RITARS-12-H-GMU

Using Social Networks and Commercial Remote Sensing to Assess Impacts of Natural Events on Transportation Infrastructure

Final Report

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EXECUTIVE SUMMARY

This project used social networks to task the collection of remote sensing imagery of transportation infrastructure conditions in response to emergencies. Such a capability is especially valuable in situations where environmental hazards and natural disasters such as hurricanes or severe weather affect very large areas. During these types of disasters it is paramount to ‘cue’ remote sensing imagery collection to assess the impact of fast-moving and potentially life threatening events on transportation infrastructure.

Data collected from social networks are diverse, complex, and overwhelming in volume, velocity, and in the variety of viewpoints they offer. Negotiating these overwhelming streams is beyond the capacity of human analysts. In order to efficiently and effectively use social media to ‘cue’ the collection of imagery, it is necessary to filter the data for content and geolocate them using a variety of text-mining and network analysis algorithms. Filtering of social media data yields a rapid and directed identification of affected area(s) which can aid authorities in prioritizing site visits and response initiatives as well as the tasking of additional data collection.

For this project a scanning application was developed to access and harvest social media data by browsing Twitter in real-time. Using the *Carbon Scanner* developed by The Carbon Project, a geosocial media software company and industry partner for this research project, tweets were filtered by keyword and hashtag, allowing the research team to locate road, bridge and natural hazard condition reports. As events progressed, the service ‘scanned’ the United States each hour to assess and generate alerts for areas with significant Twitter activity. These alerts or ‘hot spots’, were areas where natural hazards were potentially occurring, and were identified based on the clustering of filtered and, subsequently, geolocated tweets. When a ‘hot spot’ was identified, remote sensing data were collected and made available as open data services. The application system was highly flexible with filter settings managed by a portal service enabling manager-level users to quickly adjust keyword and other settings as events developed.

The geolocation of filtered tweets is accomplished by pairing geographic names identified in the tweet text to a United States gazetteer. Geographic names collected from the United States Geological Survey (USGS) were downloaded into a single database file - storing the name and the geometry properties of each named location. In cases where there are multiple points, the center point of the extent is utilized as the geometry. The resulting geonames database contains approximately 2.1 million records. The components are capable of running and reading Twitter streams and then matching the identified place names to the geonames database in real-time.

Following the filtering and geolocation of tweets, a potential natural hazard event is recognized when a significant amount of activity is identified in a region. The determination of significant activity in an area, or the threshold, can be adjusted to user requirements or preferences. When the threshold is reached an Alert Box is generated, cueing the collection of imagery for that region. The imagery is deployed in near real-time using open mapping services including Open Geospatial Consortium Web Map Service (OGC WMS), Web Map Tile Services (WMTS), Web Coverage Services (WCS), Google Maps API, Google Earth KML overlays, and Open Source Geospatial Foundation Tile Map Service (OSGeo TMS). Providing the imagery in an open source format ensures rapid deployment as well as open access to the data. System settings are adjustable and managed by a portal service enabling manager-level users to quickly add imagery, manage services, and access controls. Imagery may also be accessed by the WMS standard and combined with National Spatial Data Infrastructure (NSDI) framework data in any GIS supporting this popular standard.

The collection of remote sensing data from multiple platforms, such as satellite and aerial, provides the flexibility often necessary during hazards events due to atmospheric interferences or satellite revisit limitations. In addition, by providing archived imagery of an area, a change detection analysis can be accomplished to highlight or identify the current conditions of transportation infrastructure.

During the two years that this research proceeded (August, 2012, to August, 2014), it became abundantly clear that if the effects of natural disasters on the nation's infrastructure were to be mitigated and communicated to first responders other sources of information, in addition to the Twitter feeds used to provide the initial alerts, would have to be mined. Increasingly during this period non-authoritative data sources and volunteered geographic information (VGI) were being used to determine the impact of natural disasters on citizens affected by these events. We sought to determine the efficacy of these data sources in assessing the damage produced by three major flooding disasters: first, the flooding and damage to the US eastern seaboard (specifically the coastlines of the States of New Jersey and New York) in late October, 2012 resulting from Hurricane Sandy (Schnebele et al., 2014); second, the floods that occurred in late June, 2013, in the city of Calgary, Alberta (Schnebele et al., 2014b); and third the catastrophic flooding that occurred in the State of Colorado in mid-September, 2013. These case studies explored the use of non-authoritative data and VGI to improve the reliability of the estimates to the damage that had occurred to the transportation infrastructure during the flooding. Data sources that were mined included traffic cameras, power outages, local news reports, road closures, and photos from social media sources. In addition, in the case of Sandy images from the Civil Air Patrol were evaluated using a crowd sourcing approach. For the Boulder, Colorado, floods imagery from a UAV (Unmanned Aerial Vehicle) was included. Satellite imagery on its own was found to be insufficient for determining the extent of the natural disaster. Such traditional sources often cannot be re-tasked quickly enough and may well suffer from environmental limitations due to cloud cover remaining, for example, after a major hurricane. Such a diverse set of data sources describing the extent of a natural disaster provides its own challenges and required a new methodology for data integration or fusion. This fusion methodology was made operational using the so-called 'layer-cake' methodology within a standard GIS package, namely Esri's ArcGIS software. The layers within the 'layer-cake' were fused and weighted using spatial statistics such as kriging (Schnebele et al., 2014).

The final step of the research project was to gather input from stakeholders. Three stakeholders meetings were held over the course of the project. The details of these meetings, the members attending, both virtually and in-person, and detailed synopses of the ensuing discussions are described in detail in the Appendices of the Final Report of the Project which is to be found below. Many of the methodological innovations that occurred during the project and which are described above resulted from our interactions with the stakeholders at these meetings. It became clear that some stakeholders represented first responders from exceedingly well-resourced jurisdictions (e.g. Fairfax County) and would be able to replicate the methodology that we had developed with their own technical personnel (GIS and imagery analysts) and hardware resources (UAVs and USVs – Unmanned Surface Vehicles). Other localities might lack such resources and there remained a need for immediately delivery of the imagery and GIS maps that we had developed during the research. For these needs a Pinterest application was developed as a 'proof of concept'. Imagery Pins were collected on an Imagery Board for our 'Colorado Floods' case study This Imagery Boards was determined to be suitable for all standard web-based imagery output formats including satellite, UAV, USV and other imagery available in formats such as gif, png or jpeg. The Imagery Board may be visualized as a 'place boards' that could be used for planning new routing around the area of a natural disaster and operational strategies for the delivery of emergency services. It can be seen as a way to instantly produce a 'crisis mapping', a tool to deliver spatial information on the ongoing development of a natural disaster to first responders and citizens alike.

References:

Schnebele, E., Cervone, G., Waters, N. 2014a. Road assessment after flood events using non-authoritative data. Natural Hazards and Earth Systems Science, 14, 1007-15.

Schnebele, E., Cervone, G., Kumar, S., Waters, N. 2014b. Real time estimation of the Calgary floods using limited remote sensing data. Water, 6 (2), 381-398.

Cervone, G., Schnebele, E., Waters, N., Mattson, M., Harrison, J., Moccaldi, M., and Sicignano, R. 2014. *Using Social Media to fill the Gaps in Urban Areas During Emergencies,* National Science Foundation (NSF) Big Data and Urban Informatics Workshop, Chicago, IL, August 2014.

ACKNOWLEDGEMENTS

We wish to acknowledge the following participants in this project.

For the George Mason University team:

Dr. Nigel Waters served as Principal Investigator and project manager. Dr. Waters contributed to all publications and the various presentations listed in this report. He co-shared with Dr. Cervone the educational component responsibilities of the project.

Dr. Guido Cervone served as Co-Principal Investigator and co-developed the algorithm to fuse remote sensing data and social media, as well as co-shared with Dr. Waters the educational component responsibilities of the project. Dr. Cervone co-drafted the peer reviewed publications resulting from this research.

Dr. Emily Schnebele contributed to the analysis of user generated ground data and their application for hazard identification and damage assessment. Dr. Schnebele also co-drafted the peer reviewed publications and was the primary Research Associate for the project.

For The Carbon Project, the primary industry partner for the project:

Mr. Jeff Harrison, CEO of The Carbon Project, designed the Scanner service to mine social media, detect transportation infrastructure impacts and cue commercial remote sensing.

Mr. Mark Mattson, Vice President, Technology, developed the cloud-based Scanner service to mine social media, detect transportation infrastructure impacts and cue commercial remote sensing. Mr. Mattson also developed the Scanner application and data services for the project.

DISCLAIMER

GLOSSARY

API	**A**pplication **P**rogramming **I**nterface
CAP	**C**ivil **A**ir **P**atrol
CP	**T**he **C**arbon **P**roject
CSV	**C**omma-**S**eparated **V**alues
DOT	**D**epartment **o**f **T**ransportation
GMU	**G**eorge **M**ason **U**niversity
GIS	**G**eographic **I**nformation **S**ystems
GML	**G**eography **M**arkup **L**anguage
JSON	**J**avaScript **O**bject **N**otation
KML	**K**eyhole **M**arkup **L**anguage
NSDI	**N**ational **S**patial **D**ata **I**nfrastructure
OGC	**O**pen **G**eospatial **C**onsortium
OSGeo	**O**pen **S**ource **Geo**spatial Foundation
TMS	**T**ile **M**ap **S**ervice
UAV	**U**nmanned **A**erial **V**ehicle
WCS	**W**eb **C**overage **S**ervice
WFS	**W**eb **F**eature **S**ervice
WMS	**W**eb **M**ap **S**ervice
WMTS	**W**eb **M**ap **T**ile **S**ervice

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INTRODUCTION AND SUMMARY OF PROJECT ACCOMPLISHMENTS

We have been prolific and successful in our accomplishments over the past two years. Our primary concern was to investigate how to determine the locations for acquiring commercial remote sensing images after major natural events (floods, hurricanes, tornados, earthquakes, among others) using social media. We have focused primarily on Twitter, as specified in the proposal, but have also expanded to other sources such as videos, photos, news reports, UAVs (Unmanned Aerial Vehicles) etc. We have shown that during an emergency, social media provides an immediate assessment of the 'human terrain', or in other words, how people respond to a developing hazard. This information, which is contributed freely (Volunteered Geographic Information or VGI; see Goodchild, 2007, for a seminal article on VGI), can give near real-time insights about the 'hot spots' for which remote sensing data should be acquired.

The research team at George Mason University (GMU) worked closely with the Carbon Project (CP) to develop an operational system that would identify the spatial and temporal coordinates of a natural disaster. The Project Team worked on the research aspects of the problem, focusing on scientific issues such as how to geolocate data by analyzing text, IP information, and users' profiles. GMU also developed a multi-layer methodology based on GIS in order to fuse together data from different non-authoritative sources (see Zhang, 2010 and Zhang et al., 2014, for a discussion of the challenges of data fusion). This work focused on the assessment of transportation infrastructure during flood events.

In addition to meeting all required deliverables, this project resulted in the publication of 3 peer reviewed journal articles, 1 peer reviewed conference paper, 1 book chapter (currently in press), and 2 additional articles in the final stages of preparation and review. Furthermore, the research team made 8 presentations to audiences at the national level (see Appendix B for complete citation details of all publications and professional presentations associated with the project). Outreach and community engagement and response was also conducted through 3 meetings with an Advisory Stakeholders group as well as through a research feedback initiative. Representatives from 68 state DOTs (primarily from maintenance and emergency management divisions) were contacted and constructive and positive responses were provided from 8 of the 68 individuals contacted.

TECHNICAL STATUS: ACCOMPLISHMENTS BY MILESTONE

This project used social networks to task remote sensing imagery of transportation infrastructure conditions in response to emergencies (Figure 1). Such a capability is especially valuable in situations where environmental hazards such as hurricanes, floods or other severe weather affect very large areas. During these disasters it is important to 'cue' remote sensing and aerial imagery collection to assess the impact of fast-moving and potentially life threatening events on transportation infrastructure. During this project, our team completed all key project tasks and milestones, and exceeded the requirements of the research project by deploying a functioning capability with enhancements based on community feedback. The following sections summarize project accomplishments by task.

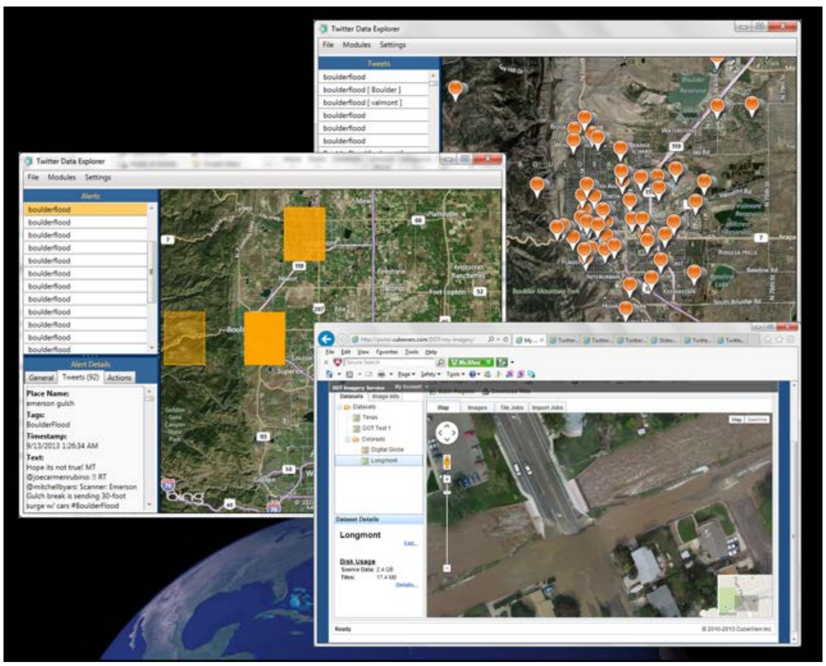

Figure 1 - This project used social networks to task remote sensing and aerial imagery of transportation infrastructure conditions in response to emergencies.

Task 1: Project Kickoff

During the Project Kickoff a meeting was organized to introduce key stakeholders to the project and to the primary team members. This meeting provided an overview of the project's goals and desired outcomes. This task was completed during the First Quarter reporting period.

Task 2: Develop Architecture Plan

This task was also completed during the First Quarter reporting period. It delivered a Project Architecture designed to share social media data among individual project elements. The project elements were divided into services, information and application components to allow social networks to cue commercial remote sensing of transportation infrastructure conditions in response to natural events (Figure 2). Delivery products included open data models, encoding and online services based on open standards. This approach allowed data services to be developed for the project to connect to any application implementing open geospatial standards (Pezanowski, et al., 2007).

Figure 2 - Project elements were divided into components that mined social network data and cue'd commercial remote sensing of transportation infrastructure

During the initial phases of the project the Architecture Plan was updated based on community feedback (see Appendix A for details of all Stakeholders' Meetings). This update included adding the ability to cue airborne and ground-based imagery for infrastructure conditions in response to natural events – in addition to cueing satellite imagery.

