# DISASTERS, DRONES, AND CROWD-SOURCED DAMAGE ASSESSMENT

Karl Kim, Pradip Pant, Eric Yamashita

## Abstract

The 2014 Pacific hurricane season was the fourth most active on record. Iselle was the strongest storm to make landfall in the County of Hawaii. It originated in the Eastern Pacific, intensifying to a Category 4 storm with maximum sustained winds of 140 mph as it approached the Hawaiian archipelago. Downgraded to a tropical storm, it made landfall at 2:30 AM on Friday, August 8, 2014. Sustained winds were as high as 51 miles per hour (Lanai City Airport), with peak gusts of 73 miles per hour (Oahu Forest National Wildlife Refuge). Peak gusts in Pahoa on Hawaii island were 70 to 75 mph. Thousands of trees were uprooted or broken, many homes were damaged by wind and storm surge and widespread power outages occurred. In addition to downed powerlines, there were many blocked roads as well as debris from flooding and high winds. The storm surge was greatest in the Kapoho area.

In this paper, we demonstrate the use of expert systems and advanced technologies for assessing damage caused by Tropical Storm Iselle. Data were collected by the State of Hawaii and the National Guard using a system known as Mobile Emergency Response and Command Interface (MERCI). MERCI was developed to collect multiple types of data for preliminary damage assessments. The system is deployed in the field and users upload data to a secure server to be analyzed in real-time at an emergency operations center. Cameras and sensors mounted on Unmanned Aircraft Systems (UAS), also referred to as "drones," provided additional data on damage due to high winds and flooding. After identifying technologies and issues associated with the use of UAS in disasters, the integration of imaging, mapping and damage assessment tools is described. The data are invaluable for rescue, response, and recovery operations. Integration with other software tools such as HAZUS-MH, geographic information systems (GIS) tools, and community based and crowd-sourced information provides new opportunities for using computerized tools for disaster risk reduction.

Computational models, expert systems and imagery and data on damaged structures as well as community based mapping exercises can provide critical information on the location and intensity of storm and other damage. In addition, through the deployment of Internet based assessment tools, residents and others can also upload vital information about damage before officials and others can arrive on scene. Notably, while it took weeks to restore power services, cellular phone and Internet services experienced only minimal disruption. The key challenge involves the integration of diverse hardware, software, and systems for quickly processing, interpreting, managing, and using data for damage assessment and decision-making. In addition to the improvement of expert systems and technical support of field-based operations, the next frontier involves better integration of decentralized, crowdsourced data collection using not just smart phones and digital cameras, but also drones and other devices for capturing different data on disasters. The technologies are useful for not just search and rescue, but also for prioritizing the deployment of emergency resources and longer term restoration and recovery of communities.

Karl Kim, Ph.D., Professor (Corresponding Author) • Pradip Pant, Ph.D
Department of Urban and Regional Planning, University of Hawaii at Manoa,
Email: karlk@hawaii.edu, pradip@hawaii.edu
Eric Yamashita
National Disaster Preparedness Training Center, Honolulu, Hawaii Email: ericyama@hawaii.edu

## INTRODUCTION

Hawaii is one of the most remote places in the world. It is also vulnerable to many different hazards and threats. In addition to volcanoes, earthquakes, tsunamis, coastal storms, sea level rise and climate change, Hawaii's isolation from other communities creates challenges for emergency management. Unlike states connected by highways and rail lines, Hawaii needs to build self-sustaining systems for effective response, relief, and recovery from natural, technological, and cascading events.

In this paper, we discuss expert systems and tools used for disaster preparedness and response and recovery operations. The research is based on ongoing development of applications for building resilient communities as part of the National Disaster Preparedness Training Center (NDPTC), funded by the Department of Homeland Security and the Federal Emergency Management Agency. While this paper reports on the efforts related to Tropical Storm Iselle in Hawaii, the findings are relevant to other jurisdictions and other threats and hazards. Among these tools are: HAZUS-MH, for estimation of wind damage by the storm; Mobile Emergency Response and Command Interface (MERCI), a system for collecting damage assessment data; and Unmanned Aircraft Systems (UAS) used to collect site specific information to improve situational awareness and gather timely, site specific information about damage levels. Data from crowd-sourced mapping and community meetings following the storm are also included in this analysis. Different expert systems and databases at different stages before, during, and after disaster events are evaluated and compared. In addition to combining information collected over different time periods, the approach enables us to evaluate information needs and to support planning and decision-making at key stages of an emergency.

The HAZUS-MH estimations of wind speeds, track, and other impacts of Hurricane Iselle provide early information regarding potential damages from the storm. The MERCI system was used by the National Guard and others to collect data immediately after the storm. A version of the software was also distributed to the public so that residents could also upload data on storm impacts and damages. Initial maps and analyses were presented to community members for updates and refinements.

## ISELLE STORM TRACK AND INTENSITY

The 2014 Pacific hurricane season was the fourth most active on record. While hurricanes Julio and Ana also both approached the Hawaiian Islands and caused little damage, Iselle resulted in widespread damage in Hawaii County. By the time Iselle made landfall as a tropical storm, it was the strongest storm on record in Hawaii County.

Table 1, “Characteristic of Hurricane Iselle,” shows the formation of Hurricane Iselle. At the end of July 2014, a low-pressure system off the coast of southwestern Mexico emerged and gathered strength and became a Category 1 hurricane on August 2, 2014. Hurricane Iselle intensified with maximum sustained winds of 120 kts (140 mph) and was classified as a Category storm on August 4 (Kimberlain, 2014).

Table 1 Characteristic of Hurricane Iselle

| Date/Time (UTC) | Latitude (°N) | Longitude (°W) | Pressure (mb) | Wind Speed (kt) | Tropical Cyclone Stage | Remarks |
|---|---|---|---|---|---|---|
| 30 / 1200 | 11.3 | 117.9 | 1010 | 20 | Low | |
| 31 / 1200 | 12.4 | 121.8 | 1007 | 30 | Tropical Depression | |
| 31 / 1800 | 12.8 | 122.5 | 1005 | 40 | Tropical Storm | |
| 02 / 0000 | 14.6 | 126.9 | 991 | 65 | Hurricane Cat 1 | |
| 02 / 1800 | 15 | 129.6 | 975 | 85 | Hurricane Cat 2 | |
| 03 / 1200 | 15.4 | 132.3 | 965 | 100 | Hurricane Cat 3 | |
| 04 / 1200 | 16.1 | 136.1 | 952 | 115 | Hurricane Cat 4 | |
| 04/ 1800 | 16.1 | 137.7 | 947 | 120 | Hurricane Cat 4 | Max Wind |
| 05 / 0600 | 15.9 | 138.3 | 955 | 110 | Hurricane Cat 3 | |
| 05 / 1800 | 16.2 | 139.9 | 967 | 95 | Hurricane Cat 2 | |
| 06 / 1200 | 16.9 | 143.9 | 985 | 75 | Hurricane Cat 1 | |
| 08 / 0600 | 18.9 | 154.4 | 995 | 60 | Tropical Storm | |
| 08/1200 | 19.2 | 155.4 | 1003 | 45 | Tropical Storm | Landfall |
| 08/1800 | 19.4 | 157.3 | 1009 | 45 | Tropical Storm | |
| 09 / 0600 | 20.2 | 160.2 | 1010 | 30 | Tropical Depression | |
| 09 / 1200 | | | | | dissipated | |

The hurricane lost strength as it approached Hawaii island. Downgraded to a tropical storm, Iselle made landfall at 2:30 AM on Friday, August 8, 2014. Sustained winds were as high as 51 miles per hour (Lanai City Airport), with peak gusts of 73 miles per hour (Oahu Forest National Wildlife Refuge). Peak gusts in Pahoa on Hawaii Island were 70 to 75 mph. Thousands of trees were uprooted or broken, many homes were damaged by wind and storm surge and widespread power outages occurred. In addition to downed powerlines, there were many blocked roads and debris from flooding and high winds. The storm surge was greatest in the Kapoho area.

