Unpiloted Aerial Systems (UASs) Application for Tornado Damage Surveys

Benefits and Procedures

MELISSA WAGNER, ROBERT K. DOE, AARON JOHNSON, ZHIANG CHEN,
JNANESHWAR DAS, AND RANDALL S. CERVENY

One of the most exciting frontiers in meteorology in recent years has been the exploratory use of drones, or more accurately, unpiloted aerial systems (UASs), in meteorological measurement and assessment. In particular, UASs can provide a unique advantage in improving the assessment of tornado intensity and path characteristics. Current storm damage assessments (i.e., ground-truth surveys or satellite imagery analyses) are restricted by available resources, accessibility to damage site, technological limitations, and damage indicators (Doswell et al. 2009; Womble et al. 2018). UAS-led storm damage surveys could improve tornado damage assessments by providing more detailed information, which would also better distinguish between tornadic and straight-line winds. This detailed information coupled with 3D-modeling capabilities of UASs could also lead to better insight into high-wind flow interactions with land cover and topography. In this article, we discuss the benefits, limitations, and procedures of UAS-led tornado damage surveys, which could augment NOAA NWS damage surveys or be used for forensic investigations or learned insight.

We have found via our project Severe Convective Storm Observations Utilizing Unpiloted Aerial Systems-based Technologies (SCOUT) that UAS technologies can allow meteorologists to 1) gain access to impassable or remote locations, 2) identify damage not observable by ground or resolvable in satellite imagery, 3) cover large surface areas at high spatial and temporal resolutions, and 4) assist with more detailed site investigations. UASs can be deployed almost immediately after a tornado event, can better capture critical damage evidence (see Womble et al. 2018), and are less likely to be affected by atmospheric contaminants (e.g., clouds, haze) due to low-altitude collection [less than 400 ft (122 m) above ground level (AGL)]. Their low-flying height coupled with technological advancements of UASs provide affordable hyperspatial damage information that can be used to better discern damage and estimate EF scale rating that either would have been difficult to identify or misclassified through traditional ground surveys or satellite analysis. For example, results from our field research show what initially appeared to be denuding north of the reservoir in satellite imagery (Fig. 1a) was actually wind-strewn hay captured in UAS imagery (Figs. 1b,c). Other findings show the capabilities of UAS technologies to differentiate high-wind impacts (e.g., erosion, scour, soil deposition, and topographic interactions) based on land-cover characteristics (e.g., Fig. 2).

UAS-based storm damage assessments using visible and multispectral imagery could better capture the extent and variability of damage, especially in rural locations. Storm damage in rural locations is often underestimated due to 1) underreporting (uninhabited areas) (Alexander and Wurman 2008), 2) limited damage indicators for vegetation, and 3) ability to detect and rate vegetation stress (Skow and Cogil 2017). UAS-based multispectral analysis may

AFFILIATIONS: WAGNER AND CERVENY—School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, Arizona; DOE—School of Environmental Sciences, University of Liverpool, Liverpool, United Kingdom; JOHNSON—NWSFO Dodge City, Dodge City, Kansas; CHEN AND DAS—School of Earth and Space Exploration, Arizona State University, Tempe, Arizona
CORRESPONDING AUTHOR: Melissa Wagner, mawagner@asu.edu

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FIG. 1. Section of tornado damage path from the 30 Apr 2017 Canton, Texas, tornadoes captured by (a) satellite imagery courtesy of RapidEye (5-m resolution) and (b), (c) UAS imagery (1.2-cm spatial resolution).

better detect vegetation damage, especially at the low end of the EF-scale, because of the hyperspatial information collected in red and near-infrared bands. For example, our preliminary results reveal a portion of the damage path detectable only in UAS multispectral imagery, providing damage path information even in areas of low vegetation cover (Fig. 3). Such findings highlight the capability to better detect and rate vegetation stress and could lead to the development of more damage indicators for vegetation impacts. More accurate damage assessments and loss analyses would improve hazard sensing and monitoring operations and awareness, especially in remote locations and areas of low population density.

UAS-based structure-from-motion (SfM) and other 3D products could provide a better understanding of high wind damage and interactions with land cover. SfM provides a 3D perspective by overlapping photographs obtained from multiple

FIG. 2. Microtopographical influences on high-wind impacts. A visible break in the 1 May 2018 Tescott, Kansas, tornado track as tornado winds interact with a sunken gully: limited erosion and scour inside the gully vs increased intensity scour with gain in elevation.

viewpoints, and is a cost-effective alternative to lidar, which is used to produce 3D topographical maps of the Earth's surface (Johnson et al. 2014). Tornado damage assessments are taking advantage

FIG. 3. Section of tornado damage path from the 12 Jun 2017 Carpenter, Wyoming, tornado captured in (a) UAS visible imagery, and UAS Normalized Difference Index (b) overview and (c) zoomed view of tornado damage in lower left corner. Analysis shows lower NDVI values for damaged vegetation and range of vegetation stress [dead, damaged (stressed), healthy].

of this technology since UAS-based products provide better views of structural and vegetative damage than previous aerial methods. For example, analysis of hyperspatial imagery could lead to a better understanding of structural damage and/or failure due to high winds (see Womble et al. 2016, 2017; Mohammadi et al. 2017). Other 3D products like Digital Surface Models (DSMs) can be used to better understand the influence of topography on tornado winds and inferred damage intensity (e.g., Fig. 4) (see Doe and Wagner 2019). Additionally, machine learning, an application of artificial intelligence (AI), automates damage estimation and could improve damage detection by identifying more storm damage than current methods, and at the microscale.