Task 3: Development of Publisher Services and Applications

Task 4: Development of Reviewer Services and Applications

Task 5: Development of WFS Services

(Note - These Tasks are reported together to facilitate understanding of the technical aspects of the research).

Data collected from social networks are diverse, complex, and overwhelming in volume, velocity, and in the variety of viewpoints they offer. These are characteristics of the phenomenon that in recent years has come to be known as ‘big data’. Research on big data has, in the last few years, become a growth industry. An introduction to its potential and limitations has been given by Boyd and Crawford (2011). A more focused discussion of big data issues that is specifically concerned with the use of Twitter data and for providing situational information during natural disasters is provided by Bruns and Liang (2012). Negotiating these overwhelming streams of big data is beyond the capacity of human analysts. In order to efficiently and effectively use social media to ‘cue’ the collection of imagery, it is necessary to filter the data for content and geolocate them using a variety of text-mining and network analysis algorithms. Filtering yields a rapid and directed identification of affected area(s) which can aid authorities in prioritizing site visits and response initiatives as well as the tasking of additional data collection.

For this project a scanning application was developed to access and harvest social media data by browsing Twitter in real-time. Using the *Carbon Scanner* tweets are filtered by keyword and hashtag, locating road, bridge and natural hazard condition reports. As events progress, the service ‘scans’ the United States to assess and generate alerts for areas with significant Twitter activity (Figure 3). These alerts or ‘hot spots’, are areas where natural hazards may be potentially occurring, and are identified based on the clustering of filtered and, subsequently, geolocated tweets. When a ‘hot spot’ is identified, remote sensing data are collected and made available as open data services. These alerts were used in several of our presentations and published papers (see, for example, Cervone et al., 2014; Schnebele et al., 2014a; Schnebele et al., 2014b and Waters et al. 2014).

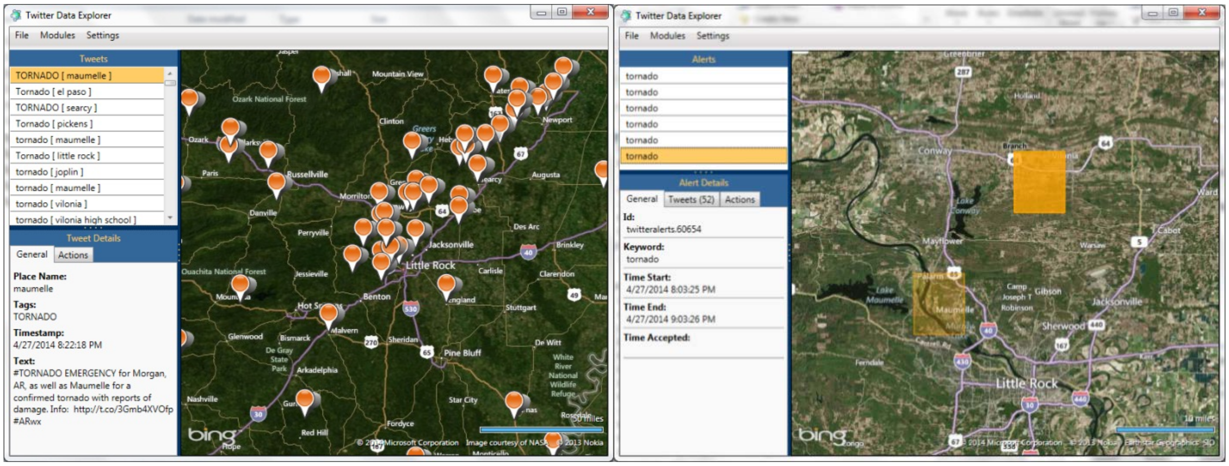

Figure 3 - Filtered and geolocated tweets captured by the scanning application (left) were used to generate alerts (right).

During the project, the following Carbon Scanner components were iteratively developed, deployed and tested on the Windows Azure Cloud -

1. Twitter Reader: This component opens a stream to Twitter (with proper search parameters) and pushes results to an Azure Storage Queue.

2. Azure Storage Queue: This component holds the tweet information from #1.

3. Twitter Queue Reader: This component reads the tweet from the queue, attempts to geolocate it, validate the language, etc. If it's acceptable, this component populates the WFS database. (Was designed as Storage Queue Reader)

4. Azure SQL Server Database: A large cloud-based storage component, able to handle significant data.

5. Web Front End: A management application to control the system configuration and settings for the Publisher service (search/scanning terms). This was derived from the WFS Plus+ upload front end.

6. Scanning Service: This component 'scans' the data using filters, figures out if an event is occurring and alerts on areas with significant activity (prototype).

7. WFS Plus+ (2014): This component provides access to Twitter social media data as geographic features.

During the project we exercised these components in live workflows against the Twitter Streaming API. The keyword management was done through the WFS Plus+ management app (Figure 4). The application system is highly flexible with filter settings managed by a portal service enabling manager-level users to quickly adjust keyword and other settings as events develop.

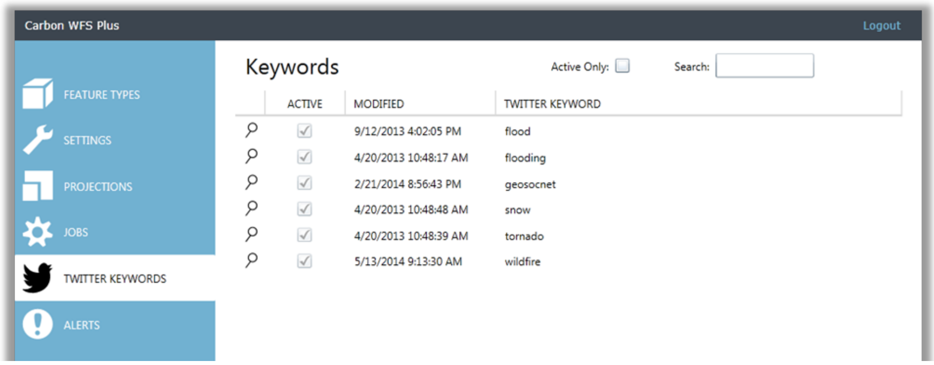

Figure 4 - Keyword management for data was done through the WFS Plus+ management app.

The geolocation of filtered tweets is accomplished by pairing geographic names identified in the tweet text to a United States gazetteer integrated into the cloud-based Carbon Scanner. Geographic names collected from the United States Geological Survey (USGS) were downloaded into a single database file - storing the name and the geometry properties of each named location. In cases where there are multiple points, the center point of the extent is utilized as the geometry. The resulting geonames database contains approximately 2.1 million records. Using this database Carbon Scanner components are capable of running and reading Twitter streams and then matching the identified place names to the geonames database in near real-time.

During the project the team enhanced the cloud-based WFS and Publisher services and applications with easy-to-use methods to access raw data. This was necessary because “power users” may need data in several formats for analysis, including CSV, JSON, KML, GML or GIS Shapefile. To help this process a set of easy-to-use Export tools was deployed on the WFS (Figure 5).

These tools allowed the data to be used for analysis and algorithm development in a variety of applications, as discussed in the next section.

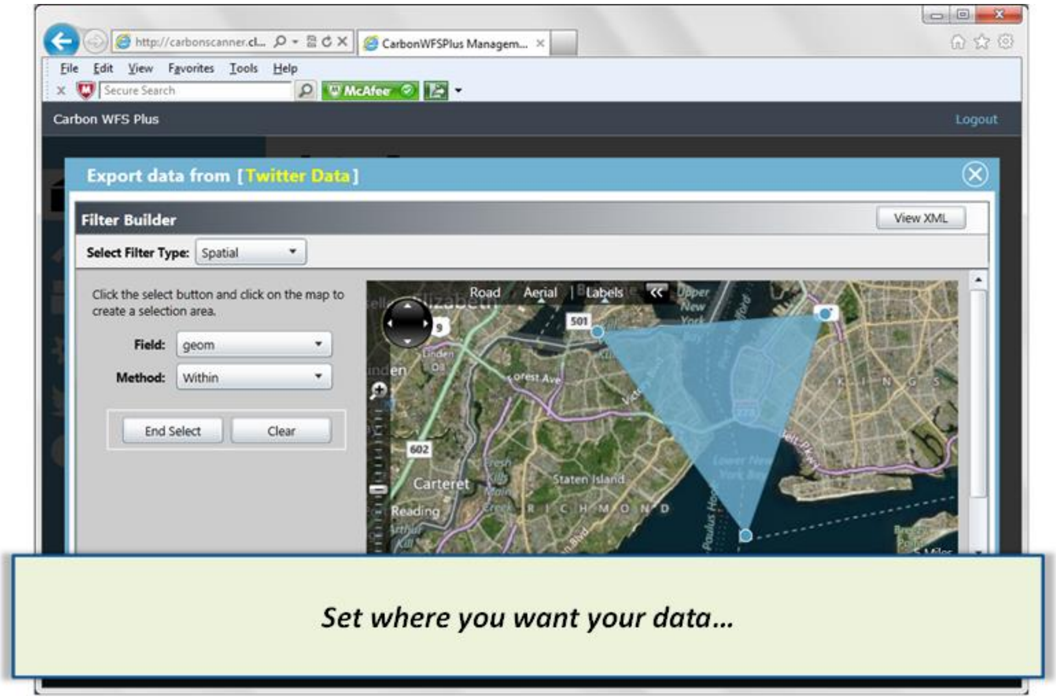

Figure 5 - Filter tools for data export.

Following the filtering and geolocation of tweets, a potential natural hazard event is recognized when a significant amount of activity is identified in a region. The determination of significant activity in an area, or the threshold, can be adjusted to user requirements or preferences. When the threshold is reached an `Alert Box' is generated (Figure 3, right), cueing the collection of imagery for that region. The imagery is deployed in near real-time using open mapping services including Open Geospatial Consortium Web Map Service (OGC WMS, 2014), Web Map Tile Services (WMTS, 2014), Web Coverage Services (WCS, 2014), Google Maps API (2014), Google Earth KML (2014) overlays, and Open Source Geospatial Foundation Tile Map Service (OSGeo TMS, 2014) (Figure 6).

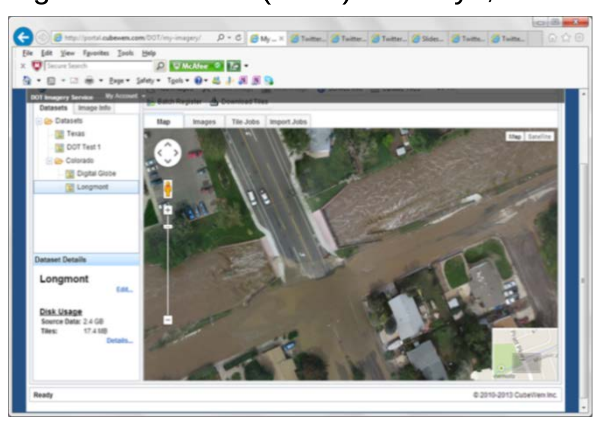

Figure 6 - Imagery deployed using open mapping services.

Providing the imagery in an open source format ensures rapid deployment as well as open access to the data. System settings are adjustable and managed by a portal service enabling manager-level users to quickly add imagery, manage services, and access controls. Imagery may also be accessed by the WMS standard and combined with National Spatial Data Infrastructure (NSDI, 2014) framework data in any GIS supporting this popular standard.

Task 6: Component Testing

During the project, Component Testing on elements of the Services Model and Information Model components was conducted with live social media, alerts and test tweets with dedicated hashtags (Table 1). Testing methodology focused on conducting test Requests which exercise operations on Publisher, Reviewer and Collector Services implementing the Information Model and live data from Twitter social media feeds. All Component Tests designated in the architecture were completed and the capability functioned as designed.

Table – 1 Component testing on elements of the Services Model.

Component	Test Request	Description
Publisher	CreateFeatureType	Creates Geographic Features as CoreGeosocialPts_Type or CoreGeosocialShape_Type
Publisher	ImportFeatureType	Imports initial test data into created CoreGeosocialPts_Type or CoreGeosocialShape_Type
Publisher	Insert Update Delete FeatureTypes	Conducts Transactions on created CoreGeosocialPts_Type or CoreGeosocialShape_Type
Publisher	SpecifyAOI	Develops BBOX Filter Set
Publisher	CreateCrossReference	Develops Comparison Operators for Filter Set
Publisher	Set Date/Time Range	Develops Temporal Operators for Filter Set
Reviewer	GetCapabilities	Requests service description
Reviewer	DescribeFeatureType	Requests CoreGeosocialPts_Type or CoreGeosocialShape_Type
Reviewer	BuildFilter	Constructs Logical, Comparison, Spatial and Temporal Requests
Reviewer	StoreFilter	Persists Stored Queries
Reviewer	FilterQuery	Submits Logical, Comparison, Spatial and Temporal Requests

Reviewer	GetFeature	Accesses CoreGeosocialPts_Type or CoreGeosocialShape_Type Features
Reviewer	CreateAlert	Accesses CoreGeosocialPts_Type or CoreGeosocialShape_Type Features as notification
Collector	CueTasking	Creates planned imagery tasking
Collector	AssessFeasibility	Conducts imagery collection feasibility
Collector	CollectImage	Executes imagery tasking
Collector	GetMap	Accesses satellite or orthorectified UAV imagery in application
Collector	GetFeatureInfo	Accesses CAP imagery in application

Task 7: Conduct Integrated Network Tests

During the project tests were conducted to ensure the components functioned together. These tests ran continuously for over a year. In this testing the Carbon Scanner opened permanent connections to Twitter, and read the information brought back. This process is based on Keyword control described in previous reports. The read Tweets were then placed into the 'Queue' on the cloud and the Carbon Scanner located the tweets at a place name in near real-time – based on 2.1 million Geographic Names we've indexed on the cloud. This general process is summarized in the graphic below (provided for background context only).

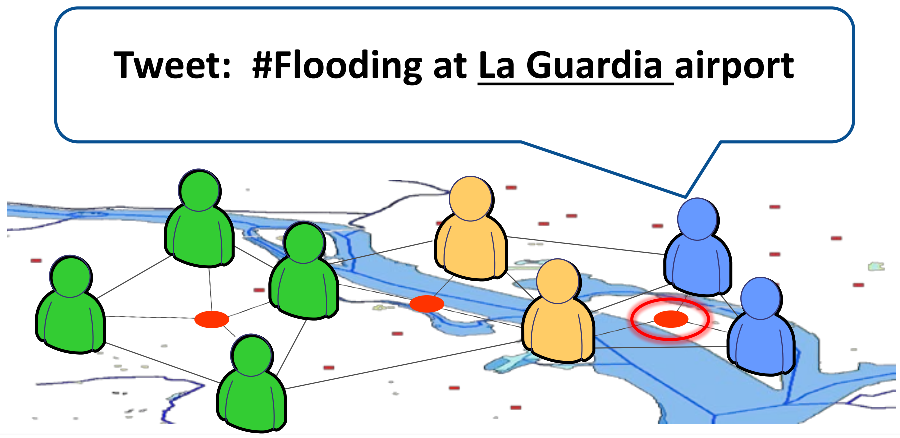

Figure 7 - Carbon Scanner locates tweets based on geographic place name in near real-time.

