerns are greater and more time-sensitive in disaster response situations than those of NWS (Table 1; Cherokee Nation Technologies 2016).

Additionally, not all disasters are characteristically “natural” or weather-related, so the frequency and breadth of disaster response obligations are more extensive for EMA personnel. Therefore, coordination of UAS operations through the local EMA is a prudent approach, especially since all emergencies are "local" to a community affected by a disaster (Cherokee Nation Technologies 2015, 2016). The ability to quickly obtain information about the scope of an event, including the hardest hit areas, is an important first step for local first responders to hasten communication of relevant details and needs up to the state and federal levels, when necessary. When operated by an experienced team of professionals possessing the latest technology and an advanced set of payloads, UAS can assist in this role. Use of this capability at the beginning of disaster response efforts provides crucial information to personnel on the ground, helps to direct emergency response resources to areas of greatest need, and assists in potential SAR operations, since every minute is critical. Some groups within the EMA and first responder community have already invested in UAS assets (Robinson 2012; C. Kessler, Telephone interview, March 15, 2016), yet many have not; therefore, the same types of imagery needed by the NWS to assist with PDA operations may also be beneficial to this group, especially for the recovery phases of the response efforts (see Table 1; NWS Jackson 2016). The positive, working relationships shared among many NWS WFOs and local emergency managers make an alliance for UAS coordination efforts easier to achieve.

Table 1. A comparison of NWS and emergency management goals, following a weather-related disaster. The overall goals differ, but many of the needs for information are complementary (highlighted rows) and may be directly addressed with UAS applications.

National Weather Service Overall Goals	**Emergency Management / First Responder Overall Goals**
• Conduct and document a thorough, efficient survey of all damaged areas • Correctly identify the natural cause of disaster	• Quickly assess area and scope of disaster • Perform search and rescue operations (if needed) • Efficiently direct resources • Rapidly determine whether or not a disaster declaration is required
National Weather Service Information Needs for Operational Objectives	**Emergency Management / First Responder Information Needs for Operational Objectives**
Beginning/End point locations of damage area	Extent of damage
Width of damage area	
Identification of worst hit areas	Identification of worst hit areas
Where to deploy personnel for ground-based survey operations	Where and what types of resources are most needed
Roadway access for sending ground-based survey teams to areas of interest	Knowledge of ingress / egress routes for transporting personnel and other resources to areas of greatest need
Cause of damage (e.g., Tornado, Winds, etc.)	
Rating of damage*	
	Information for cleanup and recovery

*If cause of damage was determined to be a tornado

4 Cases of Outsourced UAS CONOPS: Opportunities, Partners, and Timeline of Relevant Events

To investigate the feasibility of the proposed outsourced CONOPS, testing occurred in actual field operations. These activities were refined through several in-depth conversations with engaged stakeholders and executed following multiple real-world disaster events. The degree of initial planning and communication among NWS, EMA/first responders, and UAS operators weighed heavily on the potential to successfully implement this approach (Cherokee Nation Technologies 2015, 2016). These operations resulted in many key takeaways and lessons learned, highlighted in summary tables at the beginning of each sub-section and discussed at greater length in Section 6.

4.1 North Alabama – NWS Huntsville (July 2015)

NWS WFO	NWS Huntsville (Alabama) -Chris Darden and Brian Carcione	Contact: Chris.Darden@noaa.gov
Coordinating Agency	EMA–Madison County, AL -John Russell (retired) and Scott Worsham	Contact: Scott.Worsham@huntsvilleal.gov
UAS Operations Group	enrGies -Phil Owen, Mark Warner, Ken Harvey	Contact: PhilOwen@enrgies.com
Data Products Delivered	*N/A*	
Key Takeaways	• Mission unsuccessful due to controlled airspace access restrictions • Advanced familiarization, planning, and protocol development crucial to success of future disaster response operations	

The first opportunity to test the "outsourced operations" approach came during the summer of 2015 in north Alabama; however, since this was a relatively new concept for NWS, time had not yet allowed for the necessary socialization of this application or planning with local entities outside of the NWS Huntsville office. On 14 July 2015, a line of severe thunderstorms developed in southern Tennessee and propagated southward into north Alabama late in the afternoon. A weak tornado associated with these storms spawned in southwest Madison County, along the leading edge of the line of storms, and produced EF-0 damage to a residential neighborhood near the Huntsville International Airport.

The following day, personnel supporting the NOAA UASPO and management from NWS Huntsville determined that the event posed a good opportunity to test the COCO UAS operational concept. Soon, a fast-acting chain of communication had looped in the Madison

County EMA office, a local commercial UAS engineering and operations company called "enrGies", and management at the Air Traffic Control Tower at the Huntsville International Airport. However, the affected damage area resided within five nautical miles of the airport, within Class C air space (Figure 7), which ultimately forced the operation to abort despite strong support from each of these collaborating organizations (D. Schrader, Telephone interview, July 17, 2015). At that time, most UAS operations were not allowed in such areas under the FAA regulations that were in effect; although, it is important to note that newer regulations under FAA *Part 107* now provide a pathway toward accessing these regions for UAS operations.

Despite the lack of an actual UAS mission, this event was significant. The activity proved that socialization and a collaborative implementation of this concept at the local community level provides a viable path forward, and local UAS operators are well suited to respond to nearby events (Cherokee Nation Technologies 2015). Furthermore, it became a catalyst for discussion and laid the foundation for future successful efforts in north Alabama and at other NWS offices around the country. The NOAA UASPO continues to work with the NWS Huntsville office, Madison County EMA office, enrGies, GEOHuntsville, and other regional stakeholders in north Alabama to develop a mutually beneficial protocol for transitioning UAS into emergency rapid response applications.

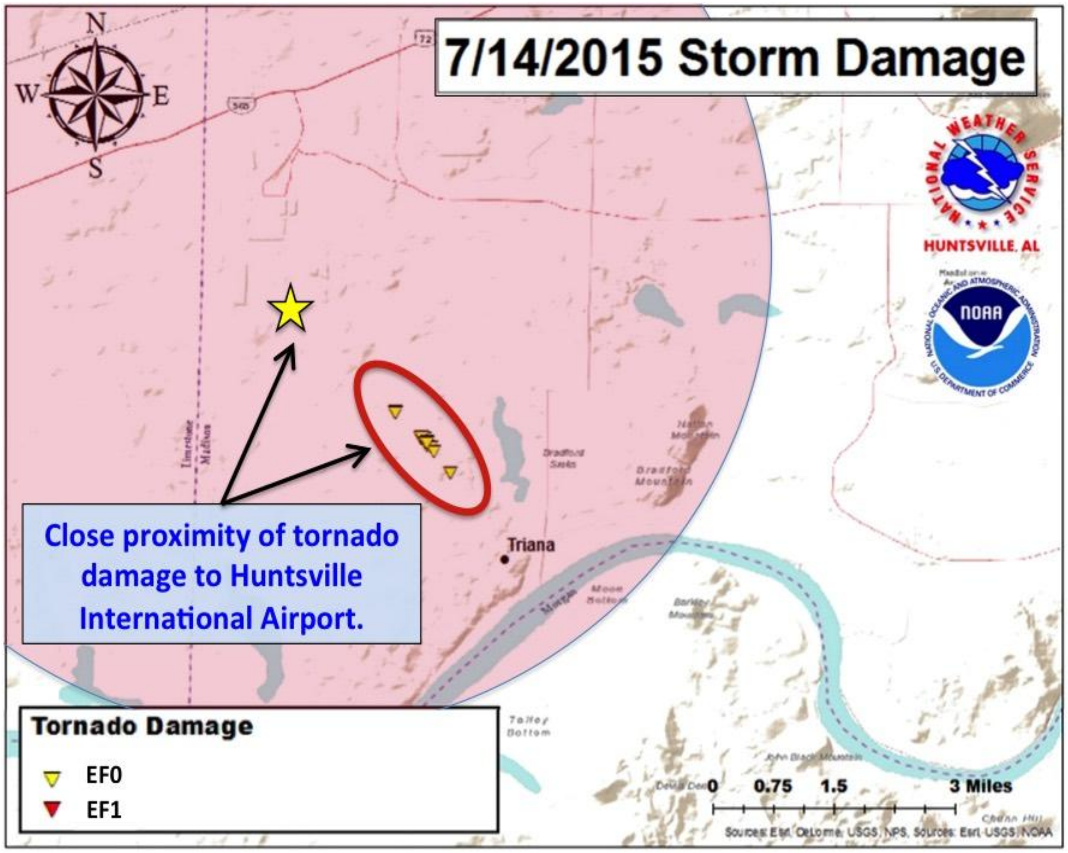

Figure 7. Map showing the short distance between Huntsville International Airport and the tornado damage produced from severe storms on 14 July 2015. The area highlighted in pink represents the surface-based Class C air space surrounding the airport, extending outward at a radius of 9 km (5 n.m.) from the airport's center point.

4.2 South Carolina – NWS Charleston / Eastern Region Drone Team (Dec. 2015)

NWS WFO	NWS Charleston (South Carolina) -Ron Morales	Contact: Ron.Morales@noaa.gov
Coordinating Agency	EMA–Berkeley County, SC -Dan Barb and Lori Kidwell	Contact: Lori.Kidwell@berkeleycountysc.gov
UAS Operations Group	SkyView Aerial Solutions, LLC -Tom Fernandez, Tom Lucey, Andy McKitrick, and Derek Brayton Platform: DJI Phantom 2	Contact: Tom.Fernandez@skyviewaerialsolutions.com
Data Products Delivered	• Real-time Full Motion Video • Still pictures • 2D Orthomosaic Map	
Key Takeaways	• Provided information needed to categorize damage as tornadic (EF-0), which would have otherwise been classified as “straight-line wind” damage • Imagery provided perspective and spatial context not possible to obtain from the ground	

The NWS WFOs in Charleston, SC, and Blacksburg, VA, each of which comprise the recently formed NWS Eastern Region Drone Team, represent two more key partners that have worked closely with the NOAA UASPO to develop an approach for transitioning UAS applications into NWS PDA activities, as captured in the March 2016 edition of NOAA’s *Aware* (Morales 2016). In autumn of 2015, officials at NWS Charleston began reaching out to local EMA offices about this concept and worked to identify a local UAS operations group, with a goal to test the outsourced COCO UAS approach during potential severe weather events in the spring of 2016. However, when severe thunderstorms passed through the Charleston CWA on 23 December 2015 and produced minor damage to a garden nursery in Berkeley County, SC, the plans to pursue use of UAS for PDA efforts were advanced. Immediately, the Berkeley County EMA office coordinated and paid for an operation with a local company, SkyView Aerial Solutions, LLC, and the flight commenced early the following morning (T. Fernandez, Telephone interview, January 05, 2016).

Since the affected damage area was relatively confined, the NWS surveyors decided to complete an independent ground-based survey, just prior to commencement of the UAS operation. Based on the ground-based survey, the team prepared to declare severe straight-line winds as the cause of the damage. However, once the EMA and NWS received the UAS aerial data, it became evident that a weak, EF-0 tornado (Figure 8) caused the damage (Morales 2015). The ground-based survey had failed to provide a wide enough perspective to detect a convergent pattern in the short vegetation and limited debris field; however, the aerial perspective captured this information quite well (Association for Unmanned Vehicle Systems International 2016). The official Public Information Statement, found in Appendix B, reflects these findings.

This PDA effort represents a significant accomplishment and marks the first known coordinated mission to have successfully followed the proposed COCO UAS operations approach to aid a local EMA and NWS damage survey. The difference in conclusions obtained from the independent ground- and aerial-based datasets helps to prove the validity of this capability for such applications. The NWS Charleston WFO, its local EMA county partners, and SkyView Aerial Solutions continue to work closely to identify future opportunities applicable to these CONOPS.

Figure 8. Short path of the documented EF-0 tornado through a Berkeley County, SC, garden nursery on 23 December 2015, depicted by the aqua line overlaid onto the base map of the NWS Damage Assessment Toolkit (DAT; left), and associated samples of aerial still photos (right, top and bottom), obtained from the UAS operation. This mission was flown by SkyView Aerial Solutions, LLC and was coordinated by the Berkeley County EMA.

4.3 Virginia – NWS Blacksburg / Eastern Region Drone Team (Feb. 2016)

NWS WFO	NWS Blacksburg (Virginia) -Mike Sporer	Contact: Michael.Sporer@noaa.gov
Coordinating Agency	VDEM Region 3; EMA–Appomattox County, VA -Gene Stewart; Bobby Wingfield	Contact: Gene.Stewart@vdem.virginia.gov
UAS Operations Group	Autonomous Flight Technologies, LLC -Josh May, Paul Stoutamire, and Chris Moody Platform: DJI Inspire 1	Contact: Info@autonomousflight.us
Data Products Delivered	• Still pictures • 2D Orthomosaic Map • 3D Textured Digital Surface Model	
Key Takeaways	• Imagery was used to document 4 miles of additional tornado track in PDA survey • Cleanup efforts begin quickly after a disaster • Aerial imagery can provide perspective and spatial context not possible to obtain from the ground (e.g., construction of damaged roof; see Section 5.4)	

Following a much larger severe weather episode just two months later, the NWS WFO in Blacksburg, VA, also had an opportunity to test outsourced COCO UAS applications for PDA. As the severe weather event developed and produced an outbreak of tornadoes across the southeastern U.S. on 23–24 February 2016, a large tornado developed and produced EF-3 damage across Appomattox County, VA. It was the largest and most destructive tornado to have ever hit this part of the state, causing numerous injuries and at least one fatality (Figure 9).

Prior to the event, officials at the NWS Blacksburg office had reached out to local EMA colleagues to discuss the developing UAS rapid response CONOPS and identified a potential UAS operations partner in the area, known as Autonomous Flight Technologies, Inc. (AFT). Through these preliminary discussions, AFT submitted the proper paperwork and underwent vetting by NOAA to become an official Weather Ready Nation Ambassador.

On the morning after the storms had passed, the NWS Blacksburg PDA survey team met on site near the areas of reported damage to coordinate the survey effort with Appomattox County EMA officials and UAS operators from AFT. Other than an agreed upon assembly location, there had been no formal planning or discussion about the capability requirements or expected weather conditions for the mission, and by the time the PDA efforts were ready to begin, post-frontal winds had begun gusting upwards of 17.5 m/s (35 knots). As these conditions posed a safety risk for small UAS platform operations, the AFT operators decided that it would be in the best interest of all involved parties to suspend the flights until the wind speeds subsided, thereby relegating the survey to traditional ground-based efforts for the rest of the day.

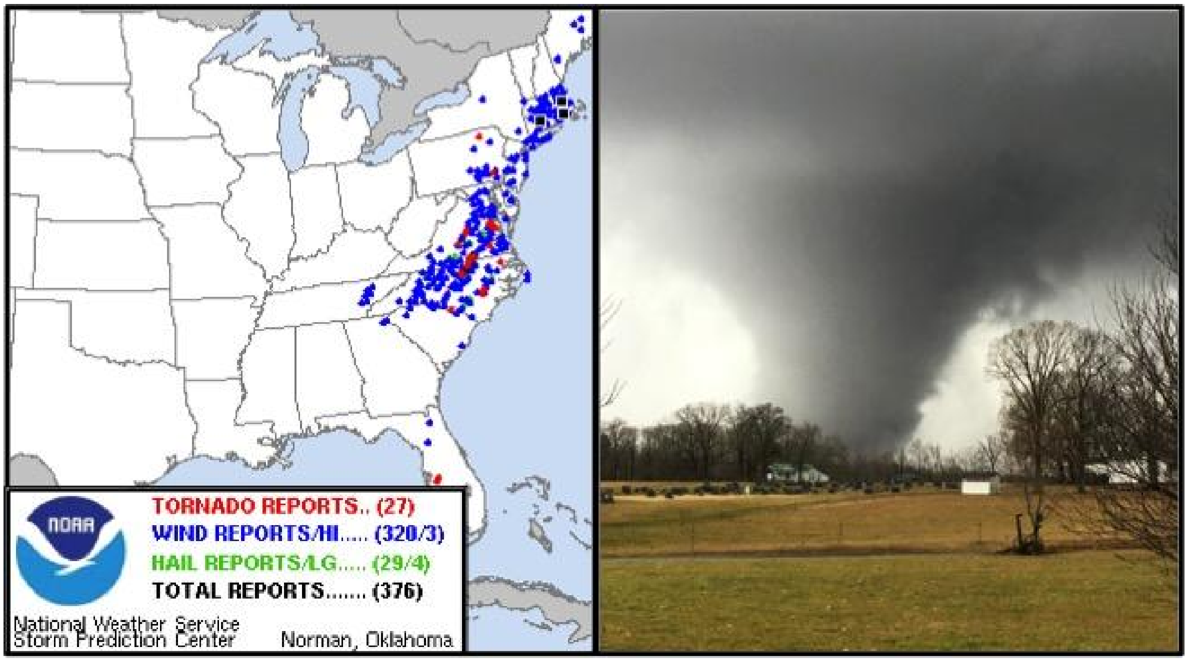

Figure 9. Severe storm reports from the Storm Prediction Center in Norman, OK, valid from 1200 UTC Feb 24 – 1159 UTC Feb 25 of 2016 (left). Also shown is a photo of the tornado that produced EF-3 damage in the vicinity of Evergreen, VA in Appomattox County, taken by Jason Smith and provided courtesy of NWS Blacksburg (right).