Three points are contained in Table 1. First, at times the storm was very strong; second, the resulting impact could have been much worse; and third, the conditions changed over just a few days. Such a dynamic situation requires real time updates.

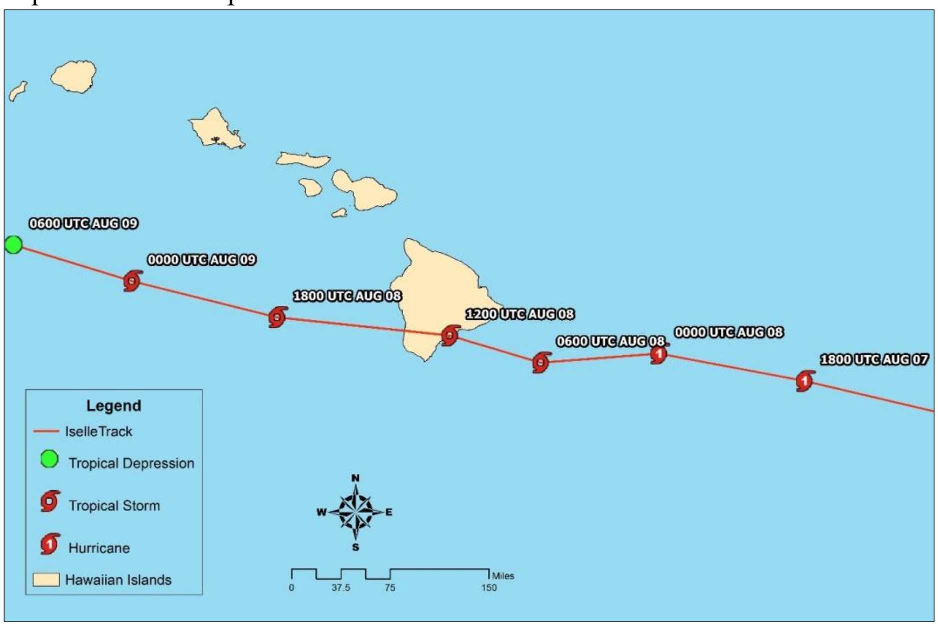



Figure 1 Hurricane Iselle Track

Hurricane Iselle shifted slightly south as it approached Hawaii and the landfall was east of Pahala on the Kau Coast. Figure 1, "Hurricane Iselle Track," shows the track of the storm and shows its dissipation from hurricane strength to tropical depression as it traveled across Hawaii. The right side of the storm typically has the strongest winds in a hurricane. The communities of Pahoa, Kapaho and lower Puna areas experienced the heaviest winds and greatest damage to homes, powerlines, and agricultural activities.

HAZUS-MH HURRICANE MODEL ESTIMATES\

HAZUS-MH was developed by the Federal Emergency Management Agency (FEMA) to estimate losses from earthquakes, floods and hurricanes. (FEMA, 2015). For this paper, HAZUS-MH runs were done using the storm track data. Figure 2, "Wind Peak Gust Predicted by HAZUS-MH," shows modeled peak gust speeds.

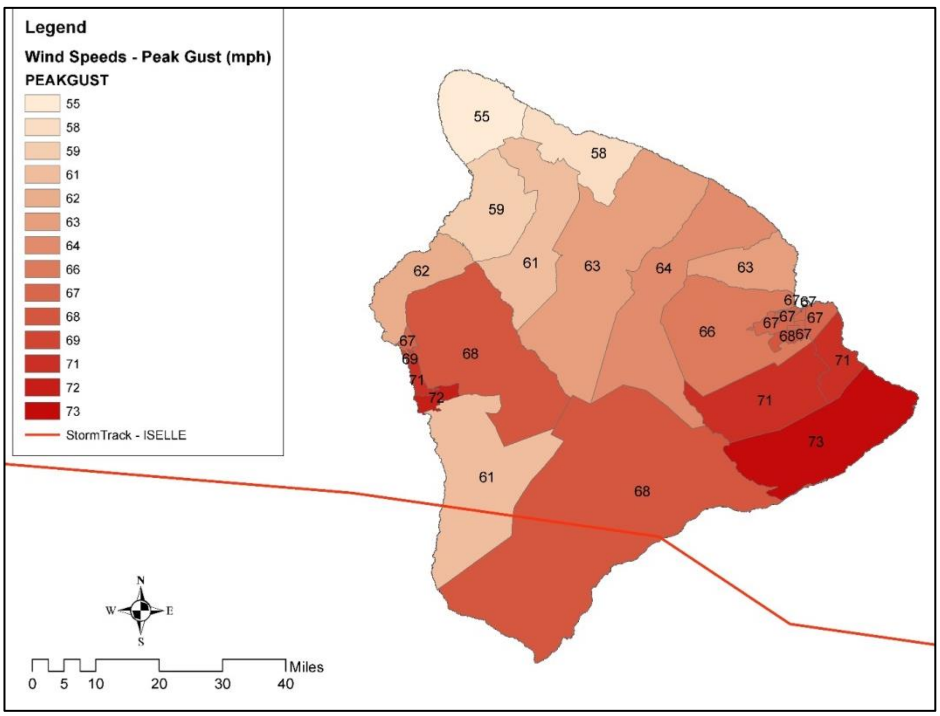



Figure 2 Wind Peak Gust Predicted by HAZUS-MH

HAZUS also provides a function for estimating the debris generated by the hurricane. The model estimated a total of 202,678 tons of debris would be generated. Of this, 192,710 tons (95%) was predicted to be tree debris. Of the remaining 9,968 tons, brick/wood comprised 3% of the total with the remainder being other types of debris. Figure 3, "Tree Debris Predicted by HAZUS-MH," shows the estimated tree debris from the HAZUS-MH model.