New York City Test

Multiple integration tests were conducted during the project. During one of the first tests the prototype Carbon Scanner picked up the late #winterstorm over New York City on March 19, 2013. During the event the prototype components were running and reading Twitter streams in real-time with test keywords, and then matched the names to the database of 2.1 million US locations (Figure 7). Using these components only we were able to assess there was #snow in Brooklyn, at JFK airport, in Manhattan, Brooklyn Bridge Park, Union Square Park, Penn Station, and multiple inches reported on the Williamsburg Bridge, plus many more named locations (Figure 8).

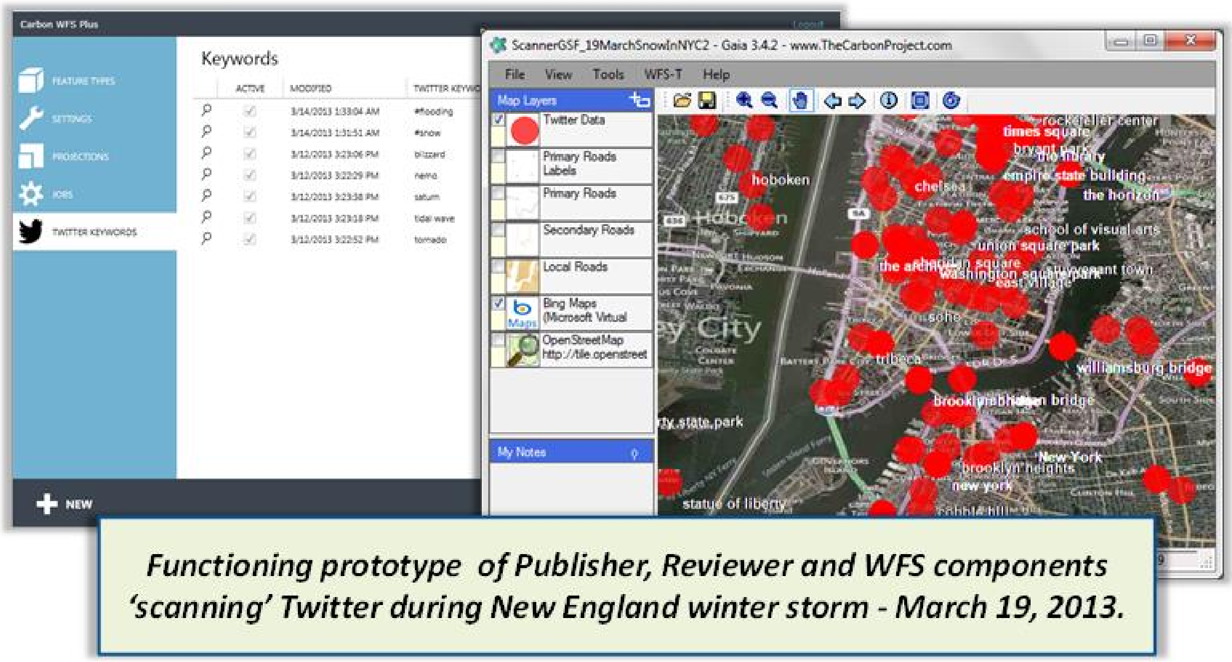

Figure 8 - First test of Carbon Scanner picked up late #winterstorm over New York City on March 19, 2013.

Denver Test

During late spring and early summer 2013 the Scanner Service was set into full operation, and deployed on the cloud and set to run once an hour with a match minimum of 10 tweets in each Alert Box. Within hours of deployment the Scanner Service detected a Tornado event at Denver International Airport and generated an alert to the system (Figure 9).

A representation of the scanning process and the actual Alert layer on the Carbon WFS+ is shown below. Alerts were made available on the WFS service with output in KML, JSON, CSV and GML, as depicted in the previous section.

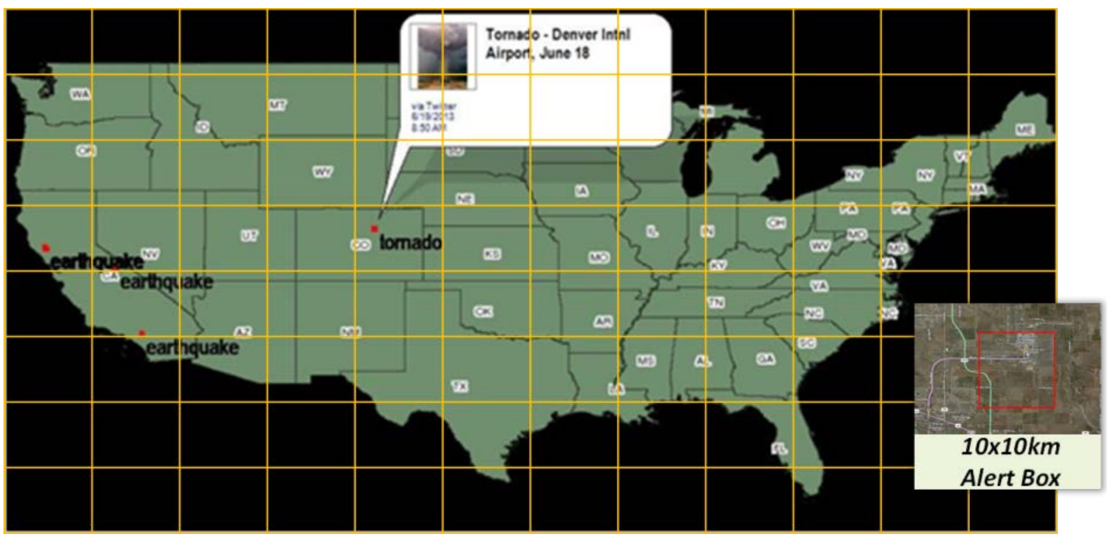

Figure 9 - Representation of the scanning process and sample actual Alert layer from the Carbon WFS+.

The Scanner Alert Box size was set at 10x10km or a 100 km2 area. The Alert Box is the size of the area that we are assessing to see if tweets fall in the region - so the network can consider requesting imagery over the area and we can make very simple applications that can be accessed by non GIS users. The United States area was covered by Alert Boxes during scanning.

The 100 km2 Alert Box size was determined to be most efficient because -

- For many urban areas significant transportation infrastructure may be found in a 10x10km (100km2) to 20x20km (400km2) area. For example, a 10x10km Alert Box is roughly the size of Staten Island, or a place like Moore, OK.

- The minimum ordering area for DigitalGlobe orthorectified imagery is 100km2.

This process raises the potential to mine social media and for cueing satellite, airborne and ground-based imagery of infrastructure conditions in response to natural events. It was refined during subsequent weeks with the development of simple Alerting applications for non-GIS users. These applications were brought into play during the Colorado floods in September2013.

Colorado Floods Test

The September 2013 flooding in Colorado was the worst hydrological disaster in the state’s history. The severity was the result of extreme precipitation, pre-existing drought, and recent wildfires which hardened the ground and reduced the vegetation layer. The flood disaster was responsible for the evacuation of over 180,000 people and 8 deaths. Damage and recovery costs for state-owned roads and bridges are estimated to be approximately $430M (Denver Post, 9/25/2013). Damage to transportation infrastructure was especially severe and debilitated large areas of the state.

The capability developed for this project achieved its primary objective, with the deployed and operational prototype Scanner, detecting and alerting on the floods in Colorado (Schnebele et al., 2014c). This capability, deployed on a cloud based infrastructure, detected and geolocated thousands of tweets and alerted on floods in Colorado within hours of the event. Satellite imagery was tasked and collected based on alerts, and deployed on imagery services (Figure 10). Due to the cloud cover, which challenged the collection capability of space-based remote sensing, UAV imagery was also collected and deployed on imagery services. In addition, the capability was tested over Waynesville, MO (Cervone and Schnebele, 2013). The Colorado and Waynesville events highlight the successful attainment of the project’s R&D objectives for Publisher, Reviewer and Collector Services, Component Testing and Integration Testing.

Twitter, through the #BoulderFlood hashtag and key words such as “flood”, provided a steady stream of information regarding flood events, enabling imagery collection.

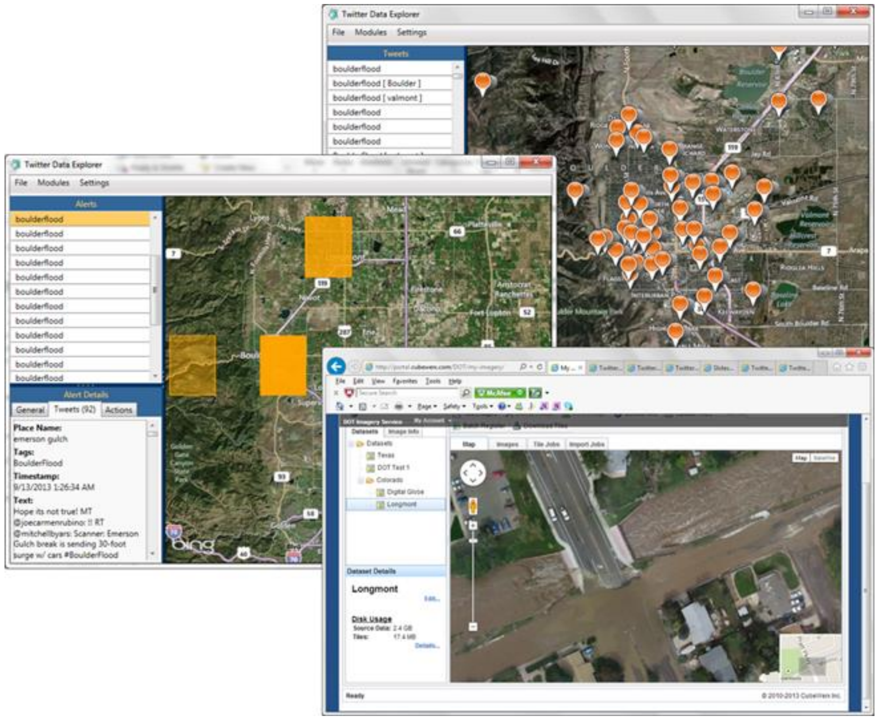

Figure 10 - Twitter, through keywords, provided a steady stream of information on Colorado flood events, enabling imagery collection.

Multiple Alert Boxes for Colorado from The Carbon Project, in GML from the WFS, were generated (Figure 11).

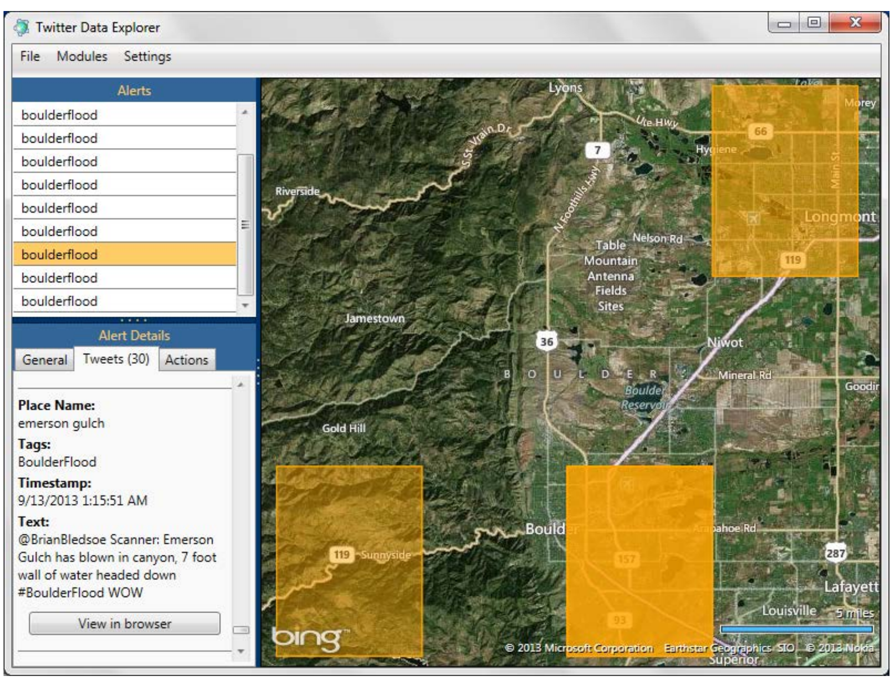

Figure 11 - Alert Boxes for Colorado from The Carbon Project, in GML, from the Carbon WFS.

In addition, tweets gathered from The Carbon Project were compared to those collected by Arizona State University and Penn State University. All illustrate a strong clustering of Tweets in downtown Boulder during the flood (Figure 12).

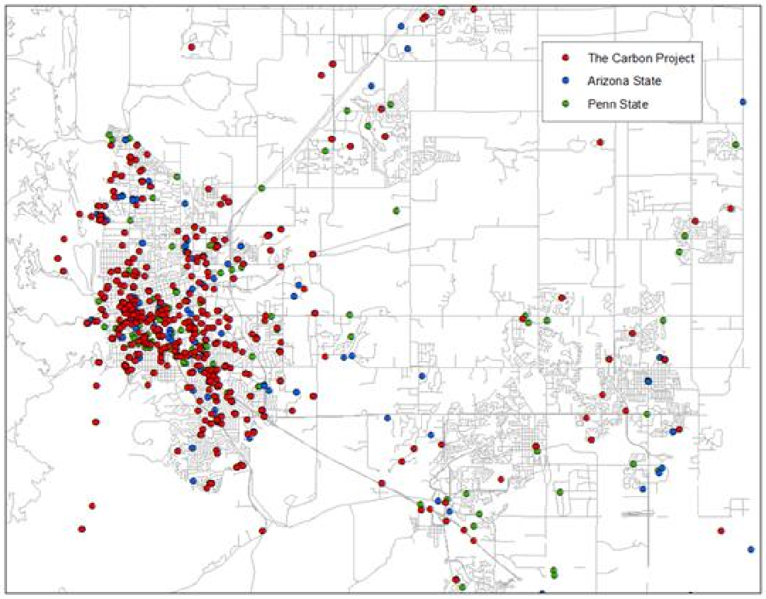

Figure 12 - Tweets gathered from The Carbon Project were compared to those collected by Arizona State University and Penn State University (Schnebele et al., 2014c).

The Tweets collected by The Carbon Project also agreed well with road closures listed on the City of Boulder emergency website on September 12, 2013 (Figure 13).