The next day, with the ground-based NWS survey complete and more favorable weather conditions present, the same group reconvened near the site of the Appomattox County tornado damage, and AFT commenced UAS operations to supplement the previous day's PDA effort as a feasibility mission. In relatively little time, multiple flights were conducted across the areas of interest, raw imagery was uploaded to a cloud-based server for processing, and the resulting products were promptly downloaded and delivered to the relevant EMA and NWS officials (J. May, P. Stoutamire, and M. Sporer, Telephone interview, March 11, 2016).

The results were impressive. Originally documented at a track length of approximately 21 km (13 mi.), based on the ground-based survey, the newly acquired aerial imagery helped NWS surveyors extend the beginning and end points of the tornado path an additional 6.4 km (4 mi.) beyond that initial measurement (Figure 10). The updated Public Information Statement in Appendix B reflects these changes. This case generated multiple types of high-resolution imagery products with 1 cm ground sampling distance (GSD), discussed later in Section 5.

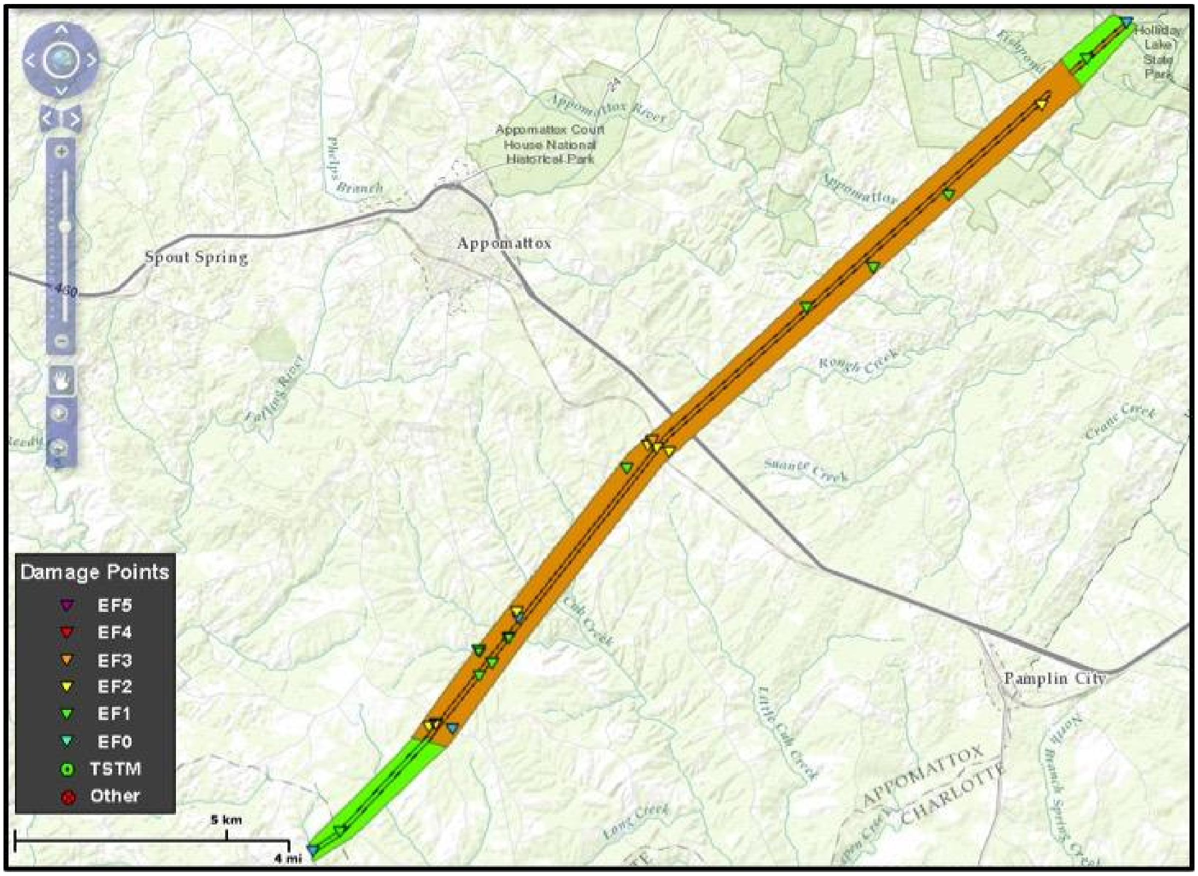

Figure 10. Appomattox County, VA, tornado track from 24 February 2016, as depicted in the NWS DAT. The additional information provided from UAS aerial imagery revealed an extra 6.4 km (4 mi.), highlighted in green, of unreported tornado track.

4.4 North Alabama – NWS Huntsville (Apr. 2016)

NWS WFO	NWS Huntsville (Alabama) -Chris Darden and Todd Barron	Contact: Chris.Darden@noaa.gov
Coordinating Agency	EMA–Morgan County, AL -Eddie Hicks, Brandy Davis, and Dede Hayes	Contact: ehicks@co.morgan.al.us
UAS Operations Group	enrGies -Phil Owen, Mark Warner, Ken Harvey Platform: senseFly eBee	Contact: PhilOwen@enrgies.com
Data Products Delivered	• Still pictures • 2D Orthomosaic Map	
Key Takeaways	• Provided information needed to update accurate start point of tornado track • Provided information about damage that occurred in otherwise inaccessible location • Change detection from 2D Orthomosaics useful for identifying old/new damage • Precious time can be wasted in search of UAS launch/recovery locations • Advanced familiarization, planning, and protocol development are crucial to the success of efficient UAS disaster response operations in the future	

On the evening of 31 March 2016, an outbreak of severe thunderstorms once again hit parts of the southeast U.S., impacting portions of Mississippi and Alabama. During this event, one of the storms produced an EF-2 tornado with a damage track of approximately 15 km (9.5 mi.) in length, stretching across parts of Morgan County in north Alabama. The primary areas of damage occurred among rural and lightly populated towns and residential centers, but, fortunately, there were no injuries or fatalities reported.

As more than eight months had passed since the previous attempt to test the rapid response UAS CONOPS in this region, there had been a great deal of discussion and socialization about this approach within the community, especially among NWS Huntsville officials and several nearby county EMA offices. As a result, many of the collaborators were better informed, and conversations about activation of UAS resources began after the immediate threat had subsided. However, a formal protocol for UAS deployment did not yet exist, and this prevented the capability from being part of the initial response effort (Cherokee Nation Technologies 2016). Post-event interviews with emergency management personnel indicated that there had been a strong desire to call upon a local UAS operations team for activation, which had placed itself on “standby” status at the time, but the ongoing priorities and demands of the response efforts precluded the officials from having the time to reach out during the critical initial response window, when it may have provided the most benefit (D. Hayes, Telephone interview, April 04, 2016).

During this time, NWS Huntsville survey teams initiated their own ground-based PDA operations. Opportunistically, aerial imagery was provided to the WFO, which had been obtained from a Chinook helicopter and a hand-held digital camera, courtesy of a graduate student at the nearby University of Alabama in Huntsville (UAH). The student worked at the Redstone Arsenal military installation and happened to be flying drills in the area within a couple of days following the severe weather event (T. Barron, C. Darden, E. Hicks, and B. Davis, Personal interview, April 22, 2016). The images provided enough information to indicate that the initial touchdown point of the tornado may have started farther to the southwest than originally suspected, but there was not enough data in the pictures to provide conclusive evidence for this, and the road network did not allow NWS surveyors to access this area of interest.

With a fresh tornado damage path present and remaining ambiguity about the exact beginning point of the tornado, the Morgan County EMA office coordinated a series of UAS flights in the following days, with significant input regarding the areas of interest provided by NWS Huntsville and assistance from the UAH's Atmospheric Science Department. enrGies conducted two flight operations targeting difficult to access portions of the damage path residing in the county's more rural and rugged terrain. In the end, the resulting image dataset was extremely useful in clearly identifying and officially redefining the NWS-documented beginning coordinate point of the tornado (Figure 11). NWS ground-based damage survey teams were not able to drive or walk to this location, which was nearly 1 km away from where the damage path crossed the nearest roadway to the northeast, across an extremely hilly and densely vegetated rural landscape.

Post-mission discussions with an expanded group, now including representation from the Morgan County EMA office, local law enforcement from Hartselle, AL, and the UAH's Atmospheric Science Department offered several potential solutions to enhance the utility and effectiveness of UAS toward addressing the needs of both NWS and EMA for disaster rapid response. Having shown that the data produces a significant amount of added value for such efforts, the primary focus evolved to determine honed methods for obtaining aerial imagery much sooner. Instead of simply supplementing aerial imagery with data obtained from an existing ground-based survey, after the fact, the goal evolved to provide aerial imagery to NWS damage surveyors *in advance of* a survey. This can provide the distinct advantage of guiding PDA efforts to make them more efficient, with potential savings of time and costs. Furthermore, obtaining this data expeditiously following a disaster is beneficial for emergency responders during the initial response efforts, which increases their stake in pursuing a local partnership to accomplish these goals.

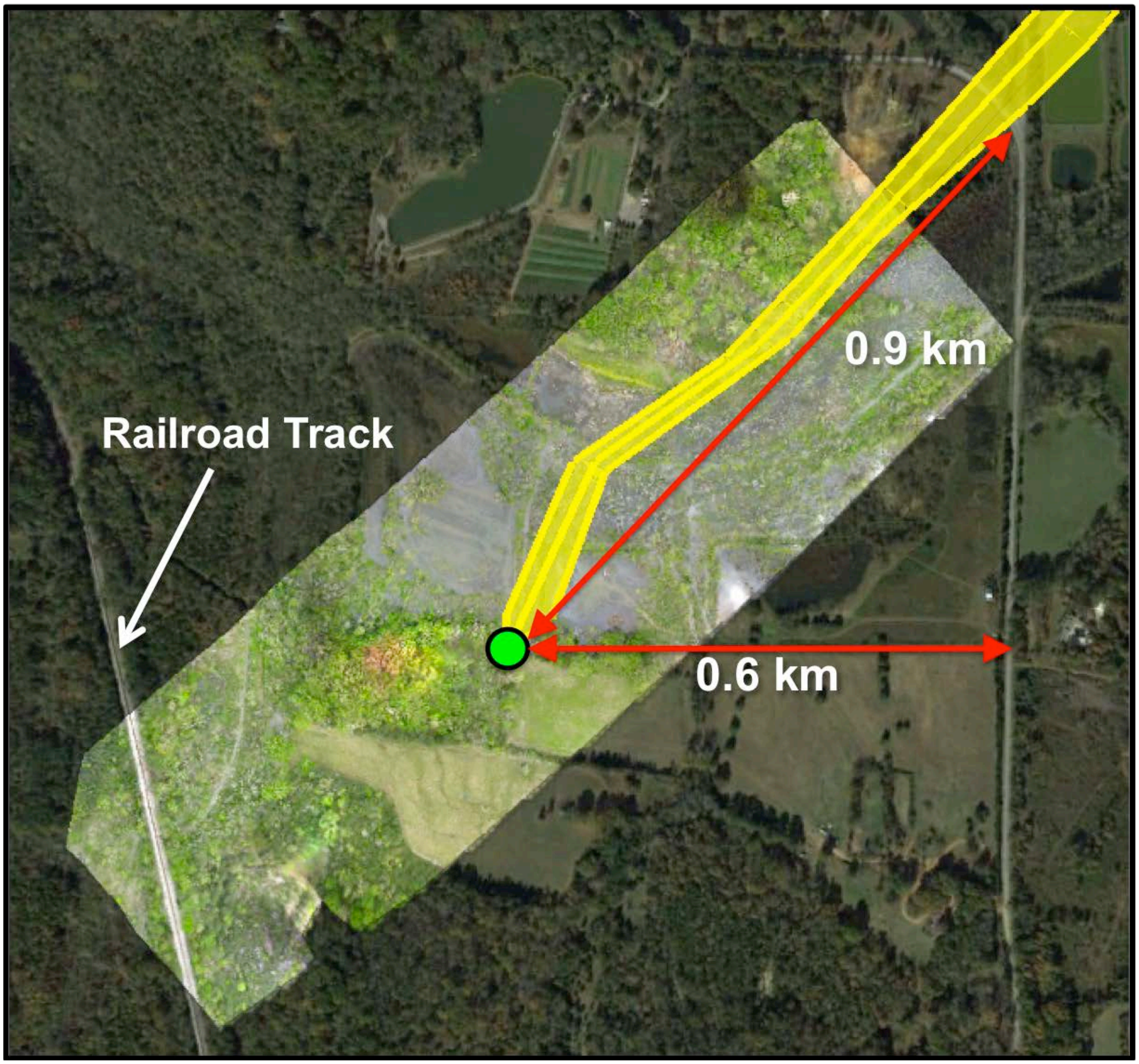

Figure 11. Revised starting point and beginning track area of the Morgan County, AL, tornado path from 31 March 2016 (green circle and yellow polygon), as surveyed and documented by NWS Huntsville. The central, highlighted portion of the figure shows a zoomed out perspective of a UAS-based orthomosaic GIS imagery product, overlaid onto a Google Earth base map. enrGies, located in Huntsville, AL, produced and provided the orthomosaic imagery.

4.5 Mississippi – NWS Jackson (Apr. 2016)

NWS WFO	NWS Jackson (Mississippi) -Eric Carpenter and David Cox	Contact: Eric.carpenter@noaa.gov
Coordinating Agency	NGI–NOAA Cooperative Institute -Dr. Robert Moorhead	Contact: rjm@gri.msstate.edu
UAS Operations Group	NGI–NOAA Cooperative Institute Platform: DJI Phantom 2	
Data Products Delivered	• Real-time Full Motion Video • Still pictures	
Key Takeaways	• Provided aerial perspective of convergent tree-fall patterns to confirm tornado path • Example of outsourced UAS operations via collaboration with other Public groups	

Also on 31 March 2016, the same night that the EF-2 tornado touched down in Morgan County, AL, another tornado formed in northeast Mississippi. The tornado generated EF-1 damage along a mostly rural 9.3 km (5.8 mi.) track in eastern Lowndes County, MS, just outside of the more populated areas surrounding the city of Columbus, before terminating near the state line in extreme western Pickens County, AL (Figure 12, left pane).

Discussions about the utility of UAS-based PDA imagery had just begun one week prior to the event between personnel supporting the NOAA UASPO, NOAA's NGI cooperative institute, Mississippi State University, and officials from the Jackson NWS WFO (C. Entremont, E. Carpenter, D. Cox, and M. Ryan, March 23, 2016). The day following the tornado outbreak, PDA surveyors from the NWS Jackson office followed along with trained UAS operators from NGI as they flew UA S over parts of the damage path and observed a convergent (aka: "cross-over") tree-fall pattern that is often indicative of damage produced by a tornadic circulation (Figure 12, right pane). During the mission, real-time imagery was displayed on a screen integrated into a hand-held ground control station. Snapshots of the real-time imagery were also taken and shared with the office. In a subsequent meeting with local stakeholders, officials from the Mississippi state EMA (MEMA) expressed interest in generating a collaborative tabletop exercise, focused on the use of UAS for rapid response. This group is working to cull relevant information that would feed into such an exercise (NWS Jackson 2016).