HAZUS estimated that 98 buildings would be at least moderately damaged. One building was predicted to be completely destroyed. Table 2, "Expected Building Damage by Building Type," summarizes the predicted damage by building type. The model predicted that 91 buildings would have minor damage. Damage was mostly predicted for wooden building construction

Figure 3 Tree Debris Predicted by HAZUS-MH

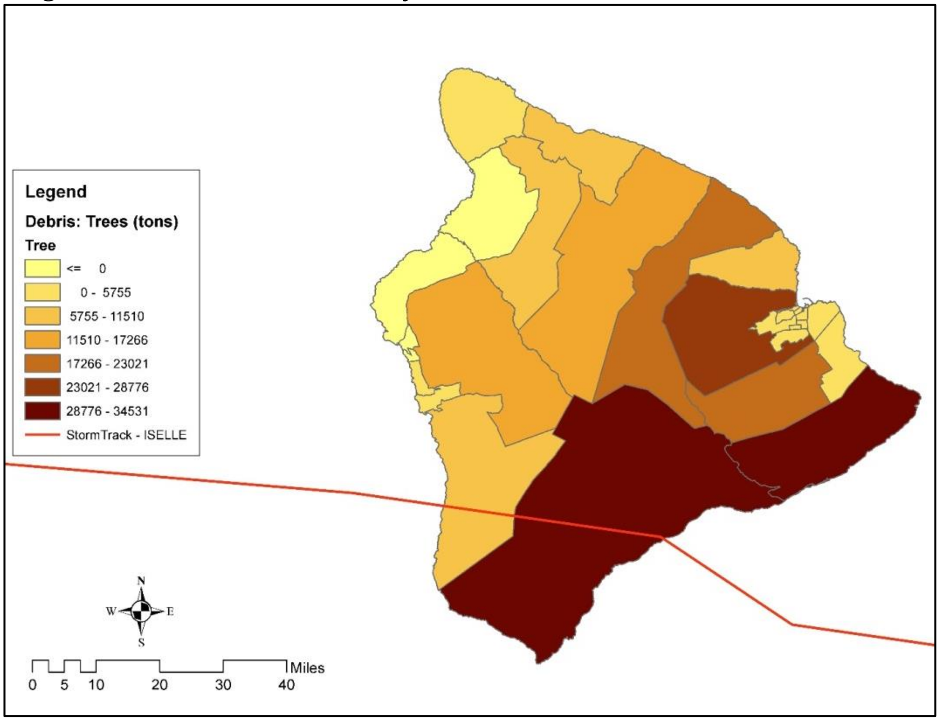



Table 2 Expected Building Damage by Building Type

| Building Type | None | | Minor | | Moderate | | Severe | | Destruction | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Count | (%) | Count | (%) | Count | (%) | Count | (%) | Count | (%) |
| Concrete | 13648 | 99.88 | 16 | 0.12 | 0 | 0 | 0 | 0 | 0 | 0 |
| Masonry | 29009 | 99.92 | 20 | 0.07 | 2 | 0.01 | 0 | 0 | 0 | 0 |
| Mobile Homes | 2614 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Steel | 6403 | 99.89 | 7 | 0.11 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wood | 289142 | 99.95 | 48 | 0.02 | 67 | 0.02 | 28 | 0.01 | 1 | 0 |
| Total | 340816 | | 91 | | 69 | | 28 | | 1 | |

HAZUS building losses are classified into direct property damage and business interruption losses. Estimated costs of building repair or replacement of buildings and its contents are provided as direct property damage losses. Losses associated with the inability to operate a business are estimated as business interruption losses which include temporary living expenses for persons displaced from their homes (HAZUS, 2015). The model predicted total property damage losses to be $15 million dollars. The largest losses were sustained by the residential properties which made up over 98% of the total loss. Table 3, “Building Related Economic Loss Estimates,” provides a summary of the losses associated with building damage.

Table 3 Building Related Economic Loss Estimates (in thousands of dollars)

| Description | Residential | Commercial | Industrial | Others | Total |
|---|---|---|---|---|---|
| Property Damage | | | | | |
| Building | 10,312 | 152 | 27 | 42 | 10,533 |
| Content | 4,044 | 5 | 3 | 1 | 4,053 |
| Inventory | 0 | 0 | 1 | 0 | 1 |
| Subtotal | 14,356 | 158 | 31 | 43 | 14,587 |
| Business Interruption Loss | | | | | |
| Income | 0 | 1 | 0 | 0 | 1 |
| Relocation | 210 | 3 | 0 | 0 | 213 |
| Rental | 62 | 0 | 0 | 0 | 62 |
| Wage | 0 | 2 | 0 | 0 | 2 |
| Subtotal | 271 | 5 | 0 | 0 | 277 |
| Total | 14,627 | 163 | 31 | 43 | 14,864 |

Compared to the HAZUS MH predictions, 250 property owners reported damages, with at least 11 houses destroyed, and 28 with major damages. Crop damage, which was not estimated by HAZUS-MH, was reported to be around $66 million. The total public damage including the cost of debris removal was $13.2 million (State of Hawaii, 2014). HAZUS-MH provides three levels of analysis. Level 1, default or "out-of-box" analysis is a basic estimate of earthquake, flood and hurricane wind losses produced by HAZUS using the national databases and expert-based analysis parameters included in the

HAZUS software. Level 2 analysis is the analysis obtained by replacing default data with detailed information on local hazard conditions and more accurate local inventories of buildings, essential facilities and other infrastructure. Level 3 analysis requires expert adjustment of analysis parameters and requires detailed information and high degree of expertise in HAZUS architecture and file structure. The community and crowdsourced data, MERCI and the UAS systems could be used to support a HAZUS-MH level 2 analysis. The community information, data obtained from MERCI can be used to refine hazard conditions predicted by the level 1 analysis. Imagery acquired by a UAS can be used to update building and infrastructure inventory. Additionally, detailed disaster information will be helpful for a level 3 analysis.

## DATA ACQUISITION THROUGH MERCI

Hawaii State Civil Defense, Hawaii County Civil Defense Agency, and the National Guard conducted damage assessments using a system known as Mobile Emergency Response and Command Interface (MERCI). MERCI is a software platform for conducting and managing emergency damage assessments following a disaster. MERCI allows first responders to collect different types of data (text, photo, and video) using smartphones, iPads, and other portable handheld communication devices, and upload the information to a MERCI Server where the data are analyzed in real-time by emergency managers. MERCI includes pre-loaded FEMA damage assessment forms. Users can create customized data collection screens based on specialized requirements with built-in reporting functionality showing real time damage calculations with geotags and time stamps to allow mapping of disaster impacts (Oceanit, 2015). The application can run on offline mode and later upload data to the server when connectivity is re-established.


Figure 4 MERCI (Mobile Emergency Response and Command Interface) Damage Assessment Software

Data were collected immediately following the storm and continued for nearly a month, resulting in 674 incident reports filed through the MERCI system. The area which was most severely affected, shown in Figure 5 included 8 business incident reports, 339 individual incident reports, and 171 infrastructure reports. One of largest problems was the issue regarding downed Albizia trees. These trees blocked access to roads and damaged property (Figure 6).