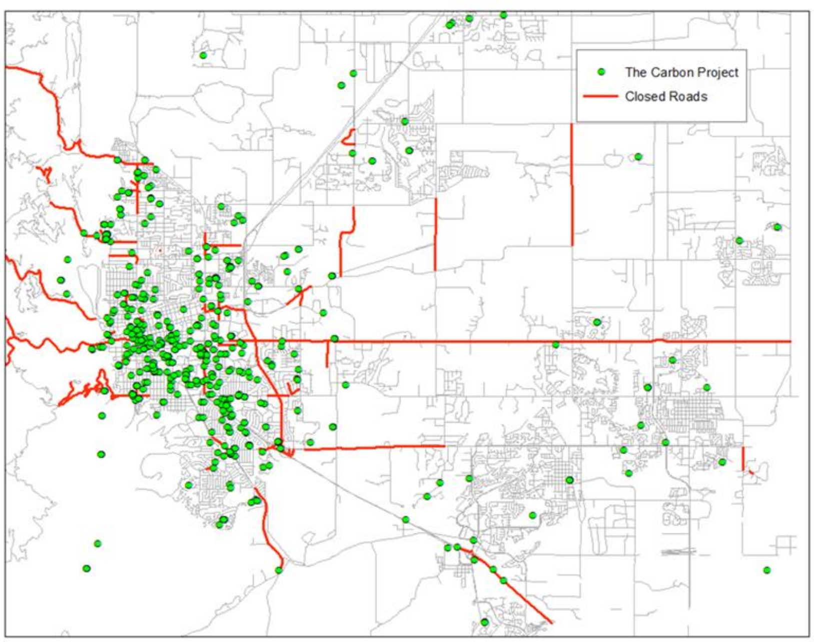

Figure 13 - The Tweets collected by The Carbon Project matched with road closures listed on City of Boulder emergency website (Schnebele et al., 2014c).

Satellite imagery was tasked and collected based on alerts, and deployed on imagery services. Due to the cloud cover, which challenged the collection capability of space-based remote sensing, UAV imagery was also collected and deployed on imagery services.

Examples of Falcon UAV imagery were collected over Boulder and deployed on the project Web Map Tile Services (WMTS) imagery services. This imagery is then accessible to any application including Google Maps, Bing Maps, Google Earth, or the project web-based portal using OpenImageMap (Figures 14, 15).

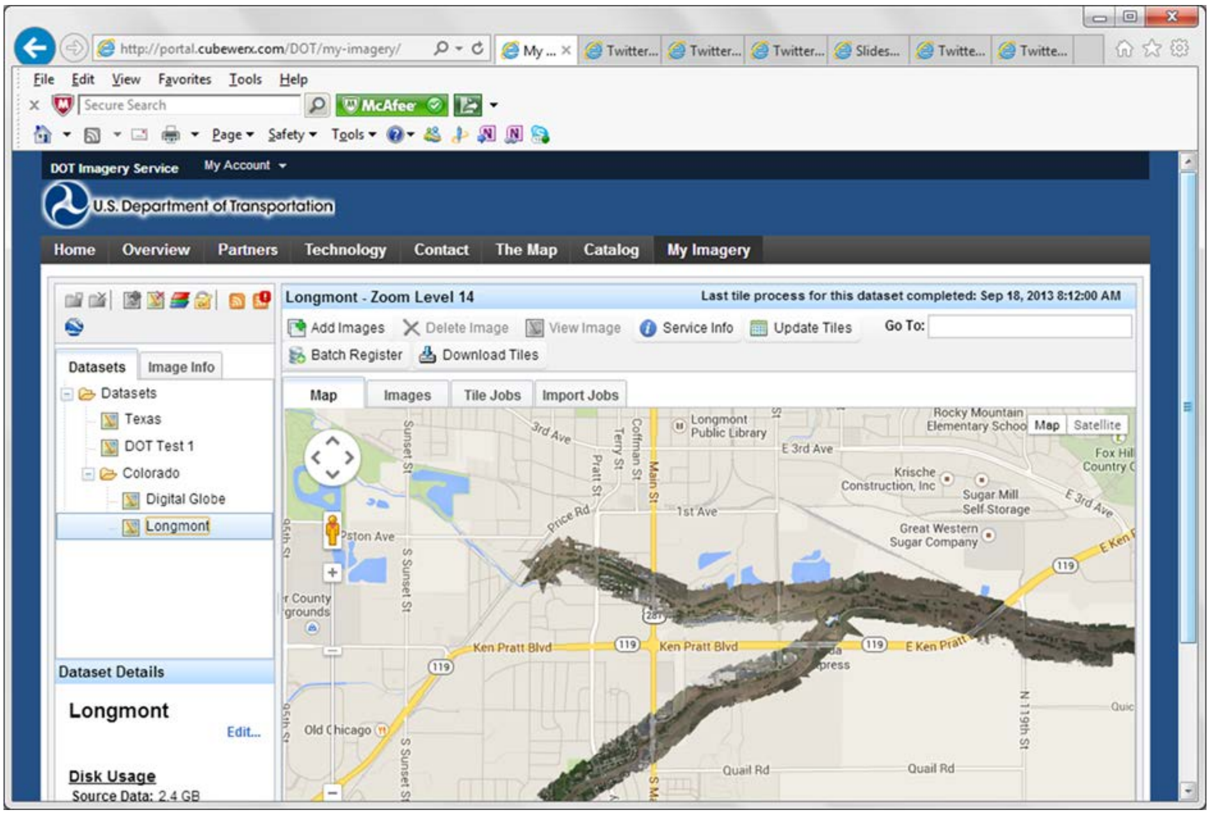

Figure 14 - Imagery accessible on the project web-based portal using OpenImageMap (2014).

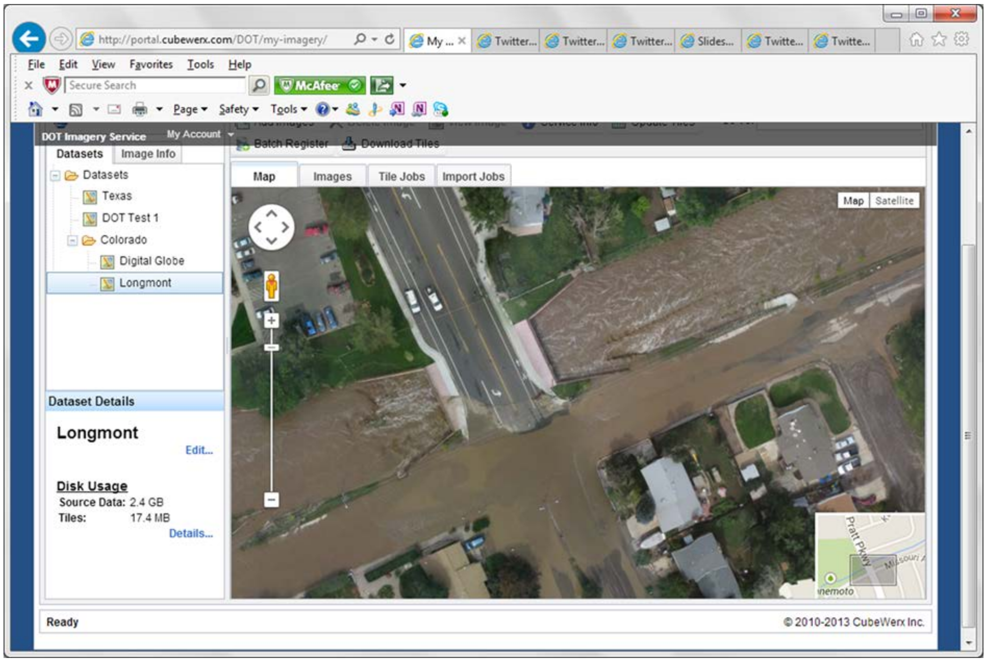

Figure 15 - Falcon UAV imagery collected over Boulder deployed as WMTS.

Falcon UAV imagery collected over Boulder was also deployed on the project Web Map Services (WMS) showing the ability to access by many applications including the Gaia application (Figure 16).

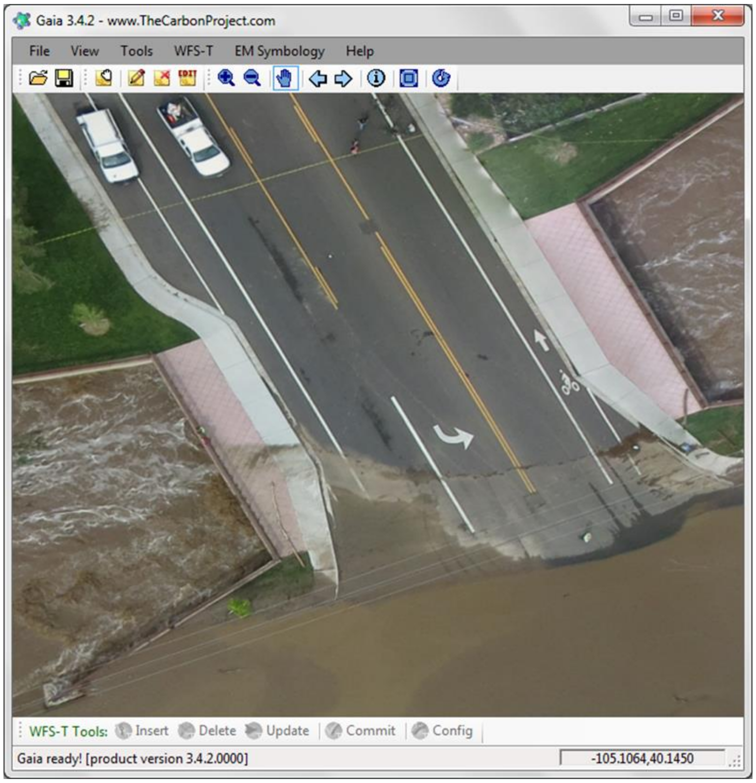

Figure 16 - Falcon UAV imagery collected over Boulder deployed as WMS.

The severity of the flooding in Colorado along with the tremendous amount of available and harvested data, created an opportunity for significant testing of the deliverables of this project. Specifically, based on community feedback and lessons learned from the Colorado floods the project team created a new layer for imagery that is not orthorectified, for example Civil Air Patrol (CAP) imagery which was vital to response efforts for Superstorm Sandy (Cervone et al., 2014) and the Colorado floods.

The approach taken was unique to this project and included development of a Web Feature Service (WFS) layer and unique information structure to both represent the Civil Air Patrol (CAP) imagery and display it on any type of map required. This information was also made available as a Web Map Service (WMS) for overlay on any map background, including Google Maps as shown below. Access to the information in the WMS CAP Imagery layer was provided through information use of the GetFeatureInfo query in the WMS standard (enhancing the ability for reuse by many remote sensing or emergency response applications).

Figures 17-19 illustrate an example of this new capability for accessing Civil Air Patrol (CAP) imagery. The first step includes logging into the response portal to access the Imagery layer WMS powered by WFS ‘behind the scenes’ (Figure 17). The next step consists of using GetFeatureInfo tools to access the imagery layer (Figure 18). Finally, imagery can be accessed for specific events (Figure 19).

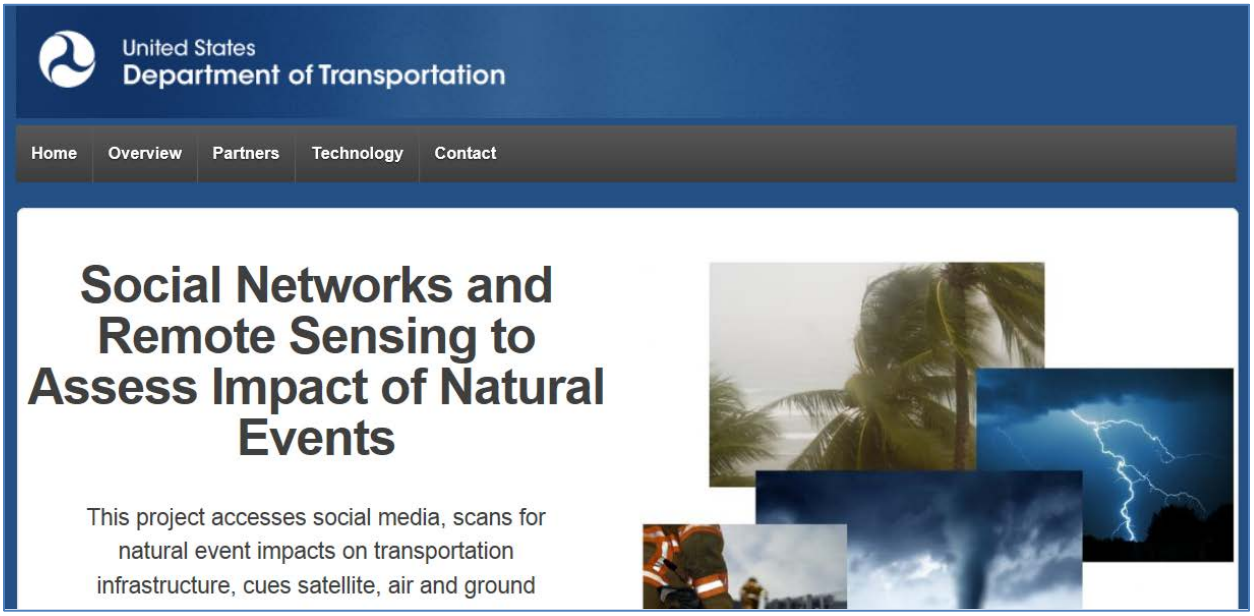

Figure 17 - Project portal based on OpenImageMap (2014).

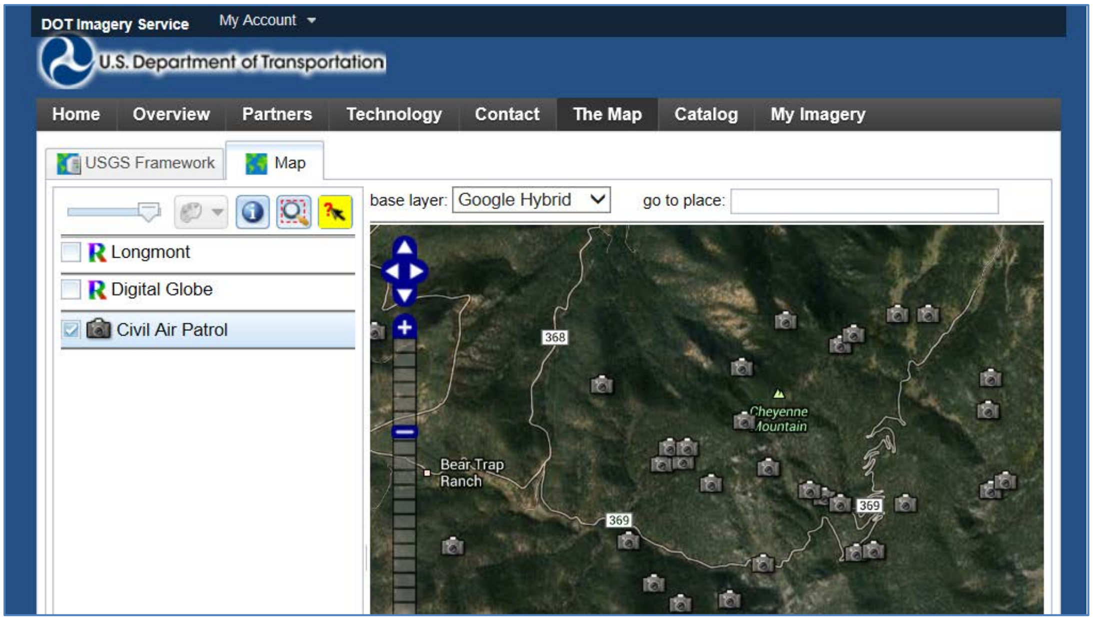

Figure 18 - Using GetFeatureInfo tools to access the CAP imagery layer.