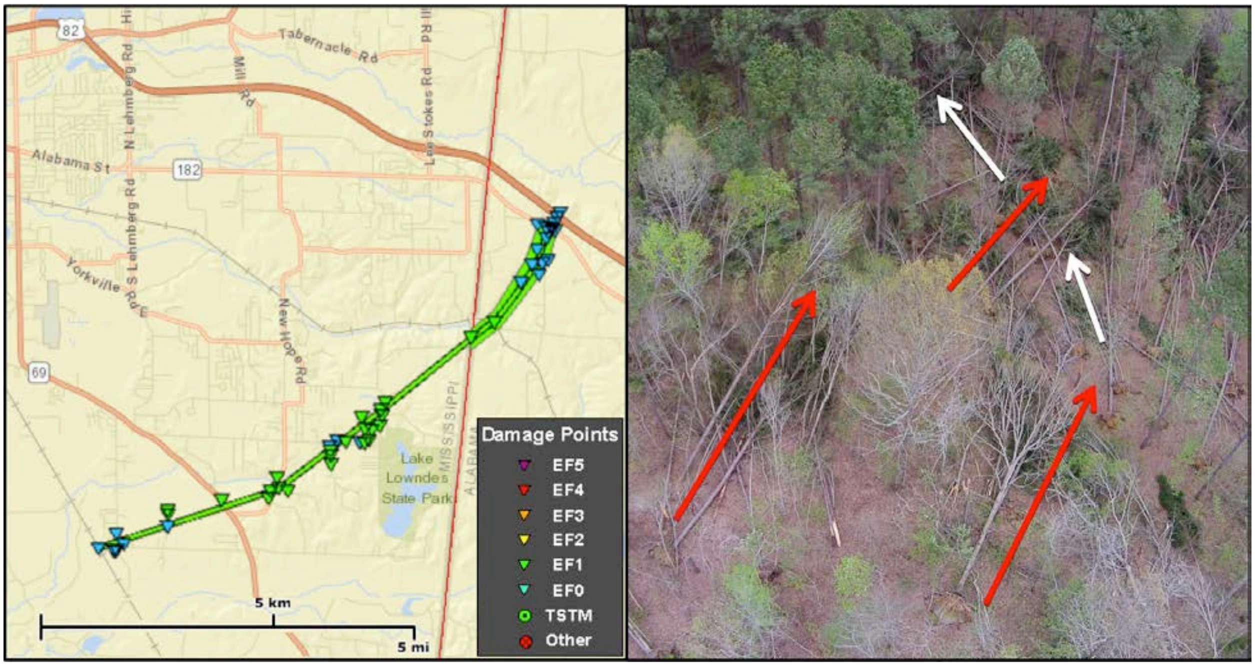

Figure 12. Track of the EF-1 tornado that hit Lowndes County, MS, and part of Pickens County, AL, on the evening of 31 March 2016, depicted in the NWS DAT (left), and an aerial still photo obtained from NGI's UAS operation over the damage area the following morning (right). The aerial image shows a convergent pattern, indicative of a tornado, where trees fell from lower-left to upper-right direction (red arrows) atop earlier tree-fall from lower-right to upper-left (white arrows). Aerial image provided courtesy of Dr. Robert Moorhead, Director of NGI.

5 Types of UAS Aerial Image Products

There are several types of aerial image products attainable by employing data from UAS platforms. This data ranges from simple, easily acquired imagery up to the more complex GIS output products, which require additional resources to produce, but provide more information and greater utility. Products tied to the Open Geospatial Consortium standards have greater interoperability, which will maximize mission impact. The still photographs, full motion video (FMV), orthomosaic maps, and textured three-dimensional digital surface models discussed in this section are a subset of aerial imagery products considered relevant to post-disaster response and PDA. Other potentially useful aerial image products, not discussed, include infrared imagery (for night-time operations), multi-spectral imagery, and processed image classification output. As a general rule, higher resolution datasets contain more information (Turner et al. 2012). This is also true for the image products referenced in the subsequent subsections.

5.1 Still Photographs

Still photographs, more commonly referred to as "still pictures", are among the most common types of available aerial imagery. For example, the AFT commercial UAS services company captured several still photographs over the February 2016 Appomattox County, VA, tornado damage path (Figures 13–16) and provided them to the local EMA and NWS Blacksburg offices.

Many baseline UAS platforms come with the ability to integrate a simple camera or other similar type of imager payload. Some of these allow real-time transmission of images to personnel on the ground, which can be geotagged for later geographic reference on a map (Wilkens et al. 2017).

Imagery of any type, provided from an aerial perspective, can provide tremendous benefit to post-hazard damage surveyors; however, there are inherent limitations to the utility provided by still photographs, primarily due to the lack of contextual information. Still pictures, alone, are extremely useful to an individual who is familiar with or has pre-existing knowledge of a location and orientation of a scene captured by such an image (Morgan et al. 2010). Yet, even with annotated and geotagged images, intended to provide general clues of spatial context (Figure 17), it can sometimes be difficult and time-consuming to integrate this information effectively and in a useful manner. Nevertheless, having access to the aerial perspective provided by this type of imagery yields tremendous gain over a ground-based perspective, alone, and UAS-based still pictures have already proven useful to NWS and EMA personnel in a number PDA survey operations (Morales and Sporer 2016).

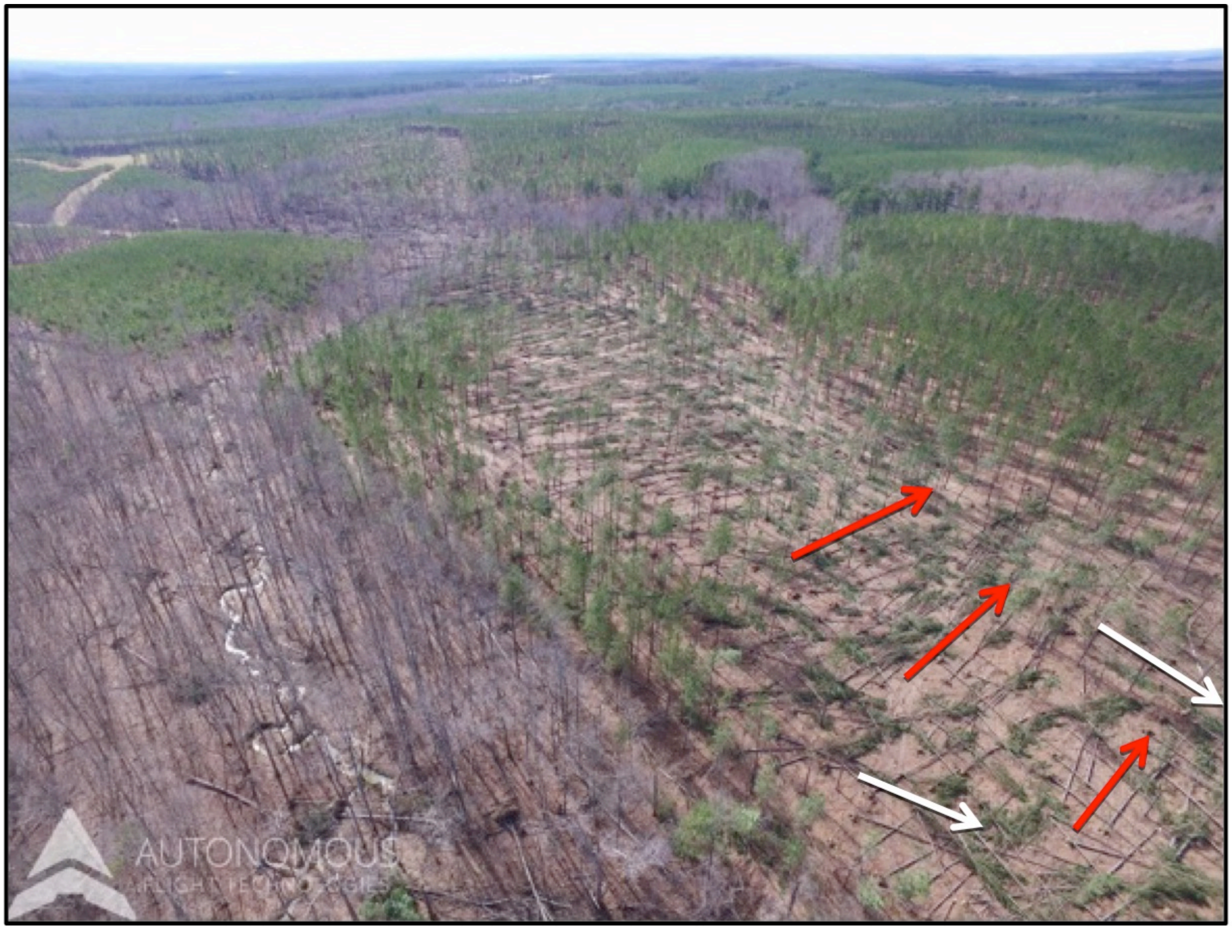

Figure 13. An oblique-angle still photograph of a convergent tree-fall pattern in Appomattox County, VA, with white and red arrows included to show ‘first wind’ and ‘second wind’, respectively. Original image produced by Autonomous Flight Technologies, Inc. and provided courtesy of NWS Blacksburg.

Figure 14. A nadir-view still photograph of a convergent tree-fall pattern showing several exposed root balls in Appomattox County, VA. Once again, white and red arrows have been overlaid to emphasize this pattern. Original image produced by Autonomous Flight Technologies, Inc. and provided courtesy of NWS Blacksburg.

Figure 15. A still photograph identifying a large expanse of downed trees in Appomattox County, VA, which precluded the need for survey teams to spend time walking through or encircling the affected area. Image produced by Autonomous Flight Technologies, Inc. and provided courtesy of NWS Blacksburg.

Figure 16. A still photograph where vast areas of tangled vegetation and debris are observed in Appomattox County, VA. Image produced by Autonomous Flight Technologies, Inc. and provided courtesy of NWS Blacksburg.

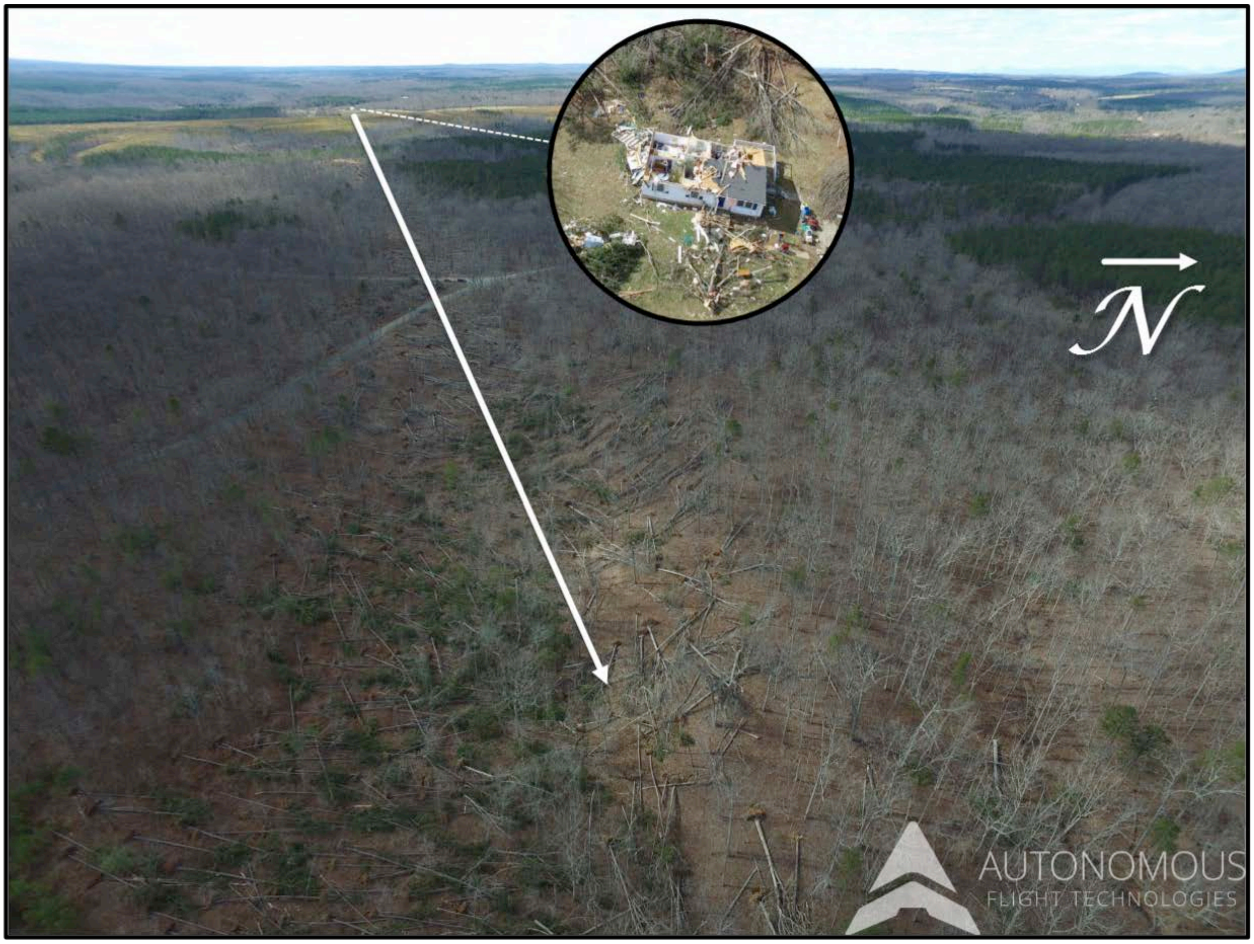

Figure 17. A still photograph showing a path of tornado damage with a damaged home on the horizon and several downed trees in the foreground of a rural area. The long white arrow indicates the damage path, and the "N" and associated short white arrow, near the upper-right portion of the image, indicate direction of north. Original image produced by Autonomous Flight Technologies, Inc. and provided, along with annotations, courtesy of NWS Blacksburg.

5.2 Full Motion Video

Full Motion Video (FMV) is another common type of aerial imagery, often recorded by hobbyists and professionals and displayed via mainstream media outlets, especially during or after a large-scale natural disaster. Like the still photo cameras referenced in Section 5.1, several baseline UAS platforms come with this technology, or with the potential to integrate a compatible FMV payload. Furthermore, some UAS platforms allow real-time steaming of FMV to personnel on the ground. This added functionality provides viewers with immediate feedback about a scene and allows them to better direct the UAS flight path to subsequent waypoints or identify targets to zoom in on for closer inspection (S. Britton, T. Barnack, and J. Birdwell, Personal interview, August 9, 2016).

Aerial FMV imagery can be useful, especially for capturing greater situational awareness and understanding the scope of a disaster-ravaged region. However, when it comes to ascertaining the specific details and locations of features from within an area of interest, this type of imagery is most suited for real-time, on-scene deployment (K. Roberts, Personal interview, August 22, 2017). As a result, real-time aerial FMV can be a great asset to the initial wave of first responders and EMA personnel, immediately following a disaster. In recent cases, such imagery has also proven useful to NWS damage survey teams already on-site. However, the objective of this study is to refine PDA operations to make them as efficient as possible; therefore, it is more beneficial to provide aerial imagery to NWS survey teams during the planning phase, *ahead* of the actual PDA deployment (NOAA 2017).

Designated operators can fly UAS over a damaged area and record FMV data for subsequent distribution to NWS surveyors, prior to mobilization of the team, but this approach lends itself to multiple issues. Without the ability to communicate feedback and direction to a UAS operator in real time, potential targets of interest may be briefly overflown with a wide-angle view of the scene, but miss important details. To avoid this issue and effectively capture more high-resolution information, operators may opt to hold a constantly zoomed perspective while recording video for follow-up examination, but this can lead to a loss of locational awareness and also require additional passes and time to adequately cover an entire area of damage (Turner et al. 2012).

A recorded FMV dataset can be cumbersome to review for the type of thorough information needed in a comprehensive damage survey (Geospatial Solutions, 2015). This approach requires the end user to spend time fast-forwarding, rewinding, and keeping track of video time stamps, while trying to also cross-reference the information with maps. Notes of approximate locations must also be tracked, based on available landmark references and other features in the imagery, to help identify the relative positions of important damage attributes. A lot of information about a damage scene can be gleaned from FMV aerial imagery, especially when viewed and directed in real time; however, its ideal use is more tactical in nature. Simply put, it lacks capabilities needed for strategic planning of PDA operations to achieve the greatest savings in time and resources.

5.3 Orthomosaic Maps

The orthomosaic map (Figure 18) product is more advanced than still photographs and FMV, and it addresses the spatial context issues that were presented with those latter two products. A process called orthographic rectification, which involves the overlapping or stitching together of multiple nadir-view still photographs using precise geographic information to correctly align them onto a map, produces these orthomosaics. To do this properly, GIS software uses a sophisticated set of computer algorithms to integrate and process detailed information about the latitude, longitude, altitude, and attitude of an airborne platform and the coincident angle of each still photograph taken from a downward pointing camera. The slope and the height of terrain features captured within a given scene are also data included in the processing. Orthomosaic products generated from a series of high-resolution still photographs captured with 70 percent or greater overlap in the relative X- and Y-coordinate directions (i.e., horizontally) at the surface provide the most accurate results (Dehaan 2015).