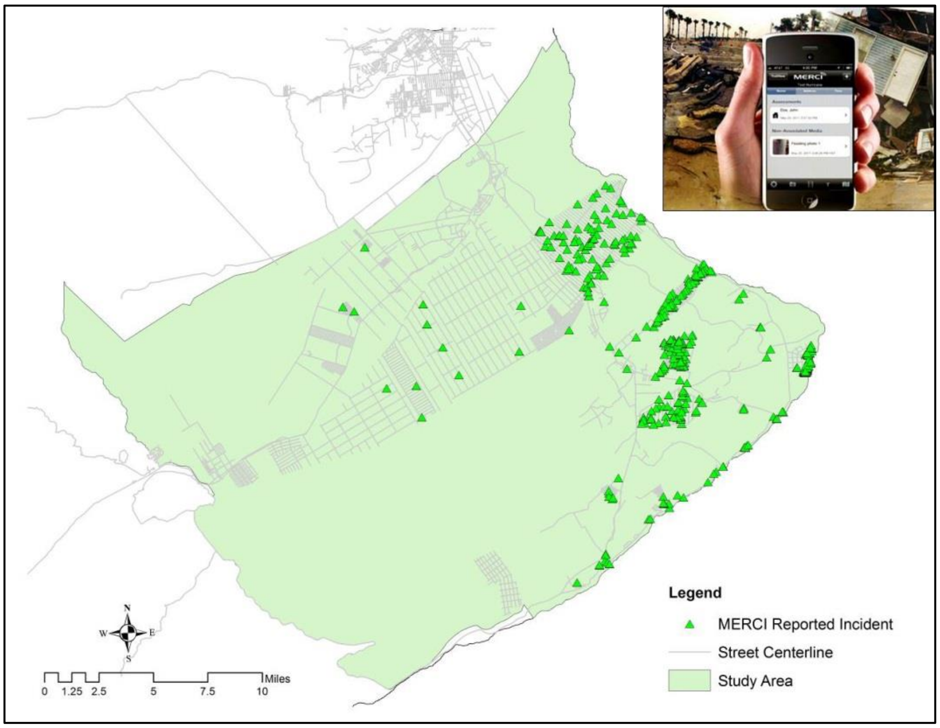



Figure 5 MERCI Reported Damage Locations

Figure 6 Albizia Tree Caused Damage
Source: University of Hawaii Magazine.
https://www.youtube.com/watch?v=nooIpodGdM8&feature=youtube

## DATA ACQUISITION THROUGH UNMANNED AIRCRAFT SYSTEMS

Unmanned aerial systems (UAS) are an emerging technology with the potential to revolutionize disaster management as well as the broader transportation industry (Kim and Davidson, 2015). The smallest UAS are less than one foot long in size and cost under $100 dollars, while military UAS can be over 80 feet long and cost over $100 million dollars. UAS are also called unmanned aerial vehicles (UAV), remotely piloted aircraft (RPA) and “drones”, though the Federal Aviation Administration (FAA) officially uses the term UAS, which includes the unmanned aircraft, control stations, control links, payloads, and other support equipment (FAA, 2013). In 1981, the FAA published Advisory Circular 91-57, Model Aircraft Operating Standards, as guidance for civilians flying model aircraft recreationally, advising that individuals are allowed to operate small UAS (under 55 pounds) for personal use, not for commercial purposes, under 400 feet above ground level, and sufficient distance from populated areas and airports (FAA, 1981). Public entities, such as police departments, fire departments, NOAA (National Oceanic and Atmospheric Administration), Universities, etc., can apply for a Certificate of Waiver or Authorization (COA) to fly a UAS. As of December 2013, there were 545 COAs in the U.S. (FAA, 2014). Other countries have allowed a wider use of UAS. Yamaha Motor Corporation has sold more 2,600 RMAX remotely piloted helicopters for agricultural use in Japan in the past 20 years. The U.S. Congress signed the FAA Modernization and Reform Act of 2012, which “requires the Secretary to develop a plan to accelerate safely the integration by September 30, 2015, of civil unmanned aircraft systems (UAS or drones) into the national airspace system,” and “Requires the FAA Administrator to develop and implement, by December 31, 2015, operational and certification requirements for the operation of public drones in the national airspace (U.S. Congress, 2012).

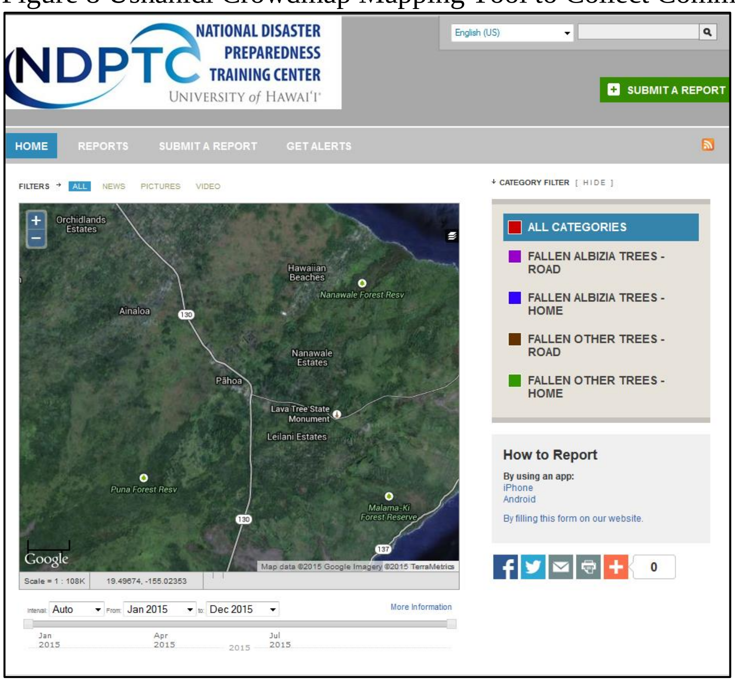
Unmanned Aircraft Systems (UAS) are useful for disaster response, recovery, and mitigation, providing imagery and information on real-time conditions and situational awareness for first responders and emergency managers. UAS can be equipped with sensors to detect body heat, and sound, and can be flown inside or outside damaged buildings to search for trapped people, and can also be used to conduct searches at night, to locate stranded or injured victims. UAS can fly into dangerous, inaccessible locations such as radioactive areas or places contaminated by hazardous materials (Kim and Davidson, 2015). UAS can provide vital information for search and rescue and damage assessment, as well as support rapid damage assessment. UAS can also serve as a planning tool for planners in prioritizing debris removal and ensuring continuity of operations. UAS can provide imagery to assess roads, bridges, railway tracks, airports, and seaports, so damage assessment teams can determine the structural soundness and prioritize repair schedules (Kim and Davidson, 2015). Two different types of unmanned aerial vehicle were used during Iselle: rotorcraft and fixed wing vehicles. The rotorcraft were particularly useful in assessing damaged buildings and also gaining situational awareness as to blocked roadways, downed powerlines. The fixed wing UAVs have been used to collect damage over a wider area and have been deployed in the Philippines following Typhoon Haiyan. Combined with both ground based control systems as well as a range of different sensors, UAS can be used to support risk assessment and hazard mitigation planning (Kim and Davidson, 2015). UAS was used for both situational awareness and to identify and quantify damage when incident locations were not accessible due to fallen trees. The acquired imagery provided information on the extent of the damages and was useful to mobilize a MERCI team. It was also used to survey wind and flooding damage in coastal areas, where roadways were blocked by debris or washed away due to storm surge. The University of Hawaii's National Disaster Preparedness Training Center has received authorization from FEMA to develop new training courses to integrate this emerging technology in mapping, spatial analysis, and disaster risk reduction.


Figure 7 UAV/UAS Systems for Real Time Data Collection of Damage Assessment

## COMMUNITY BASED AND CROWD-SOURCED INFORMATION

Community input was also used to identify damage locations. Maps and initial damage assessments were taken to community meetings and residents were asked to provide further information or correct the initial analyses. Participants in the community mapping exercises were asked to locate six types of damages: (1) damage to home/structure by Albizia trees; (2) damage to homes/structures by other trees; (3) road blocked by fallen Albizia trees; (4) roads blocked by other trees; (5) other wind damages; and, (6) damage due to storm surge or flooding. This provided a valuable source of data as community members were familiar with their neighborhoods and could report more accurately where the damage occurred.  Figure 8, "Ushahidi Crowdsource Mapping Tool to Collect Community Input," displays one of the tools used to capture community input on the location of fallen trees after the storm.