Figure 19 - Accessing CAP Imagery.

The success of the capability during the Colorado floods again raises the real potential to mine social media and for cueing satellite, airborne and ground-based imagery of infrastructure conditions in response to natural events.

Future-focused Testing

Based on recommendations from various government agencies acquired during the stakeholders' meetings (see Appendix A), Reviewer components were tested in new workflows that included Pinterest deployment of collected imagery data, and easy access by DOT users. Specifically, during the March 2014 community meeting, attendees continued to emphasize the need for simple methods to access commercial remote sensing imagery obtained as a result of Carbon Scanner cues. Specifically, ease of access was repeatedly stressed and the use of a commercial service called Pinterest was recommended.

The project team responded positively to this suggestion, indicating that in addition to the standards-based mapping services, required by the project scope of work, the output could, in addition, be readily integrated into Pinterest (2014). The team then proceeded to rapidly develop and deploy a proof of concept of this capability.

As background, and in the best tradition of new social media, Pinterest is officially described as 'a tool for collecting and organizing things that inspire you'. The basic format of Pinterest is graphic, as opposed to the more textually focused timelines of Twitter. The key organizing object of Pinterest is the 'Pin' which is like a little bookmark for an image. Pins are collected on 'Boards', and users share, follow and search for Boards based on their interests.

To integrate imagery output Pinterest image chips were created using Web Map Server (WMS) components and uploaded to a previously created Pinterest account called 'Carbon Scanner'. Image chips were deployed as Pinterest Pins, with a brief description (Figure 20).

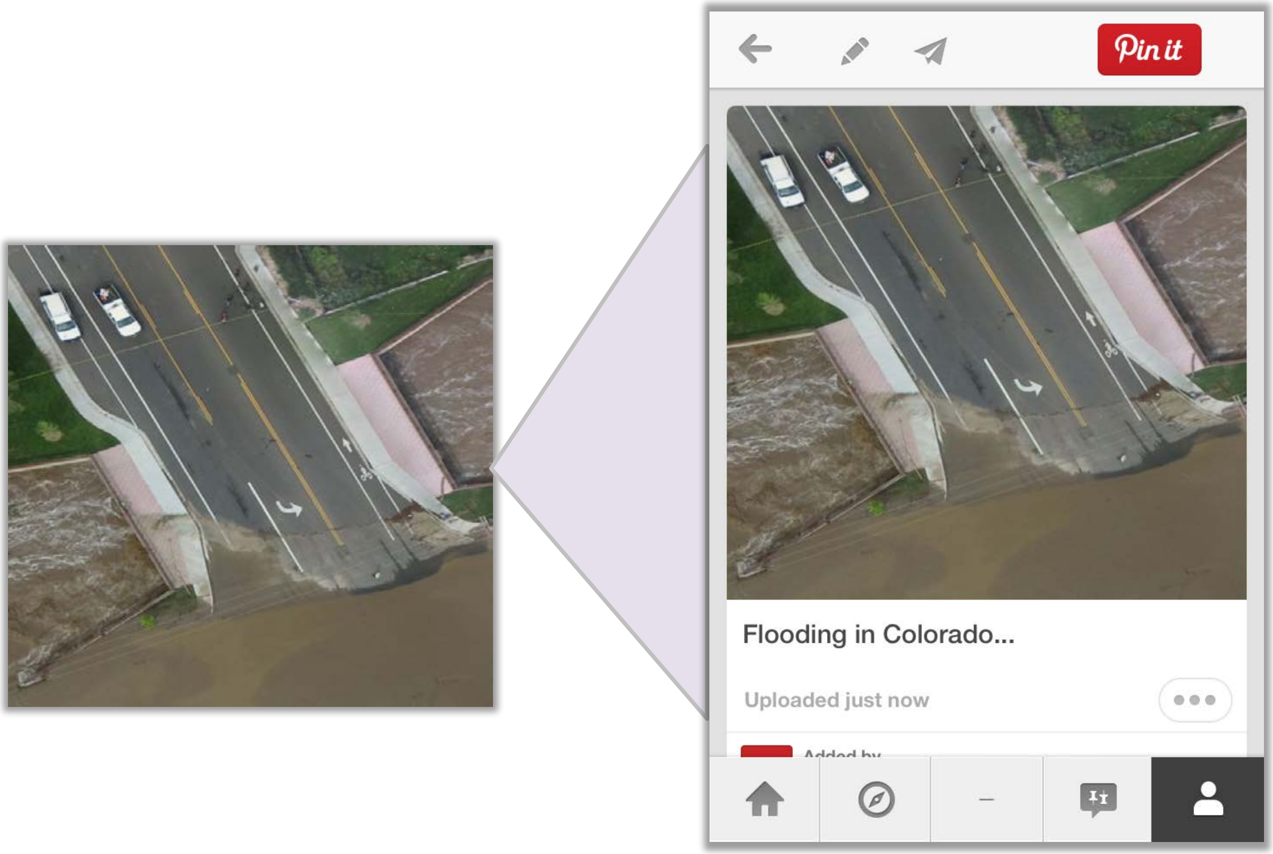

Figure 20 - Image chips deployed as Pinterest Pins.

Imagery Pins were then collected on an Imagery Board titled 'Colorado Floods' (see below). Imagery Boards can support standard web-based imagery output formats and should be suitable for satellite, UAV, USV (Unmanned Surface Vehicles) and other imagery available as gif, png or jpeg.

An Imagery Board is similar to 'place boards', where users can get ideas for planning a vacation, creating a city guide or just communicating popular visiting spots.

Once available on an Imagery Board, satellite, UAV, USV or other imagery is easily accessible to users over the web or by Pinterest mobile apps, and available using search tools on Pinterest and others web tools (Figure 21).

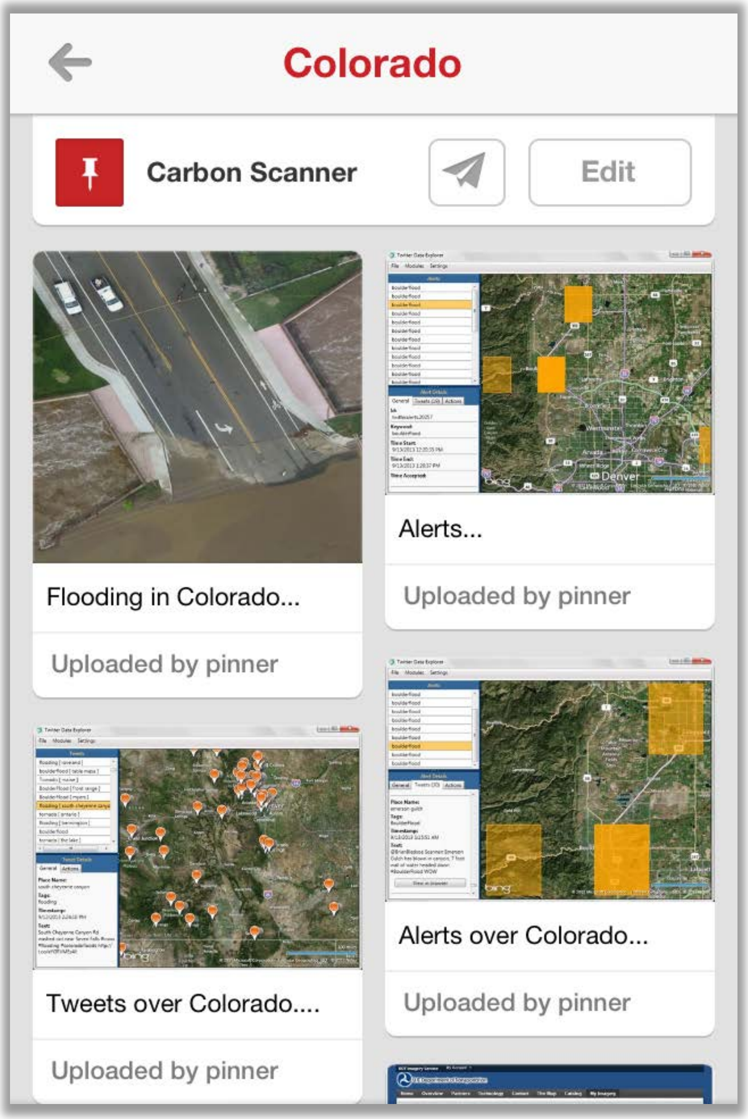

Figure 21 - Imagery Pins collected on an Imagery Board titled 'Colorado Floods'

Based on testing the project team also initiated and tested a dedicated Twitter ‘hashtag’ to improve the accuracy of social media reporting. In this test a specific hashtag was created – called #geosocnet. This hashtag was added to the scanned keyword list and a test account on Twitter was established (Figure 22).

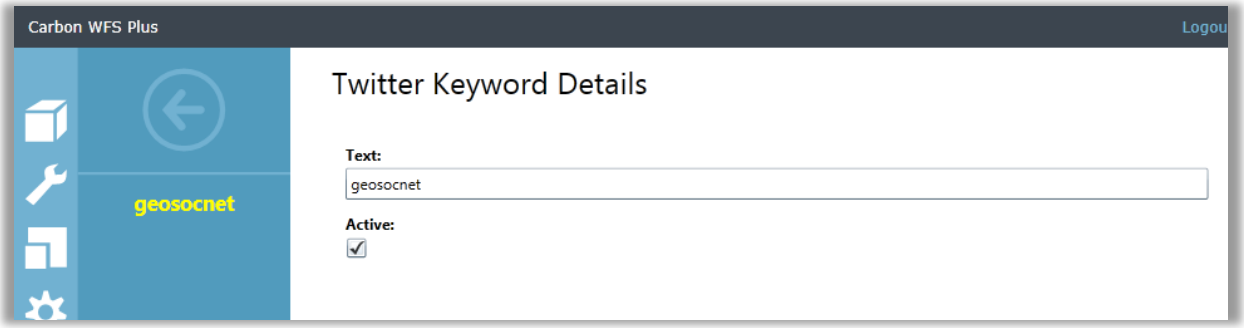

Figure 22 - Project team initiated and tested a dedicated Twitter 'hashtag' "geosocnet" to test improvement in the accuracy of social media reporting.

In this test we created a scenario over Monterey Bay, CA - and told a quick story in tweets of flooding from the perspective of someone on the ground. The placename Monterey or other easily identifiable references were not used, and the test did not raise any questions on Twitter (Figure 23).

Each tweet had an obscure place name and the hashtag #geosocnet. The team added about 15 tweets on a variety of topics. It is important to note that Twitter georeferencing was not used, only place names and hashtag in the context of a narrative ('High winds at Custom House Plaza… #geosocnet).

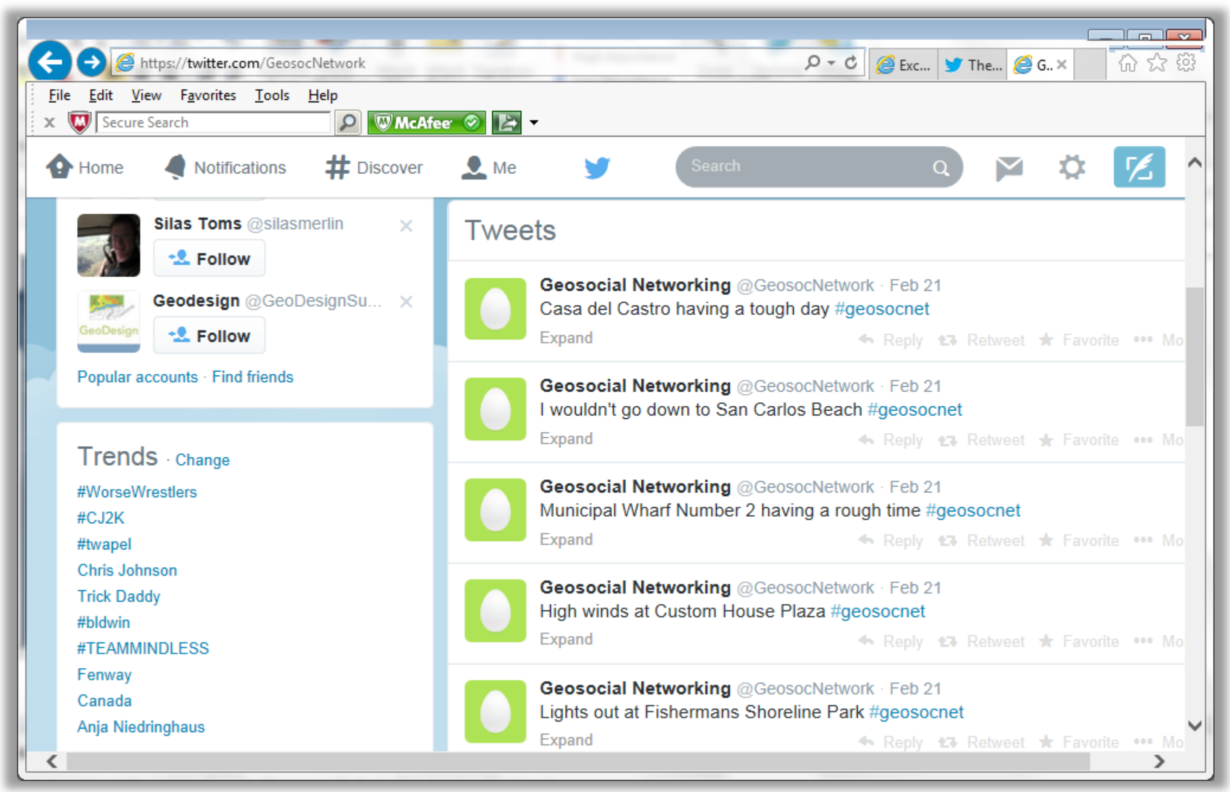

Figure 23 - Representation of the Monterey test scenario on Twitter using 'hashtag' "geosocnet".

The Carbon Scanner then found one of the hashtags, properly geocoded the tweet using the place name ‘Custom House’. This finding proves that a dedicated hashtag can improve the capability to identify impacted transportation infrastructure. Of course, such a hashtag would need to be popularized and people made aware of its use (Figure 24).