Figure 18. A high-resolution orthomosaic image, such as this, can provide a broad overview of an area, complete with geographic coordinate information, and when zoomed in, it can facilitate discovery of detailed features within the imagery. Dataset provided courtesy of Skylab Production.

Quality orthomosaic products are powerful tools in the planning and execution stages of PDA efforts. Overlaying this imagery on a digital map, such as Google Earth or ArcGIS, helps identify the spatial characteristics (Wilkens et al. 2017) of the damaged area (e.g., start and end points of damage, perimeter of damaged area, and accessible roadways) to determine locations where in-person, ground-based assessments may still be necessary and find the quickest inbound routes to get there. This product also lends itself to the integration of geotagged, ground-based photos within the same mapping application. This may act to complement the orthomosaic when needed, similar to the way many NWS WFOs currently use the experimental DAT application.

In rural areas where inadequate road networks exist, orthomosaic imagery, alone, may provide enough advanced information about a storm's damage path to preclude the need for survey teams to spend time and effort trekking out into densely vegetated regions to accomplish this task (C. Darden and J. Russell, Personal interview, August 10, 2015). Similarly, inaccessible roadways may be evident, which might be of particular use to emergency responders, but also to NWS teams that may need to gain access to a particular location; thus, helping both groups better allocate resources. Furthermore, orthomosaics provide accurate locations of mapped features allowing end users to confidently measure distances between points and widths of damaged areas using point and click toolkits available in most mapping applications (Barry and Coakley 2013).

One of the most beneficial applications of orthomosaic maps for PDA is the ability to perform quick "change detection" analyses (Figure 19). Since most available mapping applications come with base maps produced from relatively recent aerial photographs, overlaying them with new orthomosaics, then toggling the overlay layer on-and-off reveals a "before" and "after" view of an affected damage area. Such antecedent information about what an area of interest looked like before a disaster can assist damage surveyors by providing them with details about the state of vegetation and structures, pre-disaster. This capability is particularly useful in situations when buildings in the landscape are severely destroyed or missing. Upon arrival to a damage scene without this type of knowledge, it can be difficult to retroactively determine how sturdy or well built a given structure may have been. Clues provided by this type of imagery, especially when it is available in high resolution, are useful in some situations. In other cases, it may be equally important to have knowledge of what damage existed in an area of interest, prior to a more recent event. For example, a simplified orthomosaic change detection analysis (Figure 20) of tree damage that occurred near the path of the 31 March 2016 tornado in Morgan County, AL, revealed that the tree had actually fallen many months prior to the recent tornado event (Barron 2016). One of the challenges NWS Huntsville faced during this particular damage survey was the correct placement of the tornado's starting point. This data was useful in allowing the team to correctly exclude this particular area of damage and accurately accomplish the PDA mission.

Figure 19. The orthomosaic image captured in Appomattox County, VA, (top) is compared to the same scene provided in Google Earth (bottom) by toggling back and forth between the base map and the orthomosaic. Imagery produced by Autonomous Flight Technologies, Inc. and provided courtesy of NWS Blacksburg.

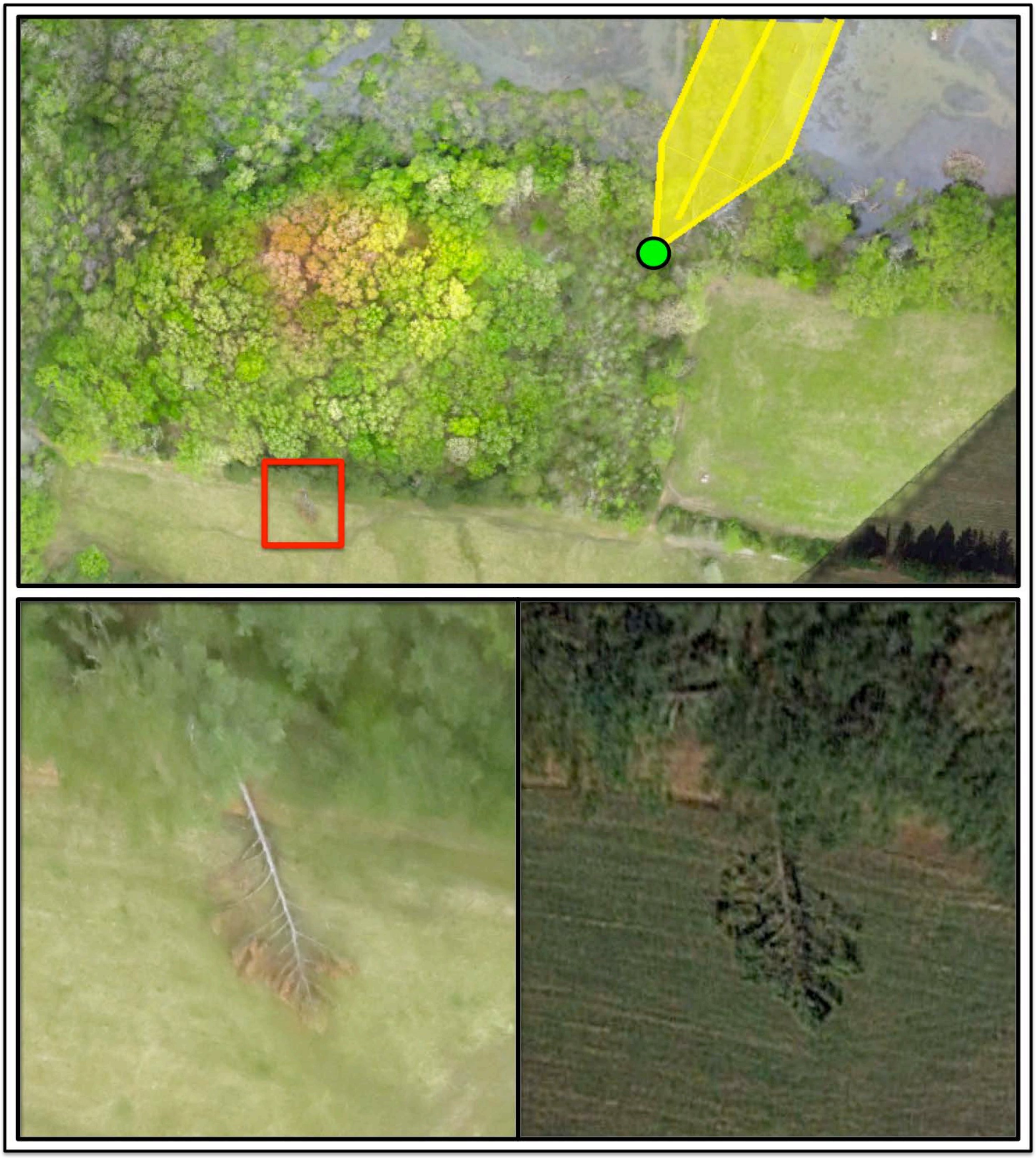

Figure 20. A change detection analysis of the fallen tree identified in the orthomosaic image from April 2016 (red box at top; zoomed in at bottom-left), and also in the older Google Earth base map from October 2015 (bottom-right) allowed for the exclusion of this damage area in determining the correct starting point for the tornado in Morgan County, AL, identified by the green circle and yellow polygon. Imagery produced by enrGies and provided courtesy of NWS Huntsville.

5.4 Textured Three-Dimensional Digital Surface Model

The textured, three-dimensional digital surface model, or "textured DSM", combines many of the benefits from other types of imagery and allows users to view a scene from multiple angles and zoom levels. Textured DSMs are generated, either by combining aerial still photograph data with coincident distance information provided from a Light Detection and Ranging (i.e., Lidar) instrument, or with aerial still photographs, alone, through a computationally-intensive process called structure from motion (Frueh and Zakhor 2003) Either way, the output product for a damaged region gives end users the ability to sit at a computer and virtually fly through an area of interest, frozen in time. Furthermore, users can zoom out to view a wide angle of a damage scene, pan around or tilt up and down to view it from a completely different angle, then zoom in to do the same thing again with specific features captured in the imagery at high resolution (NWS Jackson 2016). While orthomosaic maps provide many benefits that may aid in NWS PDA efforts, the oblique angle views provided by textured DSM products are also very important for examining damage areas (P. Sisson, A. Nash, S. Whittier, and J. O'Neil-Dunne Videoconference interview, May 24, 2017).

While still out in the field, the AFT UAS team captured still photographs over a neighborhood in Appomattox County, VA, after the EF-3 tornado event of 24 February 2016, uploaded them to a cloud-based server for remote processing, and then downloaded them as a finished textured DSM product less than two hours after completing the UAS flight across the 19 acre area (J. May, P. Stoutamire, and M. Sporer, Telephone interview, March 11, 2016). This particular dataset (see Figure 21) features several vehicles and homes that were badly damaged or destroyed by the tornado, with an option to view the entire region from a broad "zoomed out" perspective or a detailed "zoomed in" perspective of damage areas at only 1 cm GSD. One item of note, as seen in Figure 21, is a two-story home with a severely damaged roof. The textured DSM imagery allowed surveyors to obtain multiple perspectives of this structure that would otherwise have been too dangerous or impossible to acquire from the ground. To view a brief fly-through demonstration video of this particular dataset, courtesy of AFT, please use the following URL to access the online sample: http://youtu.be/JDsfWCK1oU8.

Figure 21. Computer screen captures of a textured DSM with a wide angle oblique view of an affected area (top-left), a zoomed in oblique view targeting a two-story home from multiple angles (top-right; bottom-left), and a nadir view of roof damage from the same home (bottom-right). Imagery produced by Autonomous Flight Technologies, Inc. and provided courtesy of NWS Blacksburg.

6 Lessons Learned and Best Practices

An evolving list of "lessons learned" and "best practices" has been developed through the course of this study. Multiple NWS WFOs, EMA offices, law enforcement officials, UAS operators, and other related stakeholders helped contribute to this list through conceptual conversations, operations, and post-operational "hot wash" discussions (Cherokee Nation Technologies 2015, 2016; NWS Jackson 2016; J. May, P. Stoutamire, and M. Sporer, Telephone interview, March 11, 2016). It remains in a continuous state of update and refinement as each item is validated through multiple real-world opportunities. Having shown the usefulness of aerial imagery from UAS, the greatest limitation of transforming this capability into an effective and efficient tool for disaster response is the time it takes to acquire, process, and distribute the data. Following such an event, response time is a critical factor, even for damage survey teams, so delaying ground-based operations in hopes that aerial imagery may eventually become available to aid in the effort is not practical. Therefore, most of the lessons learned focus on decreasing the amount of time elapsed between the occurrence of a disaster and the time UAS imagery is made available for use by NWS and EMA response personnel. The following subsections highlight lessons learned from the perspective of Option 2 for outsourced COCO UAS operations, the primary subject of this investigation.

6.1 Advanced Local Planning and Protocol Development

The establishment of a detailed plan and locally developed protocol well in advance of an actual event are essential for the effective implementation of UAS assets for rapid response and PDA operations in the wake of a disaster (see Sections 4.1 and 4.4; D. Hayes, Telephone interview, April 04, 2016; Cherokee Nation Technologies 2016). The first step is to become familiar with all commercial and/or public UAS operator resources within a localized region. Once identified, engaging in open discussions with these groups is a crucial step toward establishing a two-way line of communication to discover overlap between observational requirements and UAS capability solutions. For example, such communication would help determine on the front end if thermal infrared imaging capabilities are available for potential nighttime or SAR operations. Similarly, it is useful to understand whether a group has an imager with sufficient resolution, or the resources needed to generate mapped orthomosaics and textured DSM products. Real-time streaming abilities are yet another important attribute to be aware of. Therefore, it is important to understand and determine available capabilities early in the planning process to document assets and resources prior to their need during a rapid response scenario (S. Worsham and T. Barron, Personal interview, June 9, 2016).

The time required to activate a given UAS operational team is another important piece of the puzzle, as the location of a team's base of operations may affect their ability to quickly access potential target areas. In some situations, it may be prudent to identify and designate smaller operational domains for multiple UAS operating groups, spread out across the region, to ensure better coverage and faster response times. Additionally, formal agreements and a communication plan, generated in advance of anticipated operations, can be enacted to place designated UAS operators on "standby" status (P. Owen and J. Sullivan, Personal interview, August 6, 2015). This approach allows an operations group to plan ahead, providing a higher likelihood for a successful mission (Cherokee Nation Technologies 2016).

For rapid response UAS capabilities to be a reliable asset, it is important to capture the above information in the development of formal protocols and executable plans around locally available assets. While several regions may adopt this general concept, each community is unique and requires a customized approach to effectively implement these CONOPS at the city, county, and state levels. For this reason, it is essential that local NWS and EMA offices draw upon existing relationships and reach out to other potential stakeholders in the first responder community (Sullivan 2016). Together, this group can more readily identify nearby UAS resources and establish a plan that adequately addresses everyone's requirements. It is important for these partners to determine which scenarios UAS operations might provide benefit, and since not all disasters are weather-related, participating EMAs may opt to lead this effort and establish a plan (S. Worsham and T. Barron, Personal interview, June 9, 2016).

Indicating which organization and personnel have the authority to activate a UAS resource has proven beneficial when incorporated into locally customized protocols (S. Worsham and T. Barron, Personal interview, June 9, 2016). When activating an operational team, the clear and effective communication of answers to the following three questions, will assist responding operators in becoming properly equipped and prepared to successfully accomplish the given mission:

- *What observational requirements need to be addressed, and what type of imagery is desired?*
- *Where is the affected area located and approximately how large is it?*
- *Who is the onsite Incident Commander to whom the UAS team should report to upon their arrival on scene?*

After developing and refining general protocol requirements, folding them into emergency operations plans (EOP) at the county and state EMA offices will make them readily available for reference, as needed.

6.2 Two Phases to Disaster Response Operations

Regardless of the actual type of emergency, there are two phases to any full-fledged disaster response effort (Figure 22; Cherokee Nation Technologies 2016). The first phase is described as the "initial emergency response", or "Phase 1" for the purposes of this document, which begins when the first wave of emergency responders arrives at the scene of an event. At this stage, first responders and EMA personnel have an urgent need to understand the scope of a disaster, and all available resources are typically dedicated to meeting the objectives of this phase. At minimum, this requires knowledge of the size of the affected area, which locations are most severely affected, whether there is an ongoing hazard that needs to be identified, and if there are any individuals that are injured or unaccounted for. Time to properly react is critical, since the need to protect life and property are of the highest priority, and the desire for situational awareness is at its greatest during this initial response phase. During Phase 1, the use of UAS imagery and capabilities can enhance this situational awareness. An aerial perspective can help to identify the perimeter and most severely impacted portions of an affected damage area. It can also assist in SAR operations for missing persons, as well as other unscripted exploratory efforts to provide actionable information to guide ground-based personnel and resources.

The second phase of a disaster response effort is the more formal “damage survey”, or “Phase 2” in this document, which is secondary to the priorities of Phase 1. Once the Phase 1 priorities of protecting life and property are satisfied, resources can begin to transition to Phase 2 efforts. However, this leaves little in the way of overlap between the two phases. Phase 2 is an essential component of the recovery efforts directed by the EMA. For weather-related disasters, it is an important step for the accurate capturing and cataloguing of scientific documentation, which is the responsibility of the local NWS WFO. Use of UAS in this phase can help acquire data over a broad area of the disaster scene in a brief amount of time for producing higher level GIS imagery products, such as mapped orthomosaics and textured DSMs. Such products are well-suited for damage surveys, but they may also provide enhanced situational awareness for NWS partners in the first responder community involved in the Phase 1 efforts (K. Roberts, Personal interview, April 22, 2016; T. Demuth and T. Brewer, Personal interview, June 28, 2016), if made available during the early stages of the response.