Figure 8 Ushahidi Crowdmap Mapping Tool to Collect Community Input



Ushahidi Crowdmap is a software system developed by Ushahidi, Inc. for information collection, visualization, and interactive mapping. The software uses crowdsourcing to encourage social activism and public accountability, enabling local observers to submit reports with mobile phones or the Internet, while creating a temporal and geospatial database of events, which can be validated, updated, and shared with many different users. Developed in Kenya to map the violence during the 2007-2008 Kenyan Crisis, it is a popular crowd mapping tool used throughout the world during and after disasters.

Large maps were printed and input was obtained during the Puna Regional Emergency Preparedness Fair (August 30, 2014) and seven other community meetings in Puna between September to November, 2014. Table 4, "Community Events" shows the eight community meetings where feedback was gathered. Figure 9, "Attendees Identify Downed Tree Locations at Puna Watch Meeting and the Information Fair," depicts how community members used mapped and identified locations where Albizia trees damaged properties and blocked roadways. The damage data were then digitized and imported into the ArcGIS system to be further analyzed for spatial patterns.

Table 4 Community Events

| **Community Event** | **Date** | **Estimated Attendance** |
|---|---|---|
| Puna Preparedness Fair (booth staffed by NDPTC arranged by Denise Laitinen). | 8.30.14 | 500+ |
| Pahoa Rotary presentation | 9.9.14 | 15 |
| Nanawale Community Association meeting | 9.10.14 | 15 |
| Lava Flow Information Fair | 9.13.14 | 2,000+ |
| UH-Hilo Talk on Albizia trees | 9.17.15 | 50 |
| Puna Watch Community Meeting | 10.2.14 | 13 |
| HPP Neighborhood Watch monthly meeting | 11.1.14 | 40 |
| Hawaii County Dept. of Public Works staff presentation | 11.3.14 | 19 |

Source: Denise Laitnen

Figure 9 Attendees Identify Downed Tree Locations at Puna Watch Meeting and the Information Fair

Source: Denise Laitnen

In addition to the data collected at community meetings, a version of the MERCI tool was distributed to residents to document damages resulting from Iselle. The purpose of this version of the tool was twofold. First, it provided a means of collecting further data from individuals who did not attend or stay at the community meetings. Second, it also served to build the capacity of residents to conduct damage assessments and to learn about the various data elements and fields that FEMA and others involved in analyzing disaster and insurance claims. These data also were uploaded to the MERCI server and integrated into the database.

A total of 549 damage incidents were reported by the community members for the study area. Figure 10, “Community Reported Damage and Populated Land Parcel,” shows locations identified by the community members for different types of damages. The highest number of incidents were road blockage by Albizia tree (242) followed by blockage by other trees (150). Damages on homes/structures by Albizia tree, other trees and water were reported as 51, 46 and 50 respectively. Figure 10 also includes populated land parcels which were identified from the County tax assessment database.

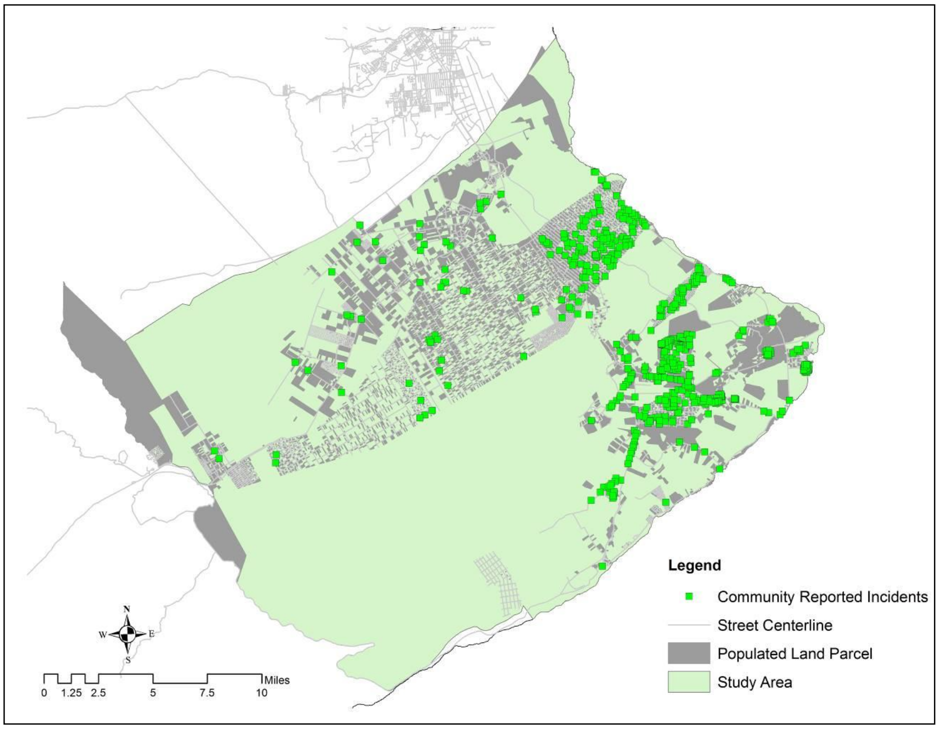



Figure 10 Community Reported Damage and Populated Land Parcel

## SPATIAL ANALYSIS OF MODELED AND REPORTED DAMAGE

In this section, methods were used to better understand the underlying spatial pattern of three datasets: 1) population location; 2) MERCI damage assessment data, and Community/Crowdsourced data.

The CrimeStat IV software program was used to measure the spatial distribution, directionality, and patterning in three datasets. CrimeStat IV has a powerful set of algorithms and methods useful for characterizing and analyzing spatial relationships of point-based data. It has been used for the analysis of crime data, traffic accidents and other point phenomena (Kim and Yamashita, 2007). The software provides a means to analyze locational data, identify hot spots, and generates GIS-based files to be viewed, analyzed, and mapped further using GIS software such as ArcGIS, MapInfo, and other commonly used GIS software.

To measure the trend for a set of points one would calculate the standard distance in both the X and Y directions separately, which will then define the axes of an ellipse that encompasses the distribution of point event features. This ellipse is referred to as the standard deviational ellipse, since it calculates the standard deviation of the X coordinates and Y coordinates from the mean center to define the axes of the ellipse. This ellipse shows that the distribution is elongated and has a particular orientation (Levine, 2015). The standard deviational ellipse is calculated by the following set of equations:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n}}$$

(1)

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{Y})^2}{n}}$$

Where $x_i$ and $y_i$ are the coordinates for feature $i. \{\bar{X}, \bar{Y}\}$ represents the Mean Center for the features, and $n$ is equal to the total number of features. The angle of rotation is calculated using the following set of equations:

$$\tan\theta = \frac{A + B}{C}$$

$$A = \left(\sum_{i=1}^{n} \tilde{x}_i^2 - \sum_{i=1}^{n} \tilde{y}_i^2\right)$$

(2)

$$B = \sqrt{\left(\sum_{i=1}^{n} \tilde{x}_i^2 - \sum_{i=1}^{n} \tilde{y}_i^2\right) + 4\left(\sum_{i=1}^{n} \tilde{x}_i \, \tilde{y}_i\right)^2}$$

$$C = 2\sum_{i=1}^{n} \tilde{x}_i \, \tilde{y}_i$$

where $\tilde{x}_i$ and $\tilde{y}_i$ are the deviations of the $xy$ coordinates from the Mean Center. The standard deviations for the $x$-axis and $y$-axix are:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} (\tilde{x}_i \cos\theta - \tilde{y}_i \sin\theta)^2}{n}}$$