Navigating data collection of UAS tornado damage investigations and policy in the United States can be challenging to those unfamiliar with Federal Aviation Administration (FAA) regulations and poststorm environments. UAS-based tornado damage surveys require preflight planning, flight operations (data acquisition), and data processing and sharing. Preflight planning necessitates understanding site characteristics of the region being surveyed, operating within specified FAA UAS

regulated airspace (i.e., airspace restrictions over military bases, airports, national parks, and other locations), assembling the proper personnel and equipment, and obtaining permissions from any citizens within the area surveyed. UAS operations must be overseen by a certified remote pilot who has obtained FAA Part 107 certification (FAA 2016) and follow FAA guidelines (see FAA 2018) and any agency specific policies [e.g., NOAA aircraft policy and requirements (see OMAO 2016)].

In addition to preflight necessities, many aspects of UAS operations, including flight operations and data processing, have been learned from three years of field work. Specifically, flight operations can be conducted and automated using a variety of flights apps (e.g., Pix4D, DroneDeploy) and should be cognizant of lighting conditions to minimize data loss due to shadows. Because flight operations are often limited to a battery life of 30 min or less (fixed-wing UASs excluded), it is important to have several batteries and a charging platform on-site. In the case of 3D mapping, photograph overlap (front and side) should be set to a minimum of 70% to achieve parallax needed for 3D modeling and producing orthomosaics. After flight operations, data can be processed using a variety of software from low-cost and automated platforms (e.g.,

Fig. 4. (a) DSM showing three areas of distinct elevation (shaded blue to green) and eroded surface roughness from the 1 May 2018 Tescott, Kansas, tornado track. Smoother surface within the red lines captures the tornado track scour in the short prairie grasses. (b) Progressive width increase with elevation gain of approximately 74 ft (22.5 m) captured in UAS imagery (2.5-cm spatial resolution), suggesting an increase in wind intensity with increasing elevation.

MapsMadeEasy) to higher-cost and user-controlled packages (e.g., AgiSoft, Pix4D). Processed data should ideally be shared with the appropriate agencies and in data formats tailored to their specific needs and infrastructure.

Specific lessons we have learned with regard to UAS flight operations in tornado damage assessments include 1) engaging stakeholders before and after the assessment, 2) obtaining flight permissions in highly sensitive areas, and 3) constructing accessible data-sharing platforms. Disaster zones are highly sensitive and stressful spaces where emergency managers and local law enforcement are often overloaded with incoming information while executing their operations. Therefore, coordinating with emergency managers, NOAA personnel, and other agencies is key to (a) assisting these organizations with regard to their specific needs, (b) gaining access in these sensitive areas, and (c) staying up to date on airspace restrictions and other emergency management operations. In the United States, UASs can be deployed with the proper authorization (airspace and emergency

management regulations) and without obtaining permission from property owners. However, we strongly recommend obtaining permissions from property owners, especially in rural communities to address privacy issues, establish trust, and ensure operations are not impeded. Policies outside the United States can be very restrictive, making it extremely difficult to operate in some countries (as seen in Europe). Therefore, organizations outside of the United States (e.g., TORRO) would need to consult their specific laws. Finally, data-sharing and decision-support platforms should be easily accessible and capable of handling large volumes of data, and ideally would include a collaborative mapping platform for visualizing and sharing large datasets with multiple agencies to facilitate better decision-making.

UAS technologies have the potential to be critical tools in the detection and analysis of tornado and other weather-related damage as demonstrated by recent studies [i.e., engineering analysis (Womble et al. 2016, 2017; Mohammadi et al. 2017), high-wind damage surveys (Walker et al. 2017; Skow and Cogil 2017)]. We foresee two contributions: specialized sensor suites on UAS platforms and state-of-the-art algorithms for optimal data acquisition and analysis of damage information (e.g., deep neural networks, segmentation, object detection training). State-of-the-art algorithms will improve damage detection by enabling precise automated detection of complex morphological features and estimation of optimal probabilistic maps (or semantic maps) of properties of interest such as damage to structures or vegetation. We believe that UASs will ultimately improve damage detection in rural locations (e.g., portions of the Great Plains), which have experienced well-documented reporting biases due to low population density, relatively inaccessible regions, and limited damage indicators for vegetation (Snyder and Bluestein 2014). This improvement will be fostered, in part, by UAS-based multispectral analyses, which have the potential to better detect damage to vegetation and could lead to the development of damage indicators for vegetation that are more reflective of tornado strength.

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