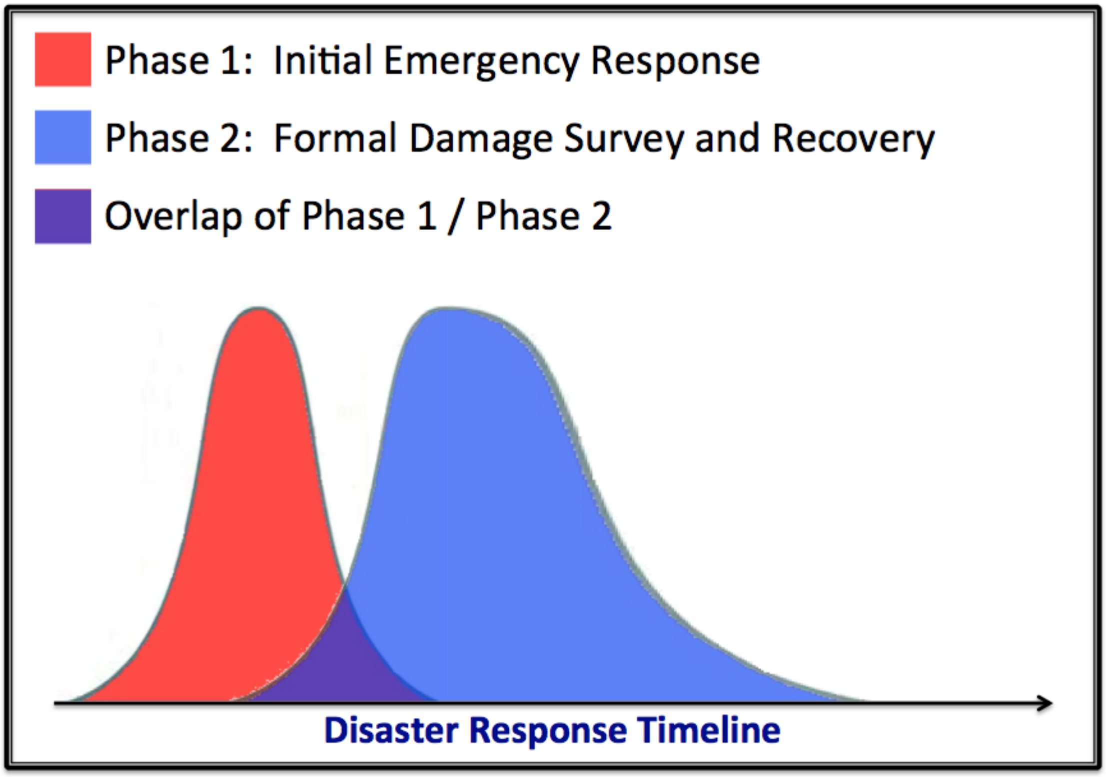

Figure 22. Conceptual plot illustrating how disaster response timelines are comprised of two partially overlapping phases, beginning with the initial emergency response phase that commences with the on-scene arrival of first responders.

6.3 Real-time Streaming of Data

UAS capabilities providing real-time data streaming during operations can provide decision makers on the ground with immediate actionable information, especially during the Phase 1 response effort, and allow them to provide instant feedback regarding where to direct the UAS next (S. Britton, T. Barnack, and J. Birdwell, Personal interview, August 9, 2016). Also, in some situations, it can aid in expediting generation of higher level GIS products while the mission is in progress, as opposed to having to wait until a UAS lands before gaining access to logged data and then beginning the computational processing. These higher-level aerial image products provide a tremendous amount of information and may be beneficial to both Phase 1 and Phase 2 components of the disaster response (Cherokee Nation Technologies 2015, 2016; NWS Jackson 2016).

6.4 Urgency Required for Secondary Priority Damage Assessment Objective

The priority for using resources during a disaster response situation goes to the initial Phase 1 efforts, since the protection of life and property is of the utmost importance; however, timeliness is also important for subsequent Phase 2 PDA efforts to adequately capture the true state, level, and extent of damage caused by a disaster (Cherokee Nation Technologies 2016). Per this investigation, UAS imagery is an optimal asset for assisting in these efforts, but it must be deployed quickly to provide ground-based EMA and NWS teams with thorough, accurate information. Not only is it important to promptly obtain this data for the benefits of efficiently directing ground-based resources, but it is also necessary to ensure that the captured imagery is representative of the damage caused by a disaster (J. May, P. Stoutamire, and M. Sporer, Telephone interview, March 11, 2016). This is the best way to guarantee that the documented surveys and subsequent recovery efforts are complete, since cleanup and restoration efforts often begin as soon as possible.

The postponed UAS operations in Appomattox County, VA, following the February 2016 tornado event reinforced this issue when excessively high wind gusts inhibited UAS operations and forced the Appomattox County EMA and NWS Blacksburg surveyors to perform a traditional ground-based survey on the day after the event (for more information, please refer to Section 4.3). On the second day of the survey, all participants reconvened on site, ready to commence UAS flights since the wind conditions had become more favorable for safe operations. During the UAS mission, survey team members noticed a brick home reduced to rubble and partially cleared from its foundation. Based on their memory and recorded information from the previous day's PDA activity, the team recalled that the same home, which had been badly damaged by the tornado, had still been standing the day before with the exterior walls mostly intact. There was no apparent evidence of a bulldozer or other type of heavy machinery typically used to demolish totaled homes after such a disaster; however, the clean up effort had, indeed, already begun, within two days after the tornado event. Had the surveyors not already performed an assessment on the day immediately following the tornado, it is possible that the apparent damage to this home and to others like it in the vicinity might have led these trained professionals to believe that a stronger tornado had been responsible for the damage. Therefore, it is necessary to accomplish the second phase of the response effort quickly, regardless of the type of PDA survey performed (e.g., ground-based, aerial-based, etc.). UAS can certainly act as an effective tool for delivering helpful information in all phases of disaster emergency response, but it must be deployed and used within a reasonably short amount of time if it is expected to provide accurate and effective information.

6.5 Locations for UAS Launch and Recovery

For any UAS operation, regardless of the purpose, one of the most challenging factors to account for is the determination of a safe and appropriate site to launch and recover the platform. However, specific locations are rarely known in advance for disaster response efforts. Without any forethought toward addressing this issue, too much time and effort may be expended in search of suitable launch/recovery sites instead of providing operational support during the first and most critical segment of a response effort (Cherokee Nation Technologies 2016).

As every region and every community is different, a combination of multiple solutions may be needed to adequately solve this problem, but to successfully execute any of them, they will require advanced planning and discussion among collaborating stakeholders, which falls closely in line with the previously referenced best practice (see Section 6.1) regarding local protocol development. One option is to identify several viable launch/recovery sites, evenly distributed across a local region, well in advance of a disaster (T. Barron, C. Darden, E. Hicks, and B. Davis, Personal interview, April 22, 2016). Ideally, there would be enough “pre-sited” locations spread out across an entire area to guarantee the sufficient radial coverage needed to eliminate all observation gaps with UAS operations. Open discussion and agreements would need to be made with property owners to obtain permission to use the land, establish points of contact, and ensure a clear understanding of exactly which types of critical circumstances may warrant the need for UAS emergency response operations. While this pre-siting approach may manifest itself as an excellent solution at first, many caveats preclude it from acting as a standalone solution. For example, after requiring a tremendous amount of initial effort to adequately cover a small region, it may be several years before the next disaster hits close to the pre-sited locations. During that time, ownership of businesses and private property may change hands, nullifying previous agreements. Therefore, this approach requires maintenance to keep agreements current and ensure the availability of sites in the event of a disaster. With increased coverage (i.e., more pre-planned sites) comes an increase in such requirements and associated time mandates.

Another viable option, which may act to complement any location pre-siting accomplishments, is to work with local law enforcement responders to use public rights of way during UAS launch and recovery operations (K. Roberts, Personal interview, April 22, 2016). During an emergency response situation, several members from the law enforcement community will typically be present on site, anyway, helping to direct and detour the flow of traffic to protect the public and assist in expediting the response effort. At the discretion of the Incident Commander, such individuals could also limit unauthorized persons from accessing roadways and otherwise open public areas that may be used as launch and recovery sites for UAS operations. Once again, this is not an approach that can be reasonably executed during a disaster scenario without the proper planning, familiarization, protocol development, and overall due diligence that should take place ahead of time. A combination of both options, along with a sufficient degree of public outreach, is likely the best method to safeguard against lost time in obtaining valuable information from UAS at the forefront of a disaster scenario.

6.6 Privacy Concerns While Performing Public Service

When performing PDA missions, it is important to maintain proper respect for the privacy of citizens and property owners. This is especially true when using UAS, which provide the advantage of a higher and broader viewpoint, even in the interest of public service. Prior to the release of the new FAA *Part 107* regulations in August 2016, the agency had produced a strict policy regarding the operation of UAS over private property; with few exceptions, UAS operating groups that had obtained *Section 333* exemptions under the previous set of rules were not allowed to operate over any piece of property without explicit permission from the owner (United States Congress 2012). This presented a tremendous challenge to the use and potential benefits of UAS for emergency rapid response initiatives, since it would have technically required the permission of virtually every single home owner in a neighborhood that had just been affected by a disaster, prior to launch and operation of UAS overhead to aid in response and recovery efforts.

However, under the currently active *Part 107* regulations, there are no longer restrictions regarding the operation of UAS over private property (FAA 2016c), as this has been left up to each individual state to produce its own legislation on this issue, if so desired. *Part 107* represents a tremendous step forward in paving the way for more commonplace use of UAS in the U.S., with particular regard to the types of use cases that have described through this study. Therefore, communicating the importance of regional, local, and community scale plans and protocols for UAS rapid response and the associated successes to state and local government representatives is important to ensure continued operational capability over private property. Support from the community is also key factor, which is why it is equally important to broadly socialize these concepts through public outreach. Stakeholders must be proactive in justifying the benefits of this activity and work to develop a proper solution for handling this sort of data to avoid the generation of state-level regulations that might hinder these efforts. Privacy is an important civil liberty; however, with education and careful planning, it can be protected without the need for prohibitive legislation, and UAS capabilities can continue to provide our public servants in the EMA and NWS communities with a valuable resource.

7 Technological Enhancements

Just as a perfect numerical weather prediction model forecast is worthless in an operational environment when it is made available only after its valid time, the best available set of aerial imagery is also greatly reduced in value if it takes too long to provide it. Section 5 discusses several useful types of aerial imagery with advancing degrees of complexity that can be generated for use in emergency response and PDA applications. However, it traditionally requires greater computational resources and additional time to produce some of the more complex, yet more beneficial, GIS products that were presented. This processing time for certain aerial image products is one of the largest gaps to overcome for the rapid application of UAS to aid in these efforts.

To aid in streamlining this task, the integration of newly available developments can exploit and enhance the existing benefits of UAS for rapid response operations (Botts and Robin 2015; Lehmann et al. 2017). For example OpenSensorHub (OSH) is an open source application that allows for the integration of data from a wide variety of sensors and platforms, including UAS. It is then able to quickly process and distribute it to end users through a variety of applications. With the integration of these types of technological enhancements into UAS, the traditional timeline for processing and producing advanced aerial image GIS products becomes obsolete.

With faster processing workflows, it is possible to generate image products, such as mapped orthomosaics, in near real-time, while a UAS flight operation is still underway. As orthomosaic maps can provide a great deal of additional utility to damage survey teams, the benefits of this enhanced capability are tremendous, since this approach allows for simultaneous multi-mission utilization. As a result, this application can feasibly lead to a much greater overlap in the concurrent use of UAS for both Phase 1 and Phase 2 disaster response efforts and, therefore, an overall reduction in the total disaster response timeline (Figure 23). A publicly available example of this capability may be found online at the following URL: https://youtu.be/FD7fvalu_NQ.

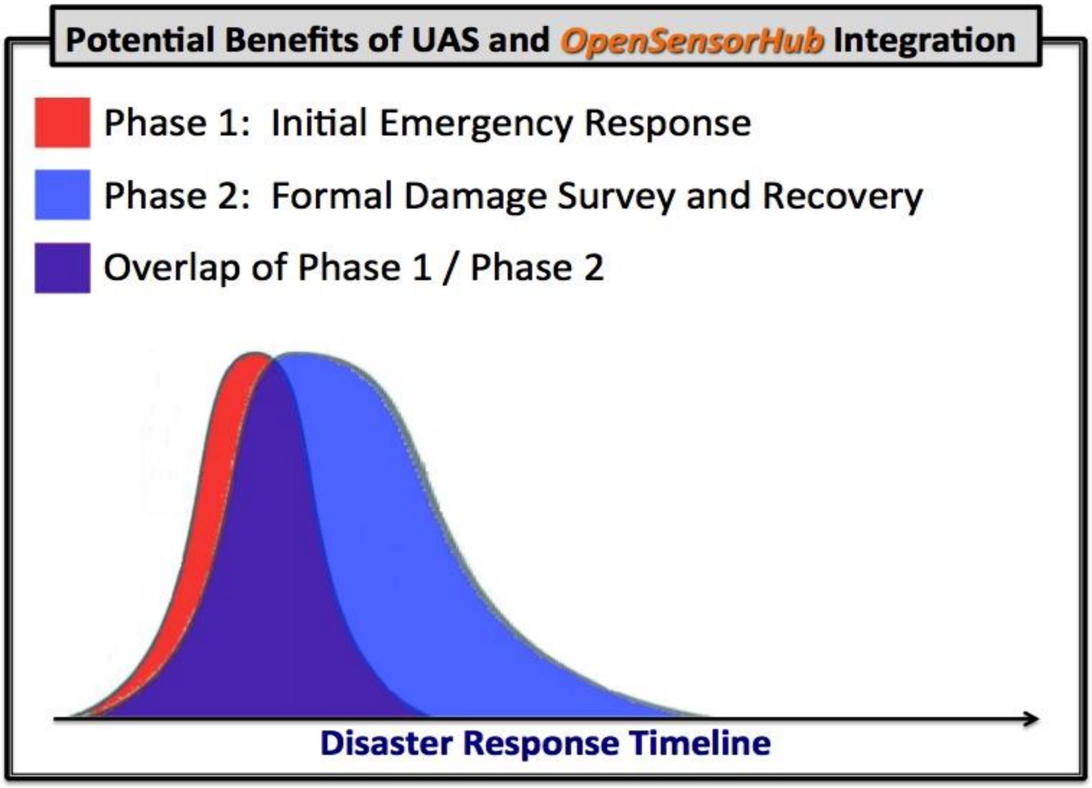

Figure 23. In reference to the two primary phases of disaster response and the conceptual timeline plot, illustrated in Figure 22, the ability to enhance existing UAS capabilities toward serving multiple objectives simultaneously has the capacity to help expedite the entire response timeline. Developing open-source applications, like what has been demonstrated with OSH, can aid in making this a reality.

Additionally, from Section 5, one of the noted deficiencies with FMV is the lack of orientation or spatial context information available when viewing the imagery. This limitation makes it difficult for a user to know the exact geographic location of the imagery at any given time. One useful application of open-source enhancements on UAS, involves the integration of a platform's positional information, a gimbaled camera payload's angular information, and real-time data streaming of FMV imagery. Using this metadata, OSH has shown great utility in integrating and relaying spatial context to users during UAS operations by "draping" the real-time FMV imagery onto a simple aerial image base map (Figure 24). With this application, users can view streaming FMV on one screen and maintain knowledge of a UAS platform's position and camera direction with the information graphically displayed on a map in another screen. For reasons previously discussed (see Section 5.2), this particular FMV utility may be more useful to Phase 1 responders, as they work to quickly understand the scope of a disaster (S. Britton, T. Barnack, and J. Birdwell, Personal interview, August 9, 2016). However, toward the benefit of both Phase 1 and Phase 2 efforts, testing of additional UAS-integrated open-source applications is currently underway.

As the development of useful open-source tools continues to advance, along with the continued push for more capable and cost-effective UAS platforms, the number of potential benefits to rapid response operations will also continue to progress in a positive direction. The developments referenced here, with specific regard to OSH applications for UAS, were performed by Dr. Mike Botts and Alex Robin. For more information, their contact information is as follows, respectively: "mike.botts@botts-inc.net" and alex.robin@sensiasoftware.com.

Figure 24. Sample screenshot of OSH application in which FMV imagery is displayed in real time at the top-right, while the UAS and camera payload positional information is provided on a static base map to the left.

8 North Alabama Demonstration and Exercise Event

NWS WFO	NWS Huntsville (Alabama) -Chris Darden and Todd Barron	Contact: Chris.Darden@noaa.gov
Coordinating Agency	EMA–Madison County, SC -Jeffrey Birdwell and Scott Worsham GEOHuntsville -Chris Johnson	Contact: Scott.Worsham@huntsvilleal.gov
UAS Operations Group	enrGies -Phil Owen, Mark Warner, and Ken Harvey Platforms: -LM-Indago quadcopter -senseFly eBee	Contact: PhilOwen@enrgies.com
Data Products Delivered	• Real-time Full Motion Video (Electro-optical & Infrared) • Still pictures • 2D Orthomosaic Map • 3D Textured Digital Surface Model	
Key Takeaways	• “Standby and Deploy” plan for executing outsourced UAS operations was successful • UAS operations team was activated via phone call from Madison County, AL EMA • Infrared imagery was demonstrated, showing potential for night-time capabilities • NWS-generated damage area of interest was provided to UAS operators and used to successfully provide aerial imagery across the entire area • Simultaneous operation of multiple UAS (by multiple remote pilots) was performed to address both phases of emergency response o Phase 1: Initial Response – Exploratory / Non-rehearsed (LM-Indago) o Phase 2: Formal Damage Survey – Programmed waypoints (eBee) • Imagery data was processed in the field and delivered to NWS and EMA within approximately 5 hours of EMA activation phone call	

In August 2016, the execution of a two-part event in Huntsville, AL, featuring a UAS capabilities demonstration and real-time rapid response exercise, broadcasted this study’s primary objective, showcased recent accomplishments, and formally tested items from the developing list of lessons learned and best practices, previously referenced (see Section 6). In preparation for this activity, many of the stakeholder groups from north Alabama, once again, banded together to further define common interests, investigate a working protocol, and continue development of a pathway toward transitioning this capability into routine operations. Along with supporting personnel from the NOAA UASPO, the diverse group responsible for hosting the event included representatives from GEOHuntsville, the NWS WFO in Huntsville, Madison and Morgan County EMA, the University of Alabama in Huntsville, OpenSensorHub, various members of the regional law enforcement and first responder communities, and the enrGies commercial UAS operations and engineering company.