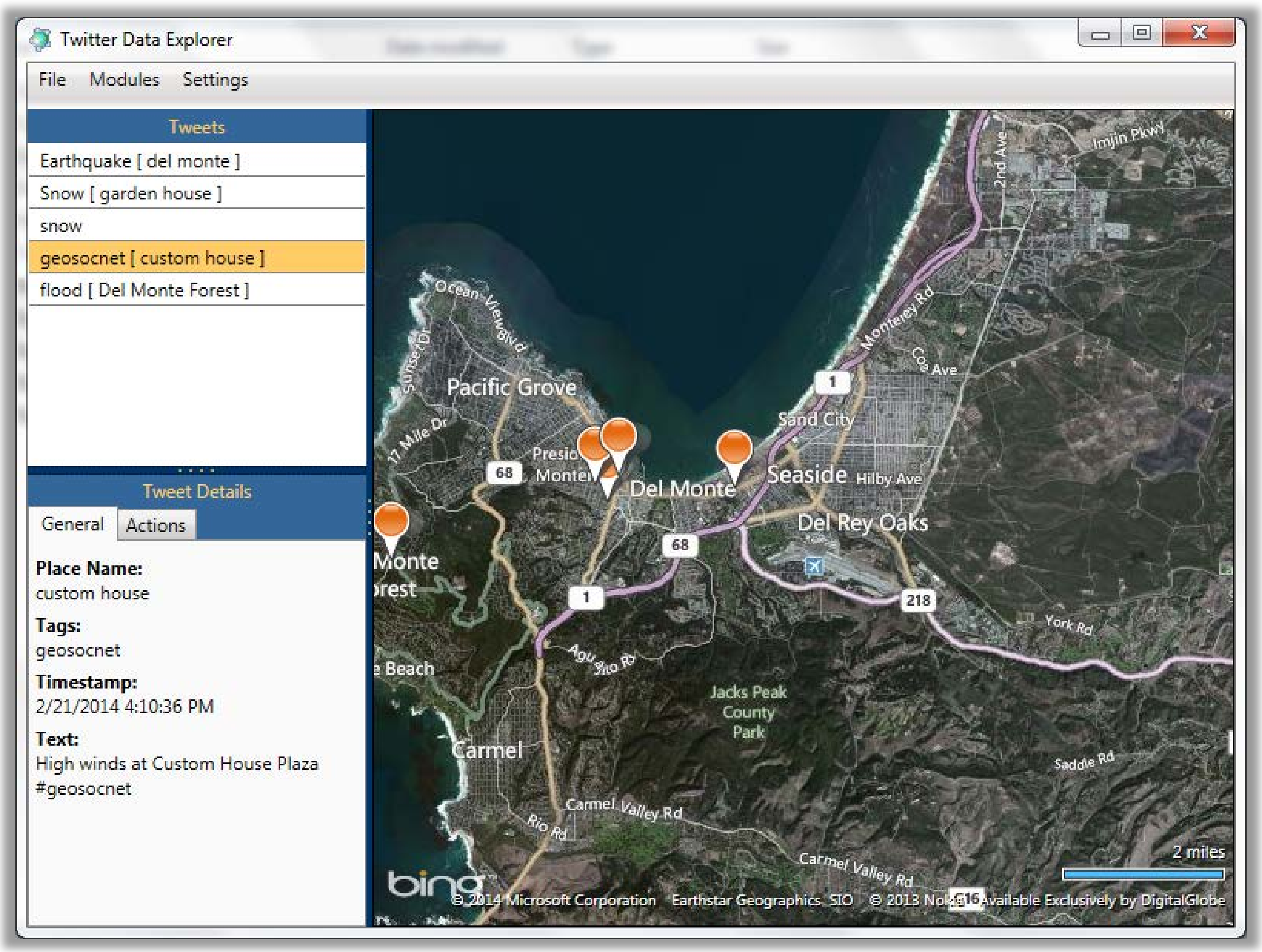

Figure 24 - Carbon Scanner finding one of the dedicated hashtag tweets, “geosocnet”, properly geocoded using the place name 'Custom House'.

Task 8: Final Testing and Demonstrations

The project successfully developed and delivered multiple live for team members, community meetings, DOT project management and state DOTs. The demonstration process culminated with the development of a live demo page and nine YouTube videos that were deployed online and shared with dozens of state DOTs (Figure 25)**.**

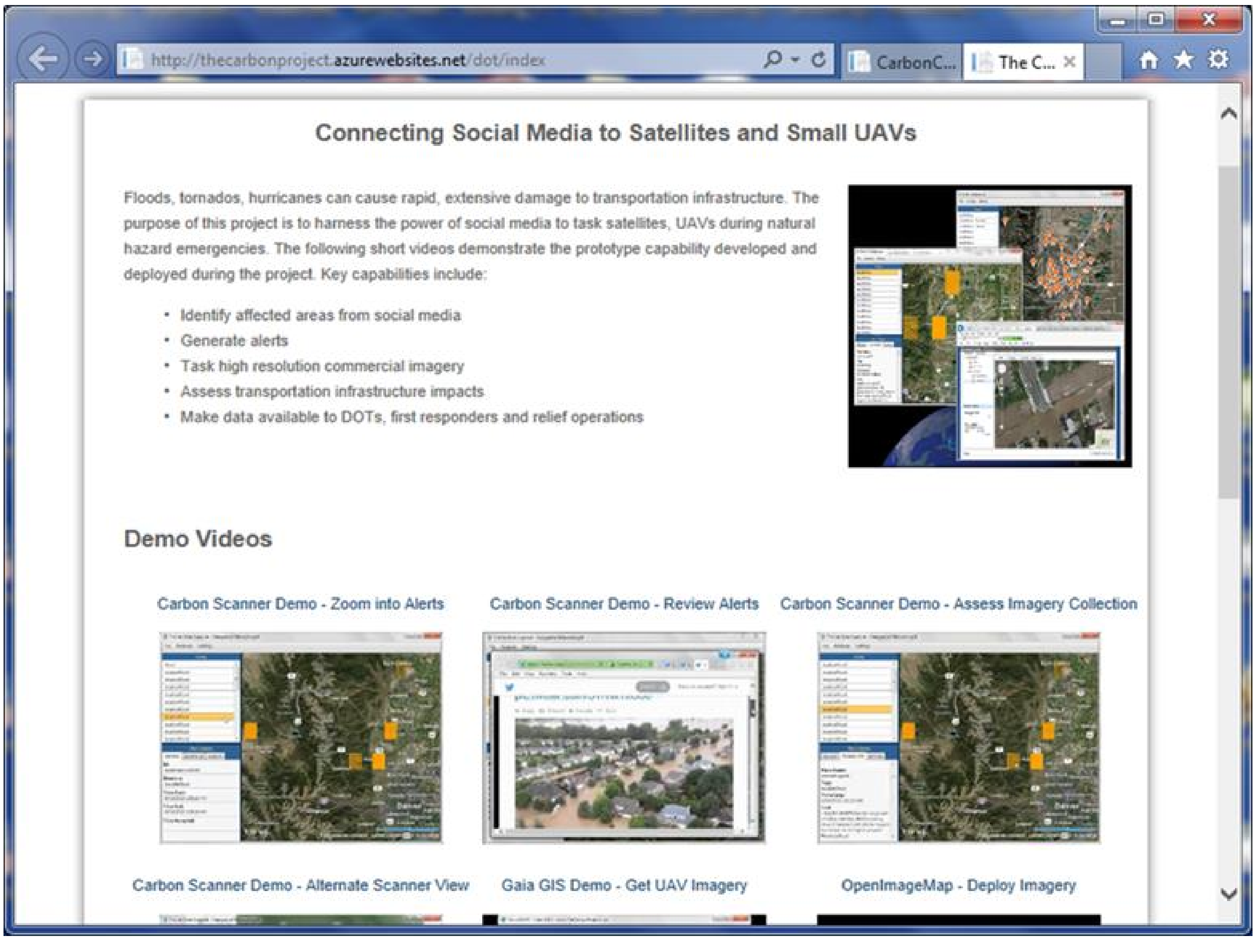

Figure 25 - Demonstration process culminated with the development of nine YouTube videos that were shared with dozens of state DOTs.

Task 9: Community Outreach and Engagement

Please see Appendix A: Agendas and Summary Notes from Advisory Stakeholders Meetings and Appendix C: State DOT Demo Package and Responses for our outreach and engagement activities. We also created a number of demonstration videos which we shared at http://thecarbonproject.azurewebsites.net/dot/index . In addition, please see Appendix D for an article in *Government Computer News (GCN)* from May 2014 and a Carbon Project press release from January 2014.

PROBLEMS ENCOUNTERED

There were no major problems encountered in this research. The project team met all project goals, and enhanced the capability beyond these goals based on community feedback. These advances highlight progress on exceeding the project's R&D objectives for Publisher, Reviewer and Collector Services, Component Testing and Integration Testing – and responsiveness to community feedback to make accessing commercial remote sensing, including satellites, UAVs and other imagery, even easier.

As of the end of this project, the developed capability is ready for operational testing and deployment. Such a fully operational capability would use social networks for cueing commercial remote sensing of transportation infrastructure conditions in response to natural events. The capability will be valuable in situations similar to 'Superstorm Sandy' in 2012 (Schnebele et al., 2014c), or the Colorado floods of 2013 that caused extensive damage to transportation infrastructure. Disasters like these highlight the need for better methods to 'cue' next generation satellites, UAVs, Civil Air Patrol aircraft and online video sources to assess the impact of fast-moving natural events on transportation infrastructure.

FINDINGS and CONCLUSIONS

This research met all the goals of the research proposal.

First, and most significantly, the research project developed a methodology that allowed social media data (specifically from Twitter) to be used to alert first responders to the occurrence of natural disasters. The 10 by 10 kilometer alert boxes that were developed using the Carbon Scanner software provided real time determination of the spatial extent of natural disasters such as floods, hurricanes, tornados, earthquakes and wild fires.

Second, it was clearly demonstrated that social media data such as Twitter was neither detailed enough nor was it “authoritative” enough to be relied upon on its own. Other sources of non-authoritative and also authoritative data were necessary to provide a richer situational awareness picture that would determine how the natural disaster was unfolding and how its impact damaged the transportation infrastructure in the affected areas. Schnebele et al. (2014c; 2014d) and Cervone et al. (2014) showed how data from traffic cameras, power outage notifications, local news (public sources/semi-authoritative) and cellphones, photos and microblogs (user generated/non-authoritative) could be used to supplement the Twitter alerts.

Third, it was determined that the satellite imagery provided by our industry partner Digital Globe needed to be supplemented with other sources of remote sensing data such as data collected from aerial platforms, for example UAVs (Cervone et al., 2014) and the Civil Air Patrol (Schnebele et al., 2014c). This was because of the limitations owing to atmospheric conditions (primarily remaining cloud cover following, for example, the immediate aftermath of a hurricane), revisit times (satellite data even when a satellite was immediately re-tasked might not be available for 24 hours or more only the most optimistic of scenarios), cost (satellite imagery was extremely expensive), and data availability.

Fourth, it was found that by pairing current and historic remote sensing data allows for change detection analysis to be conducted, thus further highlighting damages to transportation infrastructures (Waters et al., 2014).

Fifth, new methodology was developed for the fusion of the authoritative and the non-authoritative data (e.g. Twitter social media data) within a GIS framework that allowed for the determination of the extent of the damage to the transportation from the natural disaster.

Sixth, the methodology developed during this research project was repeatedly refined during the two years that the research was conducted by a number of meetings with stakeholder groups. It was because of the advice, guidance and suggestions of the stakeholders group that the research team continually modified their research approach to include new forms of non-authoritative data and to develop the Pinterest application for notifying first responders immediately of the extent of the damage to the transportation infrastructure from the natural disaster.

FUTURE PLANS

The project team is currently seeking resources to provide the applications developed during the research project to state Departments of Transportation for real-time use in both emergency response and maintenance departments.

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Appendix A: Agendas and Summary Notes from Advisory Stakeholders Meetings

I. List of Stakeholders and their titles and affiliations

II. December 12, 2012 meeting

III. March 20, 2013 meeting

IV. March 20, 2014 meeting

I. Advisory Stakeholders

Dr. Sreenivas Alampalli, Director, Structures Evaluation Services Bureau, NYSDOT; structures inspection, structures evaluation, structures management

Mr. Rafael Ameller, Chief Technology Officer, StormCenter Communications, Inc.; collaborative decision making, decision support services, geospatial common operating pictures

Ms. Catherine Bohn, Senior Project Manager, Emergency Management GIS Specialist, Dewberry; geospatial, emergency management, technology

Dr. Silvana Croope, TMC Interoperability and Mapping Engineer, DelDOT; critical infrastructure systems and risk, GIS, Intelligent Transportation Management Systems

Mr. Jim Dear, Project Manager, National Security Experimentation Lab (NSEL), MITRE; experimentation, simulation, management

Mr. Dan DeBroux, Naval Postgraduate School

Mr. Sheldon Drobot, Deputy Director, Weather Systems and Assessment Program, UCAR; climatology, road weather, satellites

Dr. Mike French, Department Head, Preparedness & Infrastructure Resilience, MITRE

Dr. Rebecca Goolsby, Program Officer, Office of Naval Research

Mr. Virgil Gray, Regional Coordinator/Manager, Region 7, Virginia Department of Emergency Management

Mr. Joe Laun, Firefighter, Fairfax County Fire and Rescue; operations and tactical

Ms. Valerie Lefler, President, Integrated Global Dimensions; public awareness, marketing, communications

Mr. Mike Liddle, GIS Emergency Operations Manager, Fairfax County

Ms. Laurel McGinley, Senior Assoc., Emergency Management, Disaster and Mitigation, Dewberry

Mr. David McKernan, Coordinator, Fairfax County Office of Emergency Management

Ms. Kasey Parr, National Capital Region Planner, Maryland Emergency Management Agency; social media for emergency management

Ms. Jessica Puchala, Social Media & Website Coordinator, Maryland State Highway Administration

Mr. Christian Rasmussen, Knowledge Management Officer, National Geospatial Intelligence Agency

Mr. Ken Rudnicki, Emergency Coordinator, City of Fairfax Office of Emergency Management

Mr. Bill Shaw, Senior Planner, Idaho Transportation Department

Col. W. Mark Valentine, Department of Defense Liaison to FEMA, FEMA

Mr. Sam Wear, GISP, Assistant CIO (GIS) Westchester County GIS, White Plains, New York

Mr. Don Willis, Virginia Department of Emergency Management

II. Advisory Meeting Notes
December 12, 2012 11:00-12:30

Summary and Meeting Notes:

Project Team, Members Present:
Dr. Nigel Waters, Project PI
Dr. Guido Cervone, Project Co-PI
Jeff Harrison, CEO, The Carbon Project, Industry Partner
Emily Schnebele, Project Research Assistant
Chris Oxendine, PhD Researcher

Stakeholders Present:
Rafael Ameller, Stormcenter Communications, Inc
Mike French, MITRE
Joe Laun, Fairfax County Fire and Rescue
Christian Rasmussen, National Geospatial Intelligence Agency

Stakeholders Participating Online:
Kasey Parr, Maryland Emergency Management Agency
Jessica Puchala, Maryland State Highway Administration

Stakeholders unable to attend:
James Dear, MITRE
Dan DeBroux, Naval Postgraduate School
Sheldon Drobot, NCAR
Rebecca Goolsby, Office of Naval Research
Virgil Gray, Virginia Department of Emergency Management
David McKernan, Fairfax County Office of Emergency Management
Ken Rudnicki, City of Fairfax Office of Emergency Management
Mark Valentine, FEMA

The Meeting began with a Power Point presentation by team members documenting research progress since the project start date on August 15th. A pdf of the presentation is attached. Following the presentation the floor was opened up for general discussion and input and suggestions by the stakeholders. This discussion is documented in these notes:

General comments:

- For this study we will use disasters that have already occurred as well as simulated data to test our methodology
- No air or space-borne platform can serve all the needs during a particular weather/hazard event
  - We will use the best available remote sensing data for each particular event. We are partnered with Digital Globe to provide images, but are not restricted to just

their data. For example, imagery collection may happen from space-borne or airborne platforms.