(3)

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n} (\tilde{x}_i \sin\theta - \tilde{y}_i \cos\theta)^2}{n}}$$

Figure 11, “Mean Center and Standard Deviational Ellipse,” shows the distribution and directionality of the three point datasets. Based on Figure 6, there is good spatial agreement between the data collected through the MERCI system and the data collected through community feedback on where the tree debris and other damage were located. The mean center for the population actually captures the location of the more heavily populated areas of the region. Note too, that the dispersion is the greatest, as we would expect for population, as compared to the reports by either the National Guard (MERCI) or residents. The mean centers for both the MERCI and community reports are quite close and the standard deviational ellipses are similar in size and shape. Interestingly, the community reports favor the more populated areas of the region, while the MERCI reports are more concentrated in the less developed areas.

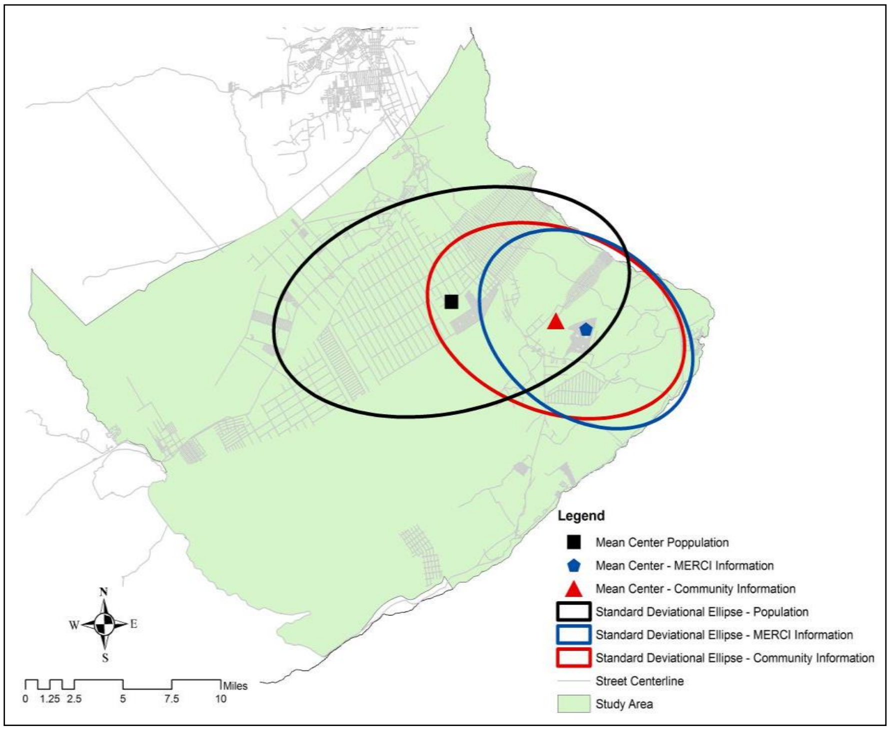



Figure 11 Mean Center and Standard Deviational Ellipse

The K-Means clustering algorithm is a partitioning procedure that groups the data into *K* groups as defined a priori by the user (Fisher, 1958; MacQueen, 1967; Aldenderfer and Blashfield, 1984; Levine, 2015). The routine looks for the best positioning of the K centers and then assigns each point to the center that is nearest. The routine assigns a point to only one cluster, but all points are assigned to a cluster, hence there is no hierarchy to the clusters. The following K-Means clustering is calculated by the following equations:

(4)

$$J = \sum_{j=1}^{K} \sum_{n \in S_j} \left| x_n - \mu_j \right|^2$$

where $x_n$ is a vector representing the $n$th data points and $\mu_j$ is the geometric centroid of the data points in $s_j$. The algorithm does not achieve a global minimum of $J$ over the assignments. Since the algorithm uses discrete assignment rather than a set of continuous parameters, the "minimum" it reaches cannot even be properly called a local minimum. Despite these limitations, the algorithm is used fairly frequently as a result of its ease of implementation. The algorithm consists of a simple re-estimation procedure as follows. Initially, the data points are assigned at random to the $K$ sets. For step 1, the centroid is computed for each set. In step 2, every point is assigned to the cluster whose centroid is closest to that point. These two steps are alternated until a stopping criterion is met, i.e., when there is no further change in the assignment of the data points.

Figure 12, “K-Means Clustering,” shows the clustering pattern for the three datasets. A priori, four clusters were selected as an input value in the CrimeStat IV application software to identify hotspot locations. The K-means clusters show the relative centers for damage and the spatial distribution. Again there are some concurrence of where the hot spots are located between the MERCI and Community datasets.

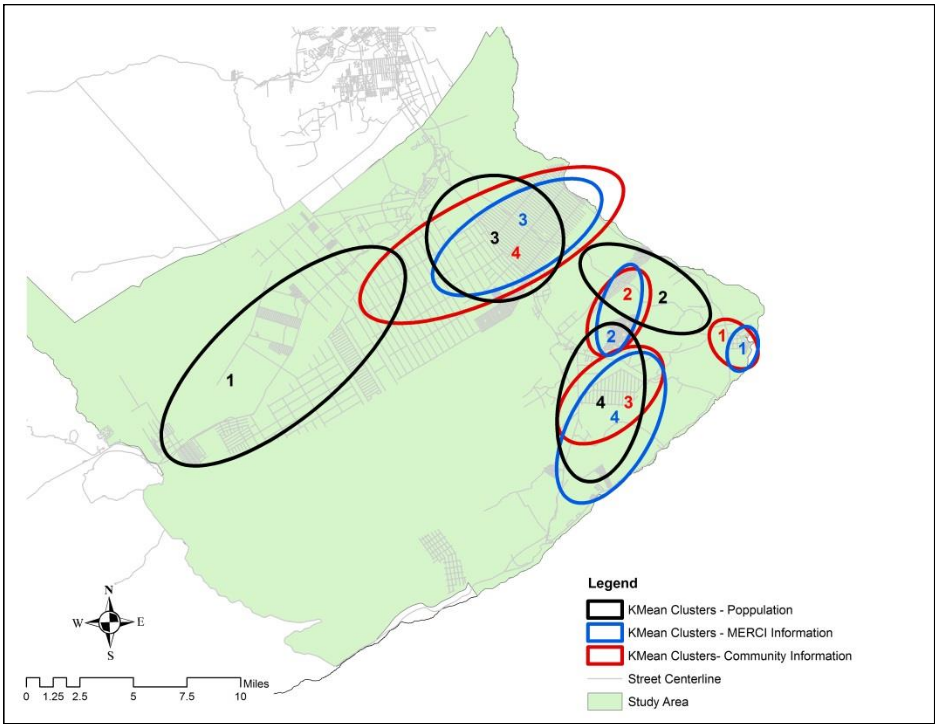



Figure 12 K-Means Clustering

Table 5, “K-Means Clustering Results,” shows the basic data about each cluster. Note, that the shape or size of the cluster does not indicate the number of cases that are included in the cluster. For example, when comparing the results in Figure 9 and Table 5 for the MERCI data, cluster number 2 has the most number of cases, 187, but the size of the cluster (area) is smaller than cluster number 3 and 4. This compactness is more reflective of the density of the cluster of fallen trees. In looking at the directionality of the clusters, this is not only an indication of damage pattern, but also an indication of the storm track and wind direction. Tropical cyclones have a counter-clockwise rotation in the northern hemisphere and with Tropical Storm Iselle it tracked on southern end of Hawaii Island (see Figure 1, 2, and 3).