On 4 August 2016, the team held a capability demonstration in John Hunt Park to share the latest findings from these efforts with other NWS personnel, EMA officials, first responders, industry partners, and elected leaders from around the region. Following an in-depth briefing regarding the background and preliminary development of the protocol for outsourced COCO rapid response UAS CONOPS, participants observed, first hand, the UAS operations, methods, and resulting types of rapid response imagery that many had just learned about. In less than an hour, a combination of multi-rotor and fixed-wing UAS had examined the entire demonstration area, using the OSH application to produce real-time, high-resolution visible and infrared FMV imagery and orthomosaic maps.

A few days later, on 9 August 2016, a subset of the demonstration attendees participated in the second part of the event, a real-time simulated tornado emergency within Madison County, AL, in the Chase Industrial Park area located just east of downtown Huntsville. The simulation included a faux warning issued by NWS Huntsville (Appendix C), fictitious reports of severe damage (Figure 25), and a resulting response by the Madison County EMA and other community first responders. The premise and hypothetical timeline leading up to the beginning of the real world activities for this exercise are provided in Table 2. The last item in the table, in which the Madison County EMA actually contacted the enrGies UAS operations team for activation and deployment, set into motion the beginning of the real-world component of the exercise. Already placed on “standby” status by the EMA office, in anticipation of potentially severe weather, the enrGies group determined from the activation phone call all of the pertinent information needed to complete the mission (see Section 6.1), loaded up, and quickly arrived on scene. There, the team quickly coordinated with the on-scene Incident Commander and commenced operations of their UAS assets, efficiently covering both phases of the operation.

During Phase 1 of the response, a multi-rotor UAS was used to scan the entire area and obtain the scope of the damaged region. Using the same unit, the execution of closer, exploratory operations over targeted locations and a demonstration of SAR capabilities was completed. These tasks were performed under direction of the on-scene Incident Commander and other emergency response personnel, who were able to view real-time streaming FMV of visible and infrared imagery (Figure 26). While this was occurring, a different crew of EMA officials across town at the Emergency Operations Center (EOC) was able to simultaneously watch the transmitted feed of imagery in real time, allowing them to immediately see remotely what first responders were seeing out in the field. Technology developed by enrGies, coordinated with Madison County EMA officials, and installed on computers at the EOC, well ahead of the deployment, made the secure, remote transmission of real-time imagery possible.

As the first, "initial response", phase of the operation continued, Phase 2 operations began to ramp up as personnel and resources became available, involving more formal aerial damage and recovery survey operations. For this, a fixed-wing UAS carrying a high-resolution camera flew back and forth in a “lawnmower pattern” semi-autonomously across the entire vicinity along a programmed path. Within a brief period, both phases of UAS operation were concluded, and the imagery was processed in the field and delivered to both the Madison County EMA and NWS Huntsville offices. For a real-world operation, this data would have allowed these groups to more efficiently direct their follow-up PDA and recovery operations in the coming hours and days.

The event was a tremendous success, and the local participants learned a great deal from the activity. Among the lessons reinforced through the exercise, the primary takeaway was that time is the crucial resource to protect. Advanced discussion, familiarization with the capability and operating team, and development of a proper protocol are the keys to gaining the most benefit from UAS applications.

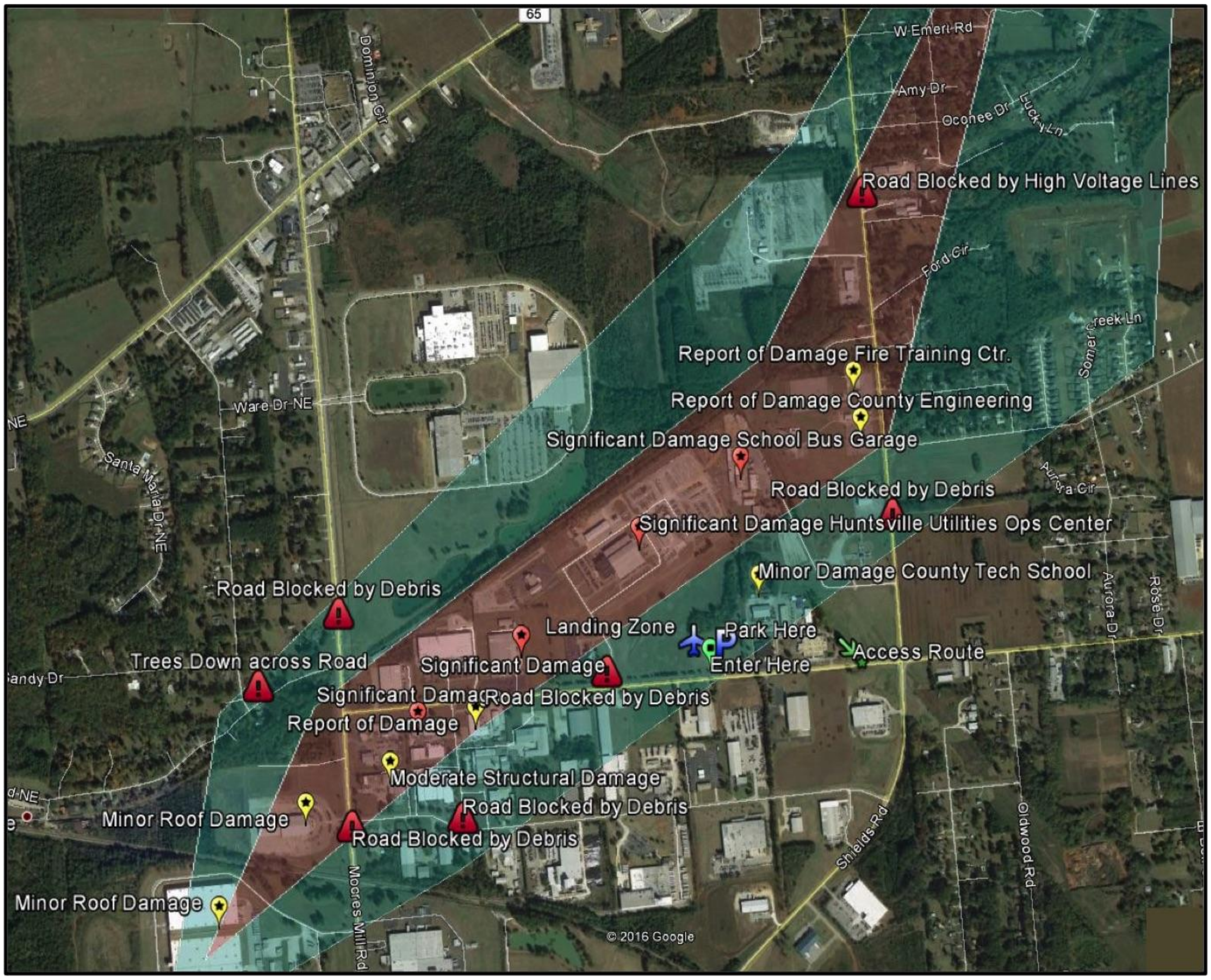

Figure 25. Map of the Chase Industrial Park area in Madison County, AL, showing a preliminary analysis of the simulated tornado damage path, based solely on fictitious damage reports used for the north Alabama UAS rapid response exercise on 9 August 2016. This map was developed by NWS Huntsville prior to the PDA portion of the UAS exercise to help guide the initial survey; it is similar to others produced and used by some NWS WFOs in the planning stage of real world disaster PDA operations.

Table 2. Chronological timeline of hypothetical events leading up to activation of the enrGies UAS operations team by the Madison County EMA in response to a fictitious tornado disaster emergency.

Days Leading Up to the Severe Weather Event (< 1 week prior to activation)
Potential for a severe weather threat is forecast by NWS Huntsville and communicated to regional EMA offices and enrGies
Day of the Severe Weather Event (< 8 hours prior to activation)
Tornado Watch is issued for north Alabama by the Storm Prediction Center in Norman, OK
NWS Huntsville provides updates regarding the likely potential for a severe weather event; EMA and other emergency response personnel in the area are put on alert; Madison County Emergency Operations Center (EOC) is activated
Madison County EMA informs enrGies of the updates and puts them on general "standby" status, in case their services may be required later in the day
Anticipated Severe Weather Impacts Imminent (<1 hour prior to activation)
Storms develop, intensify, and move into Madison County, AL
NWS Huntsville issues a tornado warning in Madison County for one of the storms
Within several minutes, damage reports begin to stream into the Madison County EOC and NWS Huntsville from the public and first responders in the Chase Industrial Park area, east of downtown Huntsville
Activation of UAS Asset
The event is determined to have hit critical mass; Madison County EMA decides to activate the enrGies UAS operations team
*enrGies answers the activation call from Madison County EMA and quickly ascertains information regarding the following questions: 1) What observational requirements exist (i.e., platform and sensor capability needs)? 2) Where to deploy? 3) Who to contact (Incident Commander that is expecting them) upon arrival to the disaster scene?

*****Indicates an actual activity, a phone call placed from the Madison County EOC to the enrGies office, which commenced the real-world component of the rapid response exercise on 9 August 2016.

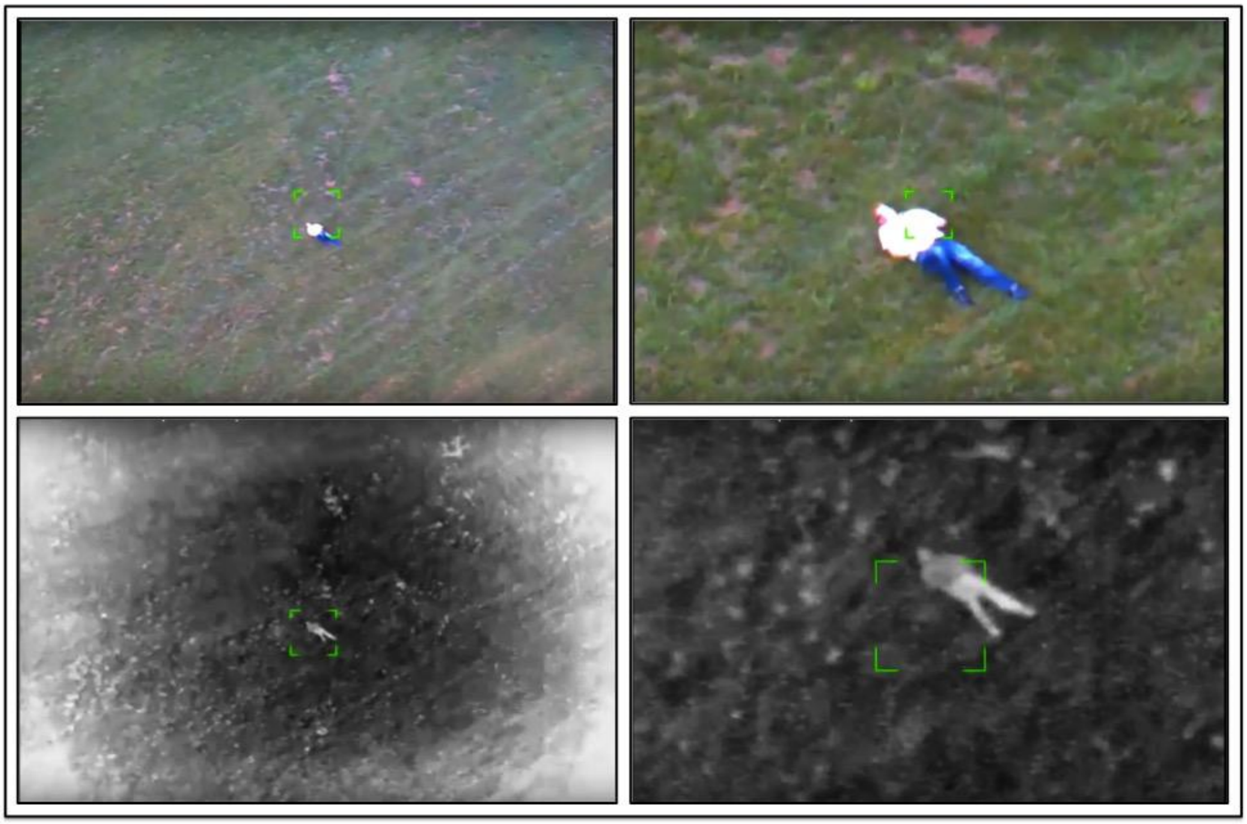

Figure 26. Sample screenshots from real-time feed of streaming FMV of visible (top) and infrared (bottom) imagery during testing of the UAS for target inspection and SAR operations, as part of the north Alabama UAS rapid response exercise on 9 August 2016 in Madison County, AL.

9 Future Work

In addition to several successful missions, this investigation has accomplished several objectives, but there are still plenty of areas to focus on toward the development and transition of UAS into routine operations for NWS PDA. Identification of the next priorities and a continued commitment to pursue these developments will help to ensure a smooth, effective integration.

9.1 Development, Testing, and Integration of UAS Functional Enhancements

Embracing and fostering emerging applications, such as OSH and other technological developments, can significantly enhance the use of UAS for future rapid response missions to aid NWS PDA efforts and address the needs of other local EMA and first responder partners. Once fully matured and integrated into the evolving UAS rapid response framework, NWS and emergency responders can capitalize on the greater efficiency provided by these types of technological advancements. Maximizing potential benefits is a clear priority for future efforts.

9.2 Data Access and Distribution

Another avenue that needs to be explored involves identification of the best method through which output UAS imagery data should be formally delivered and distributed among NWS survey teams. A preliminary look at the inclusion of certain aerial image products, like orthomosaic maps, into the experimental NWS DAT (Figure 27) was performed with the help of the National Aeronautics and Space Administration (NASA) Short-term Prediction Research and Transition Center (SPoRT) group in Huntsville, AL. However, with imagery data sets that are characterized by such high spatial resolutions (e.g., 1–5 cm GSD, nominally), it remains to be seen whether it is feasible to regularly integrate these types of products into the application. A more in-depth investigation into this path and others like it is necessary to determine the most streamlined and practical method for NWS WFOs to analyze, archive, and share this data.