Comments for crisis decision making:

- How do you use social media to get information about areas you care about? We might be able to get an image of a bridge washed out, but we might not care about that particular bridge.
- Time is very important. Information needs to be rapidly deliverable. If it is received after a certain point in a response event the information may be irrelevant.
- The information needs to be coordinated to partner with the way emergency managers operate during real life hazard response and mitigation.
- First responders need actionable real-time information.
    - Data needs to be received by emergency responders easily without having to go through a lot of bureaucratic layers.
    - Speed of imagery collection is very important, and output imagery products should be rapidly deliverable
    - Group noted the cloud cover issue.
    - Can we deliver the information so it can be received on a laptop, or better yet, a smart phone?
- Consider using HSIP Gold, or other feature data, as a reference for impacted transportation infrastructure.

Comments for future consideration:

- How do we engage and interact with the public in a better way? Can there be a response sent after someone sends in a picture or tweet- could we create a feedback loop? We should use social media to get feedback by listening as well as broadcasting.
- How much can social media stand on its own? Can we turn the vetting/verification of social media data back to the community? Consider verification by the crowd of the imagery 'cues'. (Note – project team discussed that there is a 'Verified' element in the current draft of the XML/GML information model)
- There is a bias against social media that it is not as valuable/accurate as that which comes from formal channels
    - Geolocated pictures (vs. text) tend to be more trusted by first responders. Ground photos are often a valid source of 'imagery' information.
- In the future, there may even be drone-based sources of imagery available. Consider methods to 'cue' this as well.
- Could we convey some graded level of value- some quality control to validate the tweets, and perhaps use something visual like a 'stamp' that is easily noticed by users?
- Instead of thinking in terms of just 'cues' consider outputting identified locations of potential transportation infrastructure as 'Recommendations' for imagery collection.

III. Advisory Meeting Agenda and Notes
Wednesday, March 20, 2013   11:00-12:30

Agenda:

I. Dr. Nigel Waters, Project PI

- Introduction of the project for those who were not at the first meeting
- Brief summary of the first meeting
  Specifically, the use of other sources besides satellites for remote sensing data
- Opinion of the stakeholders regarding:
  Specific DoT geoscanner hastag, app, facebook page?

II. Mr. Jeff Harrison, CEO, The Carbon Project, Industry Partner to the DoT Project

- Update from Carbon Project

III. Dr. Guido Cervone, Project Co-PI

- Research and education
- New DoT proposal using remote sensing for assessing road conditions
- Research with Emily Schnebele: data integration for Memphis, Sandy

Additional Project Personnel Participating:
Ms. Emily Schnebele; Lt. Col. Chris Oxendine

IV. Discussion with Stakeholders

Stakeholders in Attendance:
Rafael Ameller, Stormcenter Communications, Inc
James Dear, MITRE
Kasey Parr (attending virtually), Maryland Emergency Management Agency
Jessica Puchala (attending virtually), Maryland State Highway Administration
Don Willis, Virginia Department of Emergency Management
Col. W. Mark Valentine, FEMA

Summary and Meeting Notes:

Project Team, Members Present:
Dr. Nigel Waters, Project PI
Dr. Guido Cervone, Project Co-PI
Jeff Harrison, CEO, The Carbon Project, Industry Partner
Emily Schnebele, Project Research Assistant
Chris Oxendine, PhD Researcher

Stakeholders Present:
Rafael Ameller, Stormcenter Communications
James Dear, MITRE
Donald Willis, Virginia Department of Emergency Management

Stakeholders Participating Online:
Kasey Parr, Maryland Emergency Management Agency
Jessica Puchala, Maryland State Highway Administration

Stakeholders unable to attend:
Dan DeBroux, Naval Postgraduate School
Sheldon Drobot, NCAR
Mike French, MITRE
Rebecca Goolsby, Office of Naval Research
Virgil Gray, Virginia Department of Emergency Management
Joe Laun, Fairfax County Fire and Rescue
David McKernan, Fairfax County Office of Emergency Management
Christian Rasmussen, National Geospatial Intelligence Agency
Ken Rudnicki, City of Fairfax Office of Emergency Management
Mark Valentine, FEMA

The Meeting began with a Power Point presentation by team members documenting research progress since the last advisory meeting on December 12, 2012. A pdf of the presentation is attached. Following the presentation the floor was opened up for general discussion and input and suggestions by the stakeholders. This discussion is documented in these notes:

How do we engage the public as a sensor?

- Not only using their tweets, but tasking the public to provide information
    - Perhaps create a feedback loop
    - Tweets can be verified (true/false) which adds confidence in the data
        - Verification can be spatial or attribute

Social media and privacy concerns

- Currently, Federal and state governments are concerned with the use of social media and privacy
- Privacy is not an issue for this specific project as the Twitter data is freely available

Citizen engagement and emergency response

- Semantics can be used to fit emergency response to specific needs

What about locational accuracy

- How good is good enough? What locational data is important?
- Is locating a tweet, for example at LaGuardia airport, accurate enough?
- Could we use the location from Twitter IP addresses? (via GEO operation in Twitter API)

Reliability of Twitter

- Identify a user as more reliable based on their Twitter history
  - How often they post, clustering of data
  - Is person tweeting in the area they are tweeting about (see GEO API above)
- Improve the mining of social media and increase reliability of Twitter by creating a specific hastag
  - Ideas for hashtags? Perhaps *#CountMe#geoscanner #EMREP #DOTFixMe*
    - Hashtag needs to be something concise that people will remember
    - Should be related to roads because this is a DoT funded project
    - Once we identify a hashtag, how do we make it available to the community, both the public and agencies?

Collaborative Work

In September 2013,MITRE, along with GMU's C4I Center, will be running a SIMEX to assess crisis response using social media.

- This will involve a completely virtual super storm in the GMU area, including simulated GMU campus, power outages, etc.
- Includes members from DoD, FEMA, DHS, state and local emergency managers
- Perhaps we could integrate an infrastructure assessment component that would tie in with this DoT project (if Twitter can support non-public tweet streams)

IV. Advisory Meeting Agenda and Notes
Wednesday, March 20, 2014 11:00-12:30

Agenda:

I. Welcome and Introductions
Research Team Members:

- **Dr. Nigel Waters**, PI; Professor and Director of the GIS Center of Excellence, GMU; *transportation GIS, spatial statistics*
- **Dr. Guido Cervone**, Co-PI; Associate Professor, The Pennsylvania State University; Affiliate Scientist, Research Application Laboratory, NCAR; *geoinformatics, remote sensing, environmental hazards*
- **Mr. Jeff Harrison**, CEO, The Carbon Project, c*loud-based geosocial networking*
- **Dr. Emily Schnebele**, Research Assistant, GMU*; natural hazards, geoinformatics, remote sensing*

II. Overview and Summary of the Project
Dr. Nigel Waters

III. Discussion and Feedback from Advisors
Key points for discussion:
How do we make this system useable?

- How do we deliver the information to the people who need it? (i.e. Mobile app, Twitter, email, website?)
- Is the delivery method different for DoTs compared to first responders?

Stakeholders in Attendance:
Mr. Rafael Ameller, StormCenter Communications, Inc
Ms. Catherine Bohn, Dewberry
Dr. Silvana Croope (attending virtually), DelDOT
Mr. Jim Dear, MITRE
Mr. Joe Laun, Fairfax County Fire and Rescue
Mr. David McKernan (attending virtually) Fairfax County Office of Emergency Management
Ms. Kasey Parr, Maryland Emergency Management Agency
Mr. Christian Rasmussen, National Geospatial Intelligence Agency
Mr. Mike Liddle, Fairfax County
Ms. Valerie Lefler (attending virtually), Integrated Global Dimensions
Mr. Bill Shaw (attending virtually), Idaho Transportation Department
Mr. Sam Wear (attending virtually), Westchester County GIS, White Plains, New York

Stakeholders unable to attend:
Dr. Sreenivas Alampalli, NYSDOT
Mr. Dan DeBroux, Naval Postgraduate School

Mr. Sheldon Drobot, UCAR
Dr. Mike French, MITRE
Dr. Rebecca Goolsby, Office of Naval Research
Mr. Virgil Gray, Virginia Department of Emergency Management
Ms. Jessica Puchala, Maryland State Highway Administration
Mr. Ken Rudnicki, City of Fairfax Office of Emergency Management
Col. W. Mark Valentine, FEMA
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Summary and Meeting Notes:

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Ms. Kasey Parr, Maryland Emergency Management Agency
Mr. Christian Rasmussen, National Geospatial Intelligence Agency

Stakeholders Participating Online:
Ms. Catherine Bohn, Dewberry
Dr. Silvana Croope, DelDOT
Ms. Laurel McGinley, Dewberry
Mr. Bill Shaw, Idaho Transportation Department
Mr. Sam Wear, Westchester County GIS, White Plains, New York

Stakeholders unable to Attend:
Dr. Sreenivas Alampalli, NYSDOT
Mr. Dan DeBroux, Naval Postgraduate School
Mr. Sheldon Drobot, UCAR
Dr. Mike French, MITRE
Dr. Rebecca Goolsby, Office of Naval Research
Mr. Virgil Gray, Virginia Department of Emergency Management
Ms. Valerie Lefler, Integrated Global Dimensions
Mr. Mike Liddle, Fairfax County Office of Emergency Management
Mr. David McKernan, Fairfax County Office of Emergency Management
Ms. Jessica Puchala, Maryland State Highway Administration
Mr. Ken Rudnicki, City of Fairfax Office of Emergency Management
Col. W. Mark Valentine, FEMA
Mr. Don Willis, Virginia Department of Emergency Management

The Meeting began with a Power Point presentation by team members documenting research progress since the last advisory meeting on March 20, 2013. A pdf of the presentation is attached. Following the presentation the floor was opened up for general discussion, input and suggestions by the stakeholders. This discussion is documented in these notes:

How do we get the information out, how do we make the system useable and deliver the information to the people who need it (state and local DoTs, first responders, emergency management agencies)?

- Build a collaboration site, where we make our research available to Stakeholders
- Perhaps give a demo version as a free roll-out to some emergency management agencies to test the system, get the word out about our work

What are our options for output?
- Any output that is not a multipage report is good
- Perhaps a snapshot picture with an expand feature
  - No more than 3 sentences describing what is happening
  - Perhaps a “Pinterest like” card
- Some kind of brand control, with a logo, some sense of quality control
- Add “SMEM” (social media for emergency management) at the end of our hashtag so it will attract the attention of professional emergency managers and agencies.

Need to take into account people’s workflow, what they use for situational awareness, any integration into that would be successful
- Push out little tips, a snapshot or observation, and then have it link to a platform
- Roads are just one piece, property, critical facilities and infrastructures can also be identified
- Last thing an EOC manager wants to do is go to another viewer, if we can get our content to the local municipality/county then they can publish in their system. The real power at the local level for decision makers is on the desktop
- EOC only wants to get the data from authoritative sources, where is the URL and how can we consume it?

Current time frame (6-12 hours) for getting the information to first responders is too slow-within an hour they are already at the location
- Perhaps we can aid first responders by providing archival imagery which can be used for comparison
- In the near future, maybe firehouses will have their own UAV and information could be shared with us
- Can be also use data collected into the field, mobile observations and send it back to optimize site inspections?

GMU would be interested in participating in future MITRE SIMEXs to test real time support and crisis management initiatives

Information delivery method needs to be fast, brief, with the ability to be integrated into current EOC and DoT workflows

Appendix B: Publications and Presentations

I. Publications

II. Presentations

I. Publications

Book chapter:
Schnebele, E., Oxendine, C., Cervone, G., Ferreira, C., Waters, N. Using non-authoritative sources during emergencies in urban areas. In *Computational Approaches for Urban Environments*. Helbich, M., Arsanjani, J.J., Leitner, M., Eds*., in press*.

Published peer reviewed articles:
Schnebele, E., Cervone, G., Waters, N. 2014. Road assessment after flood events using non-authoritative data. *Natural Hazards and Earth Systems Science*, 14, 1007-1015.

Schnebele, E., Cervone, G., Kumar, S., Waters, N. 2014. Real time estimation of the Calgary floods using limited remote sensing data. *Water*, 6 (2), 381-398.

Schnebele, E., Cervone, G., Waters, N. PhD Showcase: Initial validation of non-authoritative data for road assessment. ACM International Conference on Advances in Geographic Information Systems. *The SIGSPATIAL Special*, 5, (3), Orlando, FL., November 2013.

*Schnebele, E. and Cervone, G. 2013. Improving remote sensing flood assessment using volunteered geographical data. *Natural Hazards and Earth System Sciences*, 13, 669-677.

Paper in review:
Schnebele E., Tanyu B., Cervone G., Waters N. Review of remote sensing methodologies for pavement management and assessment, European Journal of Transportation Research.

Paper in preparation:
Cervone, G., Schnebele, E., Waters, N., Mattson, M., Harrison, J., Moccaldi, M., and Sicignano, R. Using Social Media to fill the Gaps in Urban Areas During Emergencies.

II. Presentations

Cervone, G., Schnebele, E., Waters, N., Mattson, M., Harrison, J., Moccaldi, M., and Sicignano, R. *Using Social Media to fill the Gaps in Urban Areas During Emergencies,* National Science Foundation (NSF) Big Data and Urban Informatics Workshop, Chicago, IL, August 2014.

Schnebele, E., Cervone, G., Waters, N. *Fusion of social media and remote sensing data for creating value added products of flood damage and transportation assessments*, Association of American Geographers (AAG) Annual Meeting, Tampa, FL, April 2014.

Schnebele, E., Waters, N., Cervone, G., Harrison, J. *Fusion of remote sensing and non-authoritative data for flood disaster and transportation infrastructure assessment*, FEMA National Capitol Region HAZUS User's Group (HUG), delivered virtually, March 2014.

Waters, N., Cervone, G., Schnebele, E., Harrison, J. *Using Social Networks and Commercial Remote Sensing to Assess Impacts of Natural Events on Transportation Infrastructure*, Transportation Research Board (TRB) 93rd Annual Meeting. Washington, DC, January 12-16, 2014.

Schnebele, E., Cervone, G., Waters, N. *PhD Showcase: Initial validation of non-authoritative data for road assessment*. ACM International Conference on Advances in Geographic Information Systems (ACM SIGSPATIAL). Orlando, FL. November 4-8 2013.