Table 5 K-Means Clustering Results

| CLUSTER | MEAN_X | MEAN_Y | ROTATION | X_AXIS | Y_AXIS | AREA | SUMOFSQR | MEANSQRERR | POINTS |
|---|---|---|---|---|---|---|---|---|---|
| Population | | | | | | | | | |
| 1 | 904125.185163 | 2160000.764279 | 49.227558 | 2.843228 | 7.116872 | 63.569783 | 134529.788921 | 29.354089 | 4583 |
| 2 | 931321.307228 | 2165078.789417 | 27.960212 | 3.341465 | 1.577520 | 16.560054 | 16316.482245 | 6.821272 | 2392 |
| 3 | 920032.930825 | 2168874.770608 | 7.221064 | 3.205324 | 2.936507 | 29.570102 | 80199.600748 | 9.446361 | 8490 |
| 4 | 927991.543763 | 2156518.808308 | 10.973201 | 1.960752 | 3.748950 | 23.093103 | 22660.357781 | 8.942525 | 2534 |
| MERCI | | | | | | | | | |
| 1 | 938642.120402 | 2160560.446250 | 16.251111 | 0.695786 | 1.069603 | 2.338019 | 93.619695 | 0.800168 | 117 |
| 2 | 929376.178277 | 2163489.988001 | 16.465949 | 0.900325 | 2.201205 | 6.226006 | 523.169715 | 2.797699 | 187 |
| 3 | 921692.942318 | 2168965.638169 | 60.323502 | 1.875148 | 4.421374 | 26.046096 | 1257.027546 | 11.324572 | 111 |
| 4 | 928747.819786 | 2154627.886705 | 29.287606 | 1.931191 | 3.893361 | 23.621083 | 953.831672 | 9.260502 | 103 |
| Community Input | | | | | | | | | |
| 1 | 937966.747800 | 2160918.426269 | 46.273177 | 1.329095 | 0.937205 | 3.913275 | 101.826552 | 1.288944 | 79 |
| 2 | 929329.421628 | 2163308.599988 | 27.337897 | 1.216945 | 2.201752 | 8.417620 | 414.527723 | 3.116750 | 133 |
| 3 | 928697.914222 | 2157083.397255 | 49.616570 | 1.651838 | 2.932597 | 15.218431 | 860.980974 | 5.590786 | 154 |
| 4 | 919782.544043 | 2168365.187107 | 64.070484 | 2.406657 | 6.742167 | 50.975745 | 4638.016877 | 25.344355 | 183 |

## DISCUSSION

Effective emergency response and longer term recovery depends on having accurate, timely information. Knowing the concentration of damage as well as the spatial patterns would help in terms of rescue efforts or providing emergency services. First responders and those providing emergency relief services need to know where the population is concentrated and especially where vulnerable, at-risk populations are located. A similar type of analysis was conducted using NHTS data to estimate the populations in the region with medical conditions (Kim et al., 2013; 2015). Examination of extreme cases of flooding and existing shelter provisions highlighted the vulnerability in the community and provided critical information to enhance disaster preparedness (Kim et al., 2014). Knowing the spatial distribution of the population as well as the key concentrations of damage assessments collected from both emergency responders (like the National Guard) as well as from residents can be useful in terms of prioritizing actions and making effective decisions when local resources and capabilities are overwhelmed by a disaster such as Iselle.

Improved local information and mapping of hazards and threats can also build community preparedness before disasters by identifying possible pre-disaster mitigation projects. Not only does it require understanding of risk and vulnerability for different hazard events, pre-disaster actions such as prepositioning of supplies and resources, evacuation of at risk populations to safer areas, and implementing warning systems, exercises, drills, and capacity building can also serve to increase resilience. Tools such as HAZUS-MH are useful to predict wind speed and the anticipated amount of debris and economic loss. While HAZUS provided a reasonable estimates of wind induced economic losses and tree debris, these estimates are rather coarse as the smallest spatial unit reported in HAZUS is the census tract. With seven census tracts, a severely impacted area of more than 500 square miles, the aggregated estimates from HAZUS-MH cannot be used for detailed disaster mitigation planning. Moreover, fallen trees, especially the Albizia trees, were one of the major problems faced during the response and recovery phase which was not anticipated from the HAZUS-MH analysis.

Knowing the underlying population exposure to various hazards and risks is necessary when developing strategies for either strengthening or hardening structures, or protecting buildings and properties from high winds, debris, storm surge, flooding and other threats from hurricanes. Perhaps one of the least appreciated hazards involved fallen trees and vegetative debris. While damage to structures may be recovered through hurricane and flood insurance, and property insurance, it may be more difficult to recover the costs of damaged tree removal, hauling, and disposal.

Computer tools and expert systems such as HAZUS-MH, MERCI and emerging data acquisition platform like UAS are important tools that can be used to strengthen the resilience of communities to disasters. Moreover, the MERCI reported damage and the community damage assessments are reasonably comparable in terms of the mean centers, spatial distribution, directionality, damage concentration and density reporting. The damage clusters also relate with the population and show where the relative damage reports differ from the population clusters, identifying which areas are more heavily damaged. These tools when used synergistically, would allow first responders to prioritize their operation and deliver effective post disaster rescue and relief operations.

The analysis provides several takeaways to planners and policymakers. First, land use planning and management provides a solid base for developing resilient communities. The areas most severely affected by Iselle include the fastest growing subdivisions in the state, and are affected by different hazards. Residents are economically vulnerable compared to the rest of the State. This region is also underserved in terms of critical infrastructure to support emergency response and recovery. Many properties are not connected to the electrical grid. Others may be tied into the electrical network, but they are on catchment water systems. Power outages meant that these homes were not able to pump water. The loss of power also meant the loss of refrigeration creating other problems related to food safety and security. This storm highlighted the need to develop strategies and programs for controlling the invasive Albizia tree which was found to be the single biggest cause of disruption and damages during the storm (Crowley, 2015).

The analysis also shows that there is a need to improve tools and methods for estimating the impacts of hazards. The spatial unit used to estimate of debris, economic losses and impacts in HAZUS-MH model is really too large to be of much use. Adding current information from the MERCI system would help provide needed data at the parcel or even building level. The community information and data obtained from MERCI can be used to refine hazard conditions predicted by the default level 1 analysis. Imagery acquired through UASs can be used to update building and infrastructure inventory such that a level 2 HAZUS analysis can be conducted. Tree debris modeling in HAZUS-MH needs to be more flexible such that local species such as the Albizia tree impact can be more easily modeled. The Albizia tree is a fast growing shallow-rooted tree which quickly reaches large heights and diameters, creating problems for not just responders but residents seeking to clear their roads and properties from debris. There is also a need to develop better ways and models to incorporate community inputs and crowdsourced data to expert damage assessment tool such as MERCI and HAZUS-MH. Some of the provisions that HAZUS-MH allows only at advanced customized level need to be modified to allow for community input and to produce a post-disaster situational reports. This will be a significant addition to the HAZUS-MH capability and will require additional research. More research could and will be conducted on the use of MERCI to assess both externally visible damage as well as damage inside structures. There are some challenges with mapping and capturing data immediately following a storm or other natural disasters and more research is needed on designing and assimilating UAS technologies. It is clear that the technology is outpacing policy as there are questions regarding the legality of drone use during emergencies and for capturing data before, during, and after disasters (See Kim and Davidson, 2015) for more discussion on emerging regulations, policies, and changes related to the UAS industry.