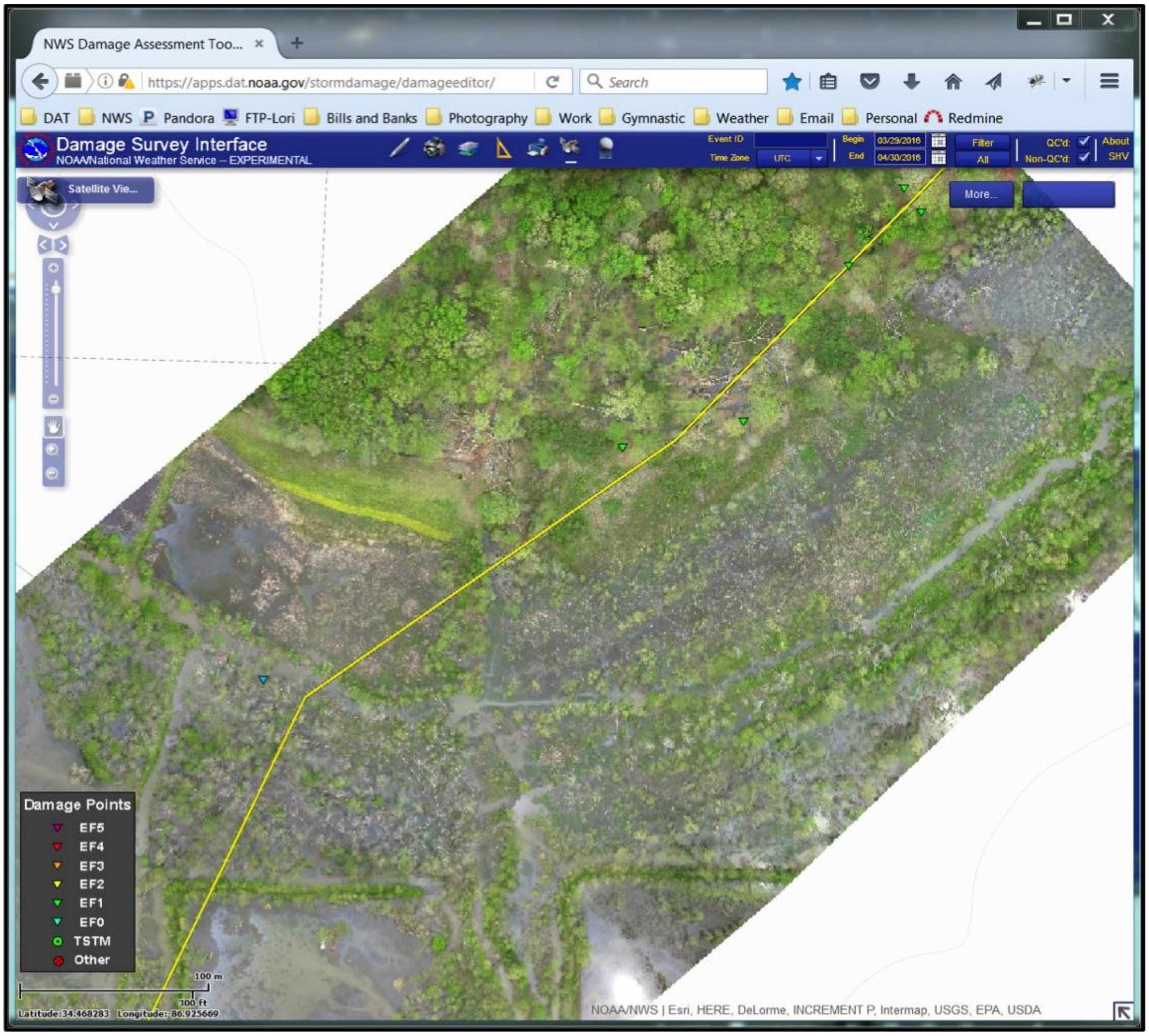

Figure 27. Sample of mapped orthomosaic data from the 31 March 2016 UAS tornado damage survey flight in Morgan County, AL, as viewed in the experimental NWS DAT application. Original imagery provided by enrGies; sample DAT output imagery provided by NASA SPoRT.

9.3 Observational Requirements

As the proposed use of UAS aerial imagery for NWS WFO PDA efforts is relatively new, there are currently no observational requirements documented in the NOAA Technology Planning and Integration for Observation (TPIO) Consolidated Observing User Requirement List (COURL) to use for guidance (NOAA, n.d.). Should UAS-based aerial imagery ever become a routine component of many NWS PDA missions, a vetted list of image product types and attributes (e.g., GSD / spatial resolution) would be helpful. This is particularly so for the recommended outsourced “data buy” UAS implementation approach, as any contracted UAS operation groups must understand the observational requirements and be capable of delivering products that meet the minimum threshold criteria.

At this juncture, the quality of such observations is rather subjective, and the opportunistic data that has been shared with various NWS WFOs has been limited. Iterative testing and evaluation of a range of aerial image products with varied attributes, subject to the preferences and needs of trained NWS surveyors, may aid in the development of these requirements. Future work may allow for these standards to be developed to address NWS and other NOAA agency requirements.

10 Summary and Conclusion

Throughout this study, the NOAA UASPO worked with multiple NWS WFOs to identify observational requirements for PDA operations that UAS capabilities could address by providing unique, affordable imagery from an aerial perspective. When made available to the NWS during the planning stages of a PDA effort, this data has the capacity to greatly save on time and other limited resources by providing upfront information about the length and width of a damaged region, locations where the most intense damage has occurred, and potential inbound routes to areas where ground-based survey teams may need to deploy for up close examination. It can also provide helpful information about damaged locations in overly hazardous or rural areas where there are no accessible roadways, making it difficult or impossible to assess damage via traditional ground-based operations.

The study investigates multiple avenues to provide local NWS offices with UAS imagery for PDA missions. The most viable path toward achieving the stated objectives is an outsourced COCO UAS operations approach, based on previous work and a review of operational UAS transition paths that other government organizations (e.g., DOI) have pursued. Through partnerships with EMA offices and other local stakeholders, a unified approach to outsourced UAS disaster response efforts can provide actionable information to NWS and EMA without any of the associated operations, maintenance, and training responsibilities. In this increasingly favorable climate of FAA regulations, a growing number of communities are experiencing a homegrown influx of public and commercial UAS operating groups with whom collaborations can be developed for disaster response events.

A significant subset of existing UAS operating groups have retained the experience, tools, and computing resources needed to generate advanced GIS aerial image products. Mapped orthomosaics can allow survey teams to overlay newly acquired damage imagery onto existing digital base maps, like Google Earth, in the field or in an office setting to provide spatial context, a reference to nearby access roadways, and the ability to perform effective change detection analyses. Change detection capabilities allow NWS surveyors to compare newly mapped aerial scenes with imagery from the same scene acquired before a given disaster occurred. Textured DSM products provide surveyors with the ability to view from a computer an entire damaged region at a broad perspective or zoom in to view detailed areas of damage, frozen in time. With this, multiple perspectives of structures, not possible to view from an in-person perspective on the ground, are visible. Many of these types of aerial imagery products can aid significantly in completing PDA missions more efficiently and lead to the production more accurate, comprehensive damage survey reports.

A growing list of lessons learned and best practices reveals that elapsed time to activate UAS assets and provide useful imagery data, following a disaster, is the largest obstacle to overcome to efficiently make use of UAS for these purposes. The jointly hosted exercise in north Alabama acted to reinforce this concept. The following items represent some of the most important lessons learned from this study:

- *Every emergency begins as a local one,* so advanced planning, preparation, and development of formal protocols with partnering stakeholders at *local* levels are at the forefront of best practices and represent a recurring theme among many of the others, including approaches for safe launch and recovery of UAS in a variety of potential locations. Rapid response missions in Florida may be vastly different than Alaska missions; therefore, discussions and locally customized plans must be facilitated prior to actual contingency operations. Establishing the administrative and contracting process in advance will reduce time to takeoff.

- *Recognition of the two primary phases to disaster response—initial response and formal damage survey*—is a crucial step toward reducing the time it takes to accomplish the mission, along with understanding the need to close the gap between the two phases by taking advantage of existing capabilities, such as real-time UAS data streaming. Applying current technological applications to enhance operational UAS data processing and distribution can also yield positive benefits and help to further diminish that gap by allowing concurrent mission sets to take place with the same finite amount of personnel and UAS resources. This also helps to address the urgent need to acquire data for that secondary PDA phase as quickly as possible, before the cleanup and recovery efforts begin in earnest.

- *Socialization and public outreach can be used to proactively address privacy concerns about these CONOPS*. Educating the public and creating an open dialogue with regional

> and state representatives about the public service merits of these developments will assist with finding a mutually beneficial solution without the need for overly restrictive legislation, which could otherwise hinder disaster response efforts and many resulting benefits for several communities across the country.

The application of UAS holds great promise in assisting NWS and partnering emergency response teams to perform their missions following various disaster scenarios. The expertise, dedication, and efforts of several diverse groups from around the country have helped accomplish many objectives, yet much work remains. Identification of common needs and objectives among local and regional community stakeholders, followed by partnerships and a commitment to work together to solve problems are among the first steps to transitioning UAS applications into post-hazard rapid response efforts. Finding the best means to proactively develop the technology, the protocol, and the operations plans during the tranquil periods, ahead of the next disaster, will help to successfully realize the maximum amount of potential benefit.

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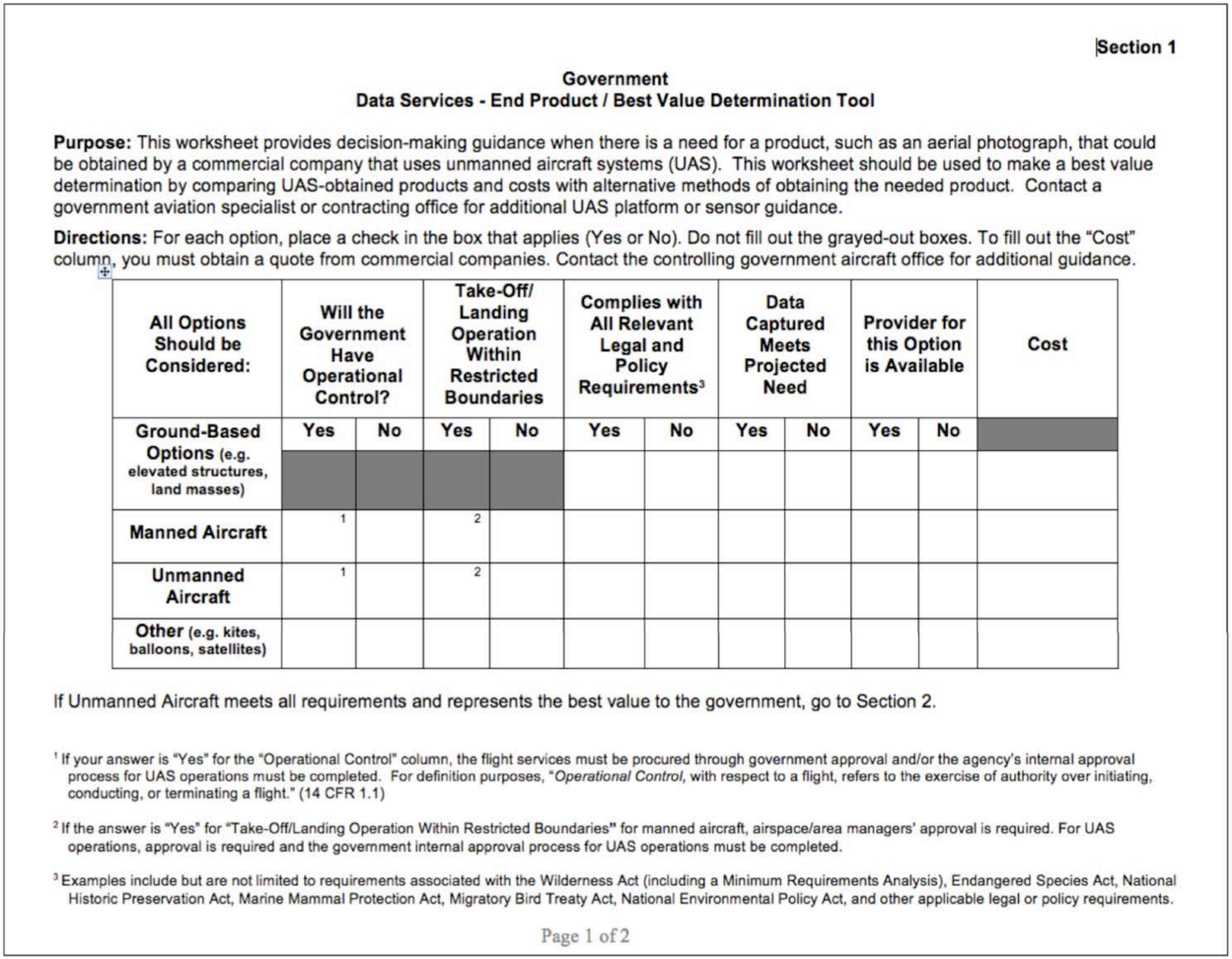
CHEROKEE NATION
Strategic Programs

Appendix A: Worksheet for Determination of UAS Use for Government Applications



Section 1

Government
Data Services - End Product / Best Value Determination Tool

Purpose: This worksheet provides decision-making guidance when there is a need for a product, such as an aerial photograph, that could be obtained by a commercial company that uses unmanned aircraft systems (UAS). This worksheet should be used to make a best value determination by comparing UAS-obtained products and costs with alternative methods of obtaining the needed product. Contact a government aviation specialist or contracting office for additional UAS platform or sensor guidance.

Directions: For each option, place a check in the box that applies (Yes or No). Do not fill out the grayed-out boxes. To fill out the "Cost" column, you must obtain a quote from commercial companies. Contact the controlling government aircraft office for additional guidance.

All Options Should be Considered:	**Will the Government Have Operational Control?**		**Take-Off/ Landing Operation Within Restricted Boundaries**		**Complies with All Relevant Legal and Policy Requirements**[3]		**Data Captured Meets Projected Need**		**Provider for this Option is Available**		**Cost**
Ground-Based Options (e.g. elevated structures, land masses)	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	▨
	▨	▨	▨	▨							
Manned Aircraft	[1]		[2]								
Unmanned Aircraft	[1]		[2]								
Other (e.g. kites, balloons, satellites)											

If Unmanned Aircraft meets all requirements and represents the best value to the government, go to Section 2.

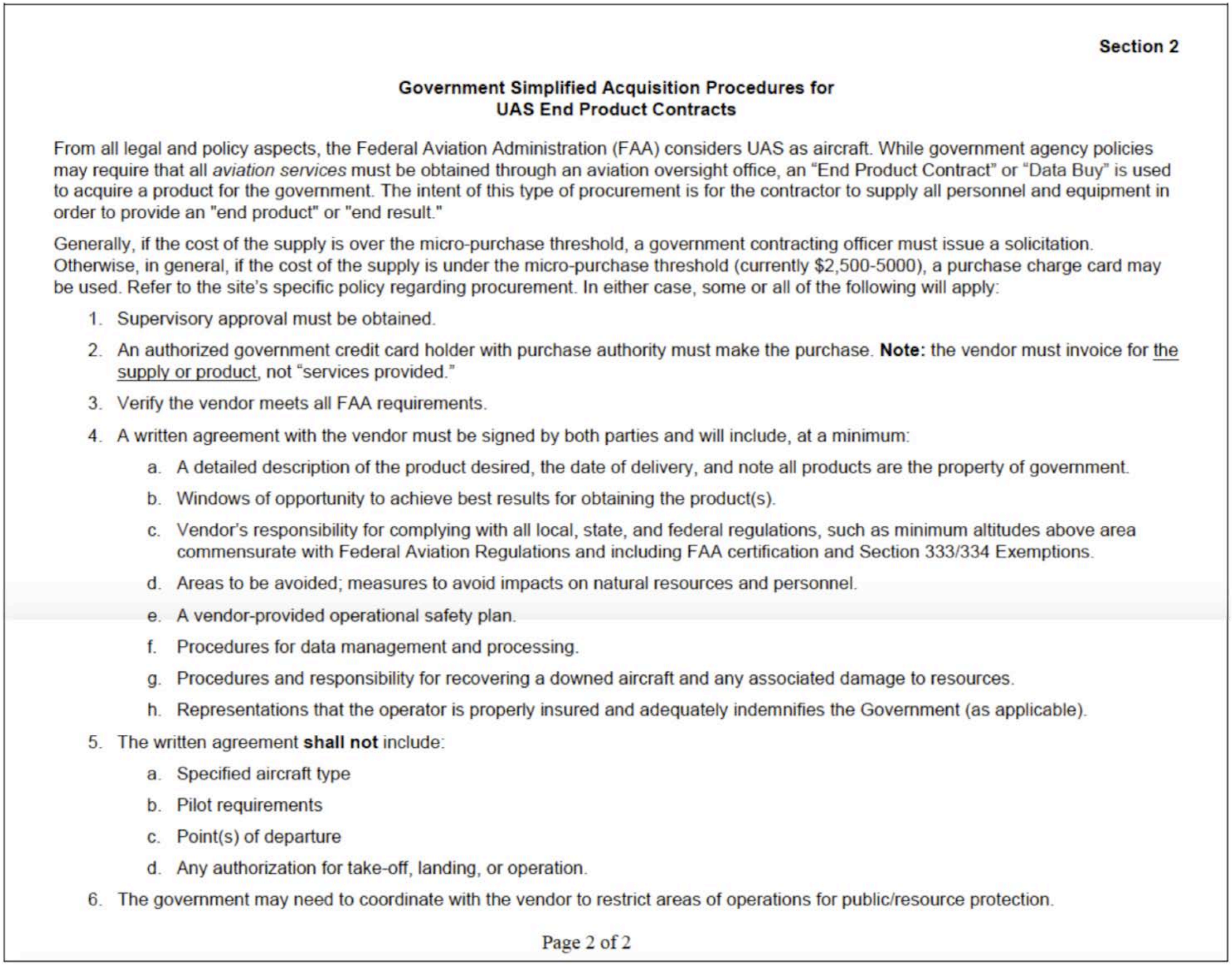
---

[1] If your answer is "Yes" for the "Operational Control" column, the flight services must be procured through government approval and/or the agency's internal approval process for UAS operations must be completed. For definition purposes, "*Operational Control*, with respect to a flight, refers to the exercise of authority over initiating, conducting, or terminating a flight." (14 CFR 1.1)

[2] If the answer is "Yes" for "Take-Off/Landing Operation Within Restricted Boundaries" for manned aircraft, airspace/area managers' approval is required. For UAS operations, approval is required and the government internal approval process for UAS operations must be completed.