Schnebele E., Cervone G., Oxendine C., Waters N. *Non-authoritative data for flood disaster and road infrastructure assessment*, the 36th Applied Geography Conference. Annapolis (AGC), MD. October 30 – November 1, 2013.

* Schnebele E., Cervone G., Oxendine C., Waters N. *Social Media and Remote Sensing Data Fusion for Post-Flood Traffic Assessment*. Presented at the Association of American Geographers (AAG) Annual Meeting. Los Angeles, CA. April 2013.

* Oxendine, C., Waters, N., Schnebele, E., Cervone, G. (2013, April). *Analysis of Social Media Data to Reduce Risk during Emergency Evacuations*. Presented at the Association of American Geographers (AAG) Annual Meeting. Los Angeles, CA. April 2013.

** Work started before the beginning of the award*

Appendix C: **State DOT Demo Package and Responses**

I. Invitation to participate email

II. Demo package email

III. Feedback responses

IV. State DOT personnel contacted for feedback/ personnel who responded

I. Invitation to participate email

Dear ____,

Our research team in the Department of Geography and Geoinformation Science at George Mason University in Fairfax, VA is working on a grant from the US Department of Transportation in which we model and assess the impact of natural hazards on transportation infrastructure using social media.

Specifically, we have developed a software architecture to collect geographic information from Twitter and other social media and news sources concerning hazardous natural events such as floods, hurricanes, and tornadoes among others.

The research team includes two industry partners. Our primary partner is The Carbon Project, a software company that has extensive experience working with the Federal Government and other governmental organizations in using social media to mitigate the impact of natural disasters such as Hurricane Sandy in 2012 and the Colorado floods in the fall 2013. The information we collect is geolocated by our research team and provides an initial estimate of the area affected by the natural disaster and the extent of the damage to the existing transportation infrastructure. Our second industry partner is the satellite company, Digital Globe. Once we have identified the approximate area of damage using social media and other geolocated sources we request that Digital Globe immediately re-cue one of their satellites to provide new imagery of the affected area. In addition, we supplement satellite remote sensing with aerial imagery from the Civil Air Patrol and UAVs. Our research term at GMU compares the new imagery with archived imagery to provide precise estimates of the damage to the transportation infrastructure. This is in order to identify regions that may have become inaccessible, isolated, or damaged. The final step in our project will be to make this information available to first responders, emergency management personnel, and local and state Departments of Transportation officials via mobile phones and computing devices.

As part of this research, we are asking a small number of experts in the field of transportation and emergency response to participate as informal advisors to provide input regarding our results. We believe that you could offer our team valuable insight into this research and we hope that you would be willing to act as one of our advisors in this very exciting and promising research initiative. Your time commitment would be minimal and we hope that you would find our research interesting, informative and useful.

Sincerely,
Emily Schnebele, PhD
Research Assistant

II. Demo package email

Dear _____.

We really appreciate your willingness to help us and support our research project. Please find below a link to videos demonstrating the applications we have developed to utilize social media to identify the locations of natural hazards, the subsequent collection of remote sensing data, and how these data can be used to aid the assessment of damage to transportation infrastructure. Following your review of the video demonstrations, we would appreciate it if you could provide us with answers to the questions below. We would be grateful if you could send us your feedback by Wednesday, June 18th.

Thank you again.

Best regards,
Emily Schnebele, PhD
Research Assistant

cc. to members of the research team

http://thecarbonproject.azurewebsites.net/dot/index

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection (e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more “user friendly”?

4. How do you see our applications fitting into your emergency management or maintenance agendas?

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?

III. Feedback responses
(questions are in black, unabridged responses in red)

1. Dr. Sreenivas Alampalli, New York

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

Hurricanes and snow storms; Most procedures utilize visual information as we do have staff all around the state and they can provide first-hand information. Then, depending on the situation, engineers are sent to assess the required information.

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection (e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

Not to my knowledge.

3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more “user friendly”?

They will be useful to get a global picture of the situation quickly. Before and after photos are very useful. If there is a way to zoom to a specific area within each shot will be great. Other than that I do not have any specific changes/additions at this time.

4. How do you see our applications fitting into your emergency management or maintenance agendas?

It may help to ascertain the situation quickly and then to utilize resources in more effective manner. We still need visual and site inspections to document the information more details and also to get quantitative information for the work that has to b done to reopen/restore services.

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?

It is a combined effort of operations (maintenance) and engineering. Of course, they do coordinate extensively with state emergency management, FEMA and others.
+++

2. Dr. Brian Bruckno, Virginia

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

The last five years have been largely free of damage due to large-scale natural hazards, although the recent 5.8 magnitude earthquake required an extensive bridge and structure inspection program as well as some bridge repairs. The inspection was field-based. The Virginia Department of Transportation does maintain a number of low-water bridges, which are designed to flood under 5- to 10- year recurrence interval events, and there have been a number of injuries and some fatalities during this period. Small-scale hazards have been numerous. These smaller-scale hazards, consisting mainly of rockfall, slope failures, and sinkholes, present their own set of challenges, in that they often remain undetected by public-sector workers, and are often reported by the traveling public. Relying on this sort of reporting can be problematic, in that the traveling public is occasionally unaware of the proper agency to which to report a hazard, resulting in communication delay. For rock slope hazards, we have generally used a field geologist-based assessment method, augmented by terrestrial LiDAR.

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection (e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

Our use of remote sensing is still very limited. We occasionally use LiDAR (mainly terrestrial but occasionally aerial) to assess the extent of slope or erosion damage, and to assist with estimates of quantities for excavation and remediation. The Virginia Department of Transportation has been a partner in several research programs investigating the use of InSAR for monitoring transportation assets, which has been successful but remains in the research stage. I anticipate the aerial LiDAR will see more use in upcoming years, and InSAR (or other spaceborne radar methods) will be implemented in a limited but significant manner in the 5- to 10-year frame.

3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more “user friendly”?

My only suggestion would be to ensure that the data can be ported to mobile platforms for immediate field use.

4. How do you see our applications fitting into your emergency management or maintenance agendas?

Our most sensitive infrastructure is bridges. Storm damage may cause considerable upset to the traveling public when roads are potholed, buckled, or otherwise difficult to navigate, but damage to bridges can cause fatalities and very long-term disruptions to commuter patterns. After events, bridges need to be inspected first, and a crowdsourced data stream could allow the inspection, which is limited by manpower, to be more efficiently directed.

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?

That depends on the extent and nature of the damage or wear. We have a number of standard details (for slope remediation, as an example) and on-call contracts that allow smaller failures to be repaired in a turnkey manner, and an inspection protocol which is fairly standard among DOTs. This is a Maintenance activity in such cases. When the damage or the nature of wear is extensive, or is such that standard drawings no longer apply, or of a novel method needs to be implemented, it becomes a design issue and is generally handled by either our Bridge or Materials Section.
+++

3. Mr. Michael Foppe/ Mr. Tom Blair, Missouri

"Tom I am going to base my answers on my experiences in the NE since I have not been involved with a lot of disasters here in my new district." – Michael Foppe

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

Flooding, heavy snows & blizzards, ice storms and wind storms
Generally for assessments of the damage it was more info from employees in the field and working with emergency management and customer service and the media broadcasts. We have had Civil Air Patrol give aerial photos of flooding and worked with NWS and Corp. of Eng. on predictions of impacts of storms then following the event having debriefs with NWS & Corp. of Eng. and EMAs about what the actual impact of the event was to compile all the info for an assessment.

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection

(e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

Aerial with Civil Air Patrol was used to monitor the levees along the Mississippi River and it NW Mo. during heavy flooding and also is set up for inspections of bridges after an earthquake of a certain magnitude.
Radar I fell is very important for tracking storms and understanding intensity of an events and timing of an event.

3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more “user friendly”?

Not at this time

4. How do you see our applications fitting into your emergency management or maintenance agendas?
Yes

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?

I would say engineering maintenance
++

4. Mr. Kevin Griffin, Utah

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

Utah has experienced some large landslides that have closed state roads. Some of these have been brought on by burn scars that we left from the summer fire season. In some of these cases we have been placing portable weather stations to help us identify when a severe weather even is going to occur so notifications can be sent to UDOT forces and public safety. We have other areas that we know the road exists over a potential land slide area. Drainage system and inclinometers have been placed to help identify movement. UDOT does use aircraft to fly over disaster areas to assess the total impact of disaster areas.

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection

(e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

Utah has used inclinometers to help identify the movement in known land slide prone areas. We have not used to my knowledge any of the devices you mention.

3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more "user friendly"?

The data portal is very interesting. I can see significant value in this type of technology. Having the ability to show these events in this format can be a significant cost savings to DOT's.

4. How do you see our applications fitting into your emergency management or maintenance agendas?

Like I mentioned earlier, UDOT has used aircraft numerous times in the past to assess these disaster areas. This technology will provide us with faster analysis capabilities for the deployment of resources and public safety. I know UDOT will be interested in having this ability.

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?

The transportation infrastructure assessment responsibility in Utah resides with UDOT. UDOT uses both the Maintenance Division and our Structures Division to provide assessment of most of our assets. Our Central Planning Division provides assessment of our pavement conditions.
++

5. Mr. Owen Hasson/Mr. Tom Blair, Missouri

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

- Snow & Ice Storm Events
- Severe Weather (Heavy rain, Thunderstorm) Events
- Tornados, Straight Line Winds
- Flooding

We assess damage and impact to our system via road reports from our field personnel or other credible sources such as highway patrol, other state agencies, or public utility contacts. In addition we use remote viewing from our highway camera system, emailed or texted field photos and local news reports.

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection (e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

- Highway CCTV Cameras
- NOAA Weather Alert Radio Notification
- Weather / Satellite Monitoring
- Local & National News
- Personal email notifications from NWS Hydrologists
- Roadway Weather Information Systems (RWIS)
- NOAA Advanced Hydrologic Prediction Service web-site
- April 18, 2008 5.4 magnitude earthquake on the Wabash Valley Seismic Zone. I use a USGS web-based notification for Seismic events per my specific user criteria.

Radar and RWIS stations and “Text” alerts seem to work well as other non-visual image forms of data and information.

3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more “user friendly”?

I did not find the data portal link particularly helpful for data. It appears to be a tabbed web-site with information on each tab. Is the intent for academia or “boots on the ground” managers and responders for events? If the target audience is for the response community I would suggest basic and standard terminology and structuring of the site using something similar to NIMS

4. How do you see our applications fitting into your emergency management or maintenance agendas?
The more real-time information the better. Sites with map layering/filtering seem to help significantly during events along with the ability to geo-select areas using free form polygons.

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?
Yes
+++

6. Mr. Chris Joncas, Nevada

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

The most recent event happened, in two fold. One, the Mt. Charleston area experienced the “Carpenter 1 fire last summer. Mt. Charleston is just north of Las Vegas, NV. About 3 months after the fire, we had some serious rain in that same area and being that there was no vegetation due to the fire, we had significant flooding in dry creek beds and other areas. It caused some pretty good damage. Nothing like flooding that Colorado had, but enough it impacted our infrastructure in that area. We used BOOTS ON THE GROUD for reporting and information gathering.

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection (e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

Our so called “Location Section”, is working on obtaining a UAV, at this point we do not have that technology.

3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more “user friendly”?

At this point, no.

4. How do you see our applications fitting into your emergency management or maintenance agendas?
At this point without spending a lot time using them I really cannot say. Using something for 15 minutes is WAY different than using it for an actual event lasting days or weeks at a time.

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?

Yes, it falls under the Emergency Management/Homeland Security section under “Maintenance & Asset Management”.
+++

7. Mr. Sam Wear, New York

This project represents a potentially valuable capability for local and state governments
++

8. Dr. Silvana Croope, Delaware

1. Over the last five years, what natural disasters have affected transportation infrastructure in your region and what procedures and techniques did you utilize for assessment?

Hurricane Irene, Sandy, the "2013/2014 snowmagedon" and other past years nor'easters. Monitoring: Hurrevac, weather sources, transportation RWIS and traffic flow detection systems. We also got a DelDOT Twitter and Facebook account where people input messages, phone calls, word-of-mouth, radio staff communication, 911 CAD and connection with cooperation agencies. We had field crew going to impact locations during and post-event (pictures, reports from our internal TMC system); with later survey and engineers working on the problem. No comprehensive process supporting damage assessment or "snow plowing" management activities.

2. Over the last five years, have you used remote sensing data to assess the impact of a natural hazard on transportation infrastructure? If so, what platform was used for collection (e.g. satellite, aerial, UAV)? What data products, other than visible images, do you feel are most important (e.g. thermal, infrared, RADAR)?

We only used cameras and the traffic detectors for traffic flow and the RWIS technology.
3. Do you have any suggestions for changes or additions to our data portal which may be found at http://terra.cos.gmu.edu/DOT-Rita-13/index.html to make it more "user friendly"?

For the orange rectangles with the "carbon scanner demo- zoom into alerts", it would be nice if they could be somewhat transparent and a link to the imagery for the flooding such as the "UAV imagery in Google Earth". This would be a complete application from the "where is it" to "what is it". Some tools such as a "red line" contour to help with measuring the before and after the impacted area could be used to help identify and mark the area for calibration for ground work and future design rebuild/adapt type of work following the visual damage assessment. The new impact area with transparency capabilities can also help with the "size of impact".

4.How do you see our applications fitting into your emergency management or maintenance agendas?

I would use it for:

- Real-time monitoring, warning and blocking roadways, bridges, send out crew for rescue/last minute evacuation
- Calibrating information from RWIS + Flooding systems and support of the activities described above
- Calibrating Hazus for a more accurate loss estimation
- Documenting reports and application for disaster money
- Calculating area of impact to support improvement in engineering design for transportation infrastructure
- Storing information and building the support for extreme events/climate change trends
- Using all of the above for planning and policy (new or changes)
- Using all of the above for regular and contingency budget and insurance/CAT bond

5. Does transportation infrastructure assessment fall under the engineering maintenance or emergency management departments for your state DOT?

Both departments because there is: an overall report and specific reports. The overall report serves the community and developments, specific reports serves DOT with FHWA and other federal agencies disaster grant/loan applications.

IV. State DOT personnel contacted for feedback/ personnel who responded

The table below lists all state DOT personnel who were contacted with a request to review our materials. The names highlighted are those who sent responses.

Name	Email/Phone	State	Title/Department
Dr. Sreenivas Alampalli	Sreenivas.Alampalli@dot.ny.gov	New York	Director, Structures Evaluation Services Bureau
Joseph Baker	joseph.baker@dot.ri.gov	Rhode Island	Administrator, Highway & Bridge Maintenance
Richard Beck, PhD	Richard.C.BECK@odot.state.or.us	Oregon	Environmental Program Coordinator
Joseph Bertoni	correspondence.unit@dot.state.nj.us	New Jersey	Acting Commissioner of the NJ Department of Transportation
Kevin S. Bloss	(