Another major issue involves the evaluation of data quality, accuracy and timeliness. Each of the datasets varies in terms of how information was collected, who collected it, how it was processed and compiled, who distributed the data and how accurate, reliable, and valid the data are. While some of the databases (Census, parcel, tax map key, NHTS, etc.) were collected and managed by government agencies, it may be outdated. While other databases such as those collected by emergency responders (i.e. MERCI data), may be more timely, but there may be issues with training, supervision, and handling of data, especially during emergency situations. While citizens may be most familiar with their communities, there may be other issues or concerns regarding self-reporting and objectivity when reporting damages.

In addition to the questions and uncertainties that exist with regard to data quality, there are also serious and challenging issues about the use and distribution of disaster data. On the one hand, while first responders and those involved in rescue and relief operations may be granted access to personal information about the location of trapped, injured or vulnerable people who need assistance, sharing this information widely may not be acceptable. Concerns about the potential misuse of personal information need to be taken seriously. Questions about who owns the data and how it can be used for planning, mitigation, and research purposes also need to be addressed. These issues become all the more complex when considering the use and posting of information on social media platforms. What is considered public and private information is complicated not just when a hurricane rips open a private dwelling unit, spreading its contents outside, but also when damage or disaster impact data are posted on the Internet. On the one hand, we want timely, accurate information to aid in decision-making for disaster response and recovery. On the other hand, we need to ensure that all the proper safeguards in terms the handling and use of sensitive, confidential, and personal data are in place. It's not just about getting access to the best possible data. It is ensuring that appropriate policies, practices, and protections are in place.

**CONCLUSIONS**

This paper grew out of an interest in combining urban planning tools to assist the information needs of emergency managers and first responders called to serve communities after a disaster strikes. We focused on the use of geospatial tools and models for both assessing the impacts of Hurricane Iselle and comparing the spatial distributions of damage reported by first responders and then residents using a variety of different tools and applications. Some of the tools were used in the field where the data was processed centrally, and sent back to emergency responders and others involved in rescue and relief actions. The data were also used in the preparation of various reports, studies, and requests for disaster declarations and support from insurance companies and the federal and state government. It is clear that in the wake of a disaster, the information needs multiple greatly. There is a need to have current, updated accessible information. It needs to be used for a variety of different purposes. There are both existing databases, such as Census data or survey data such as the National Household Travel Survey as well as state and local sources such as parcel level data or tax assessment records, which can support assessment of risks and vulnerabilities as well as damage estimates. There are also emerging new sources of data, collected on smart phones and on UASs which also need to be integrated into databases and analyses. Information is already shared on Twitter and other social media platforms. These new and emerging tools need to be integrated, tested, and improved for the purposes of supporting decision-making related to disaster response and recovery.

There are three major findings. First, we do need to do a better job of integrating different sources of data at the different stages of disaster response, recovery, and preparedness. There are excellent tools and methods used by planners that can assist emergency response and recovery. Second, new emerging sources of information, whether referring to Google and Google Earth or the many social media platforms, need to be evaluated and integrated into both emergency management and longer term planning efforts related to hazard mitigation and building resilient communities. Third, there is no shortage of research questions. At one level, there are technical concerns as to how we can better utilize these tools to improve existing programs such as HAZUS or other risk management protocols. At another level, it is recognized that new, disruptive technologies such as social media and UASs involve a dramatic reversal of the flow of information. Rather than view government or even first responders as the principal source of data collection, crowd-based sources, armed not just with smartphones and Google Earth imagery, but also their own UAVs and other sensors, may be on the ground first and will potentially stay around the longest before, during, and after disasters occur.

## REFERENCES

Aldenderfer, M. and Blashfield, R. (1984). Cluster Analysis. Sage: Beverly Hills, CA.

Crowley, J. (2015). Albizia Tree Hazard Mitigation Following Tropical Storm Iselle. Presented at the International Conference on Solid Waste Technology and Management. Philadelphia, Pennsylvania, March 17, 2015.

Federal Aviation Administration (FAA). (1981). Model Aircraft Operating Standards. Advisory Circular 91-57.

Federal Aviation Administration (FAA). (2013). Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap. First Edition, p 8.

Federal Aviation Administration (FAA). (2014). Fact Sheet – Unmanned Aircraft Systems. http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=14153. Accessed March 2015.

FEMA. (2015). Hazus. https://www.fema.gov/hazus. Last accessed 3-5-15.

Fisher, W. (1958). On grouping for maximum homogeneity. Journal of the American Statistical Association. 53, 789-798.

Kim, K. and Davidson, D. (2015). Using Unmanned Aircraft for Disaster Management. National Academy of Sciences, 94th Transportation Research Board Annual Meeting, Jan 11-15, 2015, Washington DC.

Kim, K., Pant, P. and Yamashita, E. (2015) Using NHTS to Estimate Transportation Needs of People with Medical Conditions during Disasters in Hawaii."  Presented at the National Academy of Sciences, 94th Transportation Research Board Annual Meeting, Jan 11-15, 2015, Washington DC.

Kim, K., Pant, P., and Yamashita, E. (In Press). Evacuation Planning for Plausible Worst Case Inundation Scenarios in Honolulu, Hawaii. Journal of Emergency Management.

Kim, K., Pant, P. and Yamashita, E. (2013) Using National Household Travel Survey Data for the Assessment of Transportation System Vulnerabilities. Transportation Research Record: Journal of the Transportation Research Board. 2376, 71-80.

Kim, K. and Yamashita, E. (2007). Using a K-Means Clustering Algorithm to Examine Patterns of Pedestrian Involved Crashes in Honolulu, Hawaii. Journal of Advanced Transportation. 41:1, 69-89.

Kimberlain, T. (2014). Hurricane Iselle. http://www.nhc.noaa.gov/data/tcr/EP092014_Iselle.pdf. Last accessed 3-5-15.

Levine, N. (2015). CrimeStat IV: A Spatial Statistics Program for the Analysis of Crime Incident Locations (version 4.02). Ned Levine and Associates, Houston, TX and the National Institute of Justice, Washington, DC.

MacQueen, J. (1967). Some methods for classification and analysis of multivariate observations. 5th Berkeley Symposium on Mathematics, Statistics and Probability. 53, 281-298.

Oceanit. (2015). MERCI. http://merci.oceanit.com. Last accessed 3-5-15.

State of Hawaii. (2014). Request for Presidential Disaster Declaration: Major Disaster or Emergency.

U.S. Congress. (2012). H.R.658 – FAA Modernization and Reform Act of 2012, Subtitle B: Unmanned Aircraft Systems. 112th Congress.