[3] Examples include but are not limited to requirements associated with the Wilderness Act (including a Minimum Requirements Analysis), Endangered Species Act, National Historic Preservation Act, Marine Mammal Protection Act, Migratory Bird Treaty Act, National Environmental Policy Act, and other applicable legal or policy requirements.

Page 1 of 2



Government Simplified Acquisition Procedures for UAS End Product Contracts

From all legal and policy aspects, the Federal Aviation Administration (FAA) considers UAS as aircraft. While government agency policies may require that all *aviation services* must be obtained through an aviation oversight office, an "End Product Contract" or "Data Buy" is used to acquire a product for the government. The intent of this type of procurement is for the contractor to supply all personnel and equipment in order to provide an "end product" or "end result."

Generally, if the cost of the supply is over the micro-purchase threshold, a government contracting officer must issue a solicitation. Otherwise, in general, if the cost of the supply is under the micro-purchase threshold (currently $2,500-5000), a purchase charge card may be used. Refer to the site's specific policy regarding procurement. In either case, some or all of the following will apply:

1. Supervisory approval must be obtained.
2. An authorized government credit card holder with purchase authority must make the purchase. **Note:** the vendor must invoice for the supply or product, not "services provided."
3. Verify the vendor meets all FAA requirements.
4. A written agreement with the vendor must be signed by both parties and will include, at a minimum:
    a. A detailed description of the product desired, the date of delivery, and note all products are the property of government.
    b. Windows of opportunity to achieve best results for obtaining the product(s).
    c. Vendor's responsibility for complying with all local, state, and federal regulations, such as minimum altitudes above area commensurate with Federal Aviation Regulations and including FAA certification and Section 333/334 Exemptions.
    d. Areas to be avoided; measures to avoid impacts on natural resources and personnel.
    e. A vendor-provided operational safety plan.
    f. Procedures for data management and processing.
    g. Procedures and responsibility for recovering a downed aircraft and any associated damage to resources.
    h. Representations that the operator is properly insured and adequately indemnifies the Government (as applicable).
5. The written agreement **shall not** include:
    a. Specified aircraft type
    b. Pilot requirements
    c. Point(s) of departure
    d. Any authorization for take-off, landing, or operation.
6. The government may need to coordinate with the vendor to restrict areas of operations for public/resource protection.

Appendix B: National Weather Service Public Information Statements

The subsections of this appendix contain formal public information statements released by NWS WFOs in Charleston, SC, and Blacksburg, VA, following tornadic events. In both instances, the UAS data provided additional information, such as the type and extent of the damage, not captured during the associated ground-based survey.

B.1 NWS Charleston, SC, Public Information Statement: 24 December 2015

128
NOUS42 KCHS 241846
PNSCHS GAZ087-088-099>101-114>119-137>141-SCZ040-042>045-047>052-250700-

PUBLIC INFORMATION STATEMENT
NATIONAL WEATHER SERVICE CHARLESTON SC
146 PM EST THU DEC 24 2015

...EF-0 TORNADO CONFIRMED IN BERKELEY COUNTY SOUTH CAROLINA...

LOCATION...CAROLINA NURSERIES IN BERKELEY COUNTY SOUTH CAROLINA
ESTIMATED TIME...DECEMBER 23 2015 AT 327 AM EST
MAXIMUM EF-SCALE RATING...EF-0
ESTIMATED MAXIMUM WIND SPEED...AROUND 70 MPH
MAXIMUM PATH WIDTH...100 YARDS
PATH LENGTH...0.20 MILES

THE NATIONAL WEATHER SERVICE OFFICE IN CHARLESTON SC EXAMINED PHOTOGRAPHS PROVIDED BY BERKELEY COUNTY EMERGENCY MANAGEMENT AND AERIAL DRONE FOOTAGE PROVIDED BY SKYVIEW AERIAL SOLUTIONS LLC AND DETERMINED THAT AN EF-0 TORNADO OCCURRED FOR ABOUT ONE MINUTE AT CAROLINA NURSERIES...ABOUT 3 MILES SOUTH SOUTHWEST OF MONCKS CORNER IN BERKELEY COUNTY SOUTH CAROLINA. THE TORNADO INITIALLY FORMED AT OR NEAR EMERALD ISLE DRIVE. STRAIGHT-LINE WIND DAMAGE JUST SOUTH OF THIS ROAD INCLUDED NUMEROUS WOODEN PALLETS WHICH WERE TOSSED TOWARD THE NORTHEAST. JUST NORTH OF EMERALD ISLE DRIVE A TELEPHONE POLE WAS BLOWN OVER...AND A TWO BY SIX PIECE OF WOOD PIERCED THE EAST SIDE OF A BUILDING. ROOFING MATERIAL WAS ALSO MISSING FROM A BUILDING SITUATED JUST TO THE NORTH. EMERGENCY MANAGEMENT PERSONNEL ALSO INDICATED THAT A 200 SQUARE FOOT SHED WAS DESTROYED...AND THE ROOF OF THE SHED WAS FOUND 300 FEET FROM THE ORIGINAL LOCATION. MULTIPLE CARTS ESTIMATED AT 150 POUNDS EACH WERE ALSO FOUND TOSSED AWAY FROM THE SHED SIGHT. FARTHER NORTH- NORTHEAST ALONG THE TORNADO PATH...VEGETATION REVEALED A SWIRLING...CONVERGENT DAMAGE SIGNATURE PRODUCED BY THE WEAK TORNADIC CIRCULATION.

$$
ROWLEY

B.2 NWS Blacksburg, VA, Public Information Statement: 26 February 2016

783
NOUS41 KRNK 262106
PNSRNK
NCZ001>006-018>020-VAZ007-009>020-022>024-032>035-043>047-058-059-
WVZ042>044-507-508-270115-

PUBLIC INFORMATION STATEMENT
NATIONAL WEATHER SERVICE BLACKSBURG VA
406 PM EST FRI FEB 26 2016

...TORNADO CONFIRMED NEAR EVERGREEN IN APPOMATTOX COUNTY VIRGINIA...

LOCATION...FROM EXTREME NORTHEAST CAMPBELL COUNTY THROUGH EVERGREEN INTO FAR NORTHEAST APPOMATTOX COUNTY IN VIRGINIA
DATE...02/24/2016
ESTIMATED TIME...3:27PM EST TO 3:44PM EST
MAXIMUM EF-SCALE RATING...EF-3
ESTIMATED MAXIMUM WIND SPEED...140 TO 145 MPH
MAXIMUM PATH WIDTH...400 YD (PRELIMINARY)
PATH LENGTH...17 MILES (PRELIMINARY)
BEGINNING LAT/LON...37.229, -78.864
ENDING LAT/LON...37.403, -78.648
* FATALITIES...1
* INJURIES...7

* THE INFORMATION IN THIS STATEMENT IS PRELIMINARY AND SUBJECT TO CHANGE PENDING FINAL REVIEW OF THE EVENT(S) AND PUBLICATION IN NWS STORM DATA.

...SUMMARY...
THE NATIONAL WEATHER SERVICE IN BLACKSBURG VA HAS CONFIRMED A TORNADO FROM EXTREME NORTHEAST CAMPBELL COUNTY THROUGH EVERGREEN IN APPOMATTOX COUNTY INTO FAR NORTHEAST APPOMATTOX COUNTY IN VIRGINIA ON 02/24/2016.

A TORNADO TOUCHED DOWN JUST INSIDE THE CAMPBELL AND APPOMATTOX COUNTY LINE JUST SOUTH OF COUNTY LINE ROAD. THIS TORNADO CONTINUED TO TRACK NORTHEAST PASSING JUST TO THE SOUTHEAST OF THE TOWN OF APPOMATTOX IMPACTING THE COMMUNITY OF EVERGREEN BEFORE ENDING AROUND HOLIDAY LAKE STATE PARK. THIS TORNADO WAS ON THE GROUND FOR 17 MILES WITH A WIDTH OF 400 YARDS...AND DAMAGED OVER 100 HOMES AND STRUCTURES...INCLUDING ONE WELL-BUILT BRICK HOUSE. ONE FATALITY AND SEVEN INJURIES RESULTED FROM THIS TORNADO.

A SPECIAL THANK YOU GOES OUT TO APPOMATTOX EMERGENCY MANAGEMENT, VIRGINIA DEPARTMENT OF EMERGENCY MANAGEMENT, AND THE CENTRAL VIRGINIA ALL-HAZARDS INCIDENT MANAGEMENT TEAM...WHO PROVIDED CRUCIAL SERVICES DURING THIS ASSESSMENT PROCESS.

WE WOULD ALSO LIKE TO THANK AUTONOMOUS FLIGHT TECHNOLOGIES FOR

AERIAL PHOTOS AND VIDEOS.
THIS INFORMATION CAN ALSO BE FOUND ON OUR WEBSITE AT
WEATHER.GOV/RNK.

FOR REFERENCE...THE ENHANCED FUJITA SCALE CLASSIFIES TORNADOES
INTO THE FOLLOWING CATEGORIES:

EF0...WIND SPEEDS 65 TO 85 MPH.
EF1...WIND SPEEDS 86 TO 110 MPH.
EF2...WIND SPEEDS 111 TO 135 MPH.
EF3...WIND SPEEDS 136 TO 165 MPH.
EF4...WIND SPEEDS 166 TO 200 MPH.
EF5...WIND SPEEDS GREATER THAN 200 MPH.

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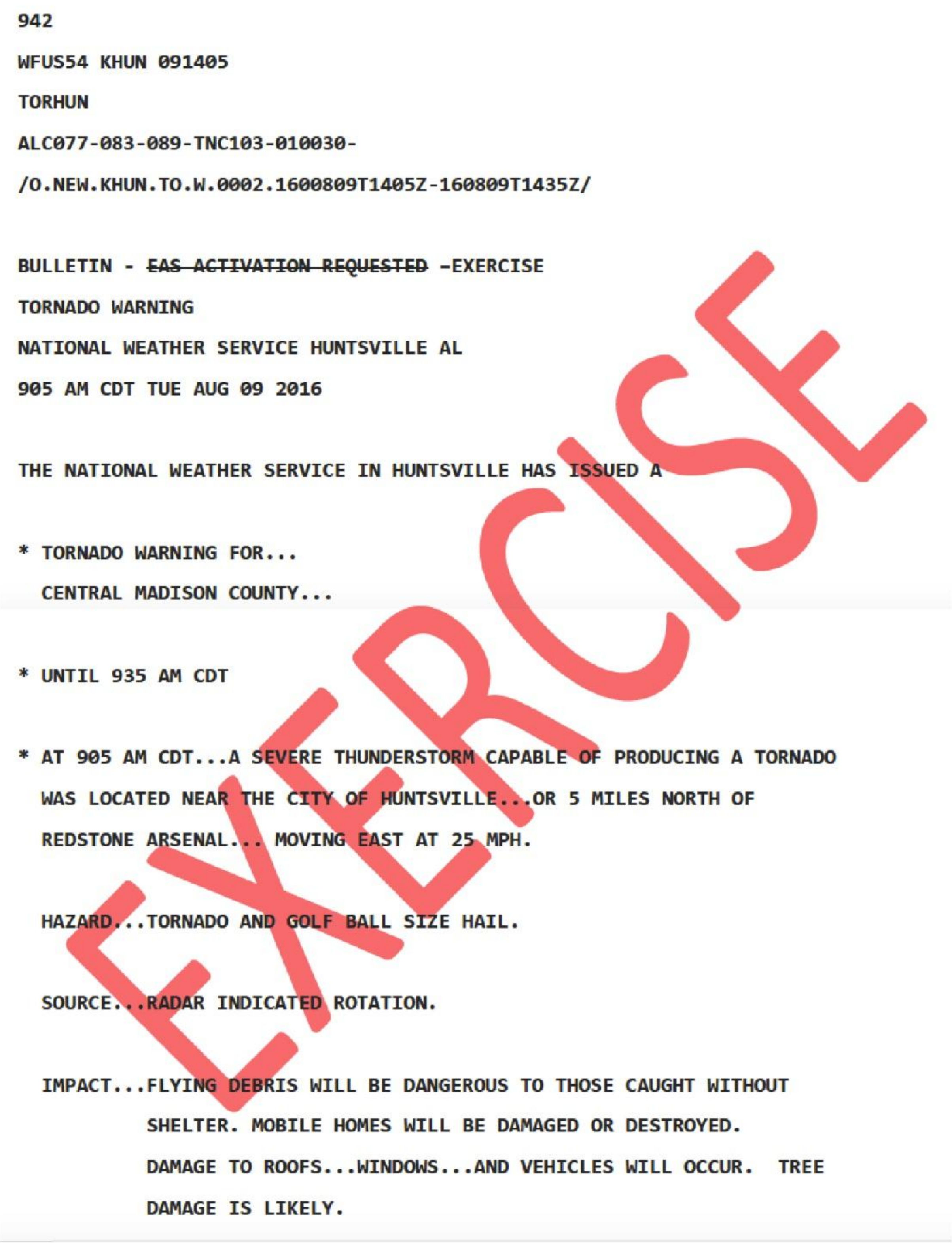
JJM

Appendix C: Fictitious NWS Huntsville Tornado Warning for North Alabama Exercise



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TORHUN

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BULLETIN - ~~EAS ACTIVATION REQUESTED~~ -EXERCISE

TORNADO WARNING

NATIONAL WEATHER SERVICE HUNTSVILLE AL

905 AM CDT TUE AUG 09 2016

THE NATIONAL WEATHER SERVICE IN HUNTSVILLE HAS ISSUED A

* TORNADO WARNING FOR...
  CENTRAL MADISON COUNTY...

* UNTIL 935 AM CDT

* AT 905 AM CDT...A SEVERE THUNDERSTORM CAPABLE OF PRODUCING A TORNADO
  WAS LOCATED NEAR THE CITY OF HUNTSVILLE...OR 5 MILES NORTH OF
  REDSTONE ARSENAL... MOVING EAST AT 25 MPH.

HAZARD...TORNADO AND GOLF BALL SIZE HAIL.

SOURCE...RADAR INDICATED ROTATION.

IMPACT...FLYING DEBRIS WILL BE DANGEROUS TO THOSE CAUGHT WITHOUT
SHELTER. MOBILE HOMES WILL BE DAMAGED OR DESTROYED.
DAMAGE TO ROOFS...WINDOWS...AND VEHICLES WILL OCCUR. TREE
DAMAGE IS LIKELY.

* LOCATIONS IMPACTED INCLUDE...

HUNTSVILLE...CHASE...MERIDIANVILLE...MOORES MILL...BROWNSBORO... AND NEW MARKET.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

TAKE COVER NOW! MOVE TO A BASEMENT OR AN INTERIOR ROOM ON THE LOWEST FLOOR OF A STURDY BUILDING. AVOID WINDOWS. IF YOU ARE OUTDOORS...IN A MOBILE HOME...OR IN A VEHICLE...MOVE TO THE CLOSEST SUBSTANTIAL SHELTER AND PROTECT YOURSELF FROM FLYING DEBRIS.

&&

LAT...LON 3511 8666 3485 8667 3494 8735 3500 8735
      3499 8684 3510 8683
TIME...MOT...LOC 1405Z 271DEG 22KT 3499 8699

TORNADO...RADAR INDICATED
HAIL...1.75IN

Appendix D: Abbreviations

AFT	Autonomous Flight Technologies, Inc.
COCO	Contractor Owned Contractor Operated
CONOPS	Concept of Operations
CWA	County Warning Areas
DAT	Damage Assessment Toolkit
DOI	U.S. Department of the Interior
DSM	Digital Surface Model
EMA	Emergency Management Agency
FAA	Federal Aviation Administration
FMV	Full Motion Video
GBNERR	Grand Bay National Estuarine Research Reserve
GIS	Geographic Information System
GOGO	Government Owned Government Operated
GSD	Ground Sampling Distance
NAS	National Air Space
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NGI	Northern Gulf Institute
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OSH	OpenSensorHub
PDA	Post-Hazard Damage Assessment
SAR	Search and Rescue
SFM	Structure from Motion
SPoRT	Short-term Prediction Research and Transition Center
UAH	University of Alabama in Huntsville
UAS	Unmanned Aircraft Systems
UASPO	Unmanned Aircraft Systems Program Office
WFO	Weather Forecast Offices
WRN	Weather Ready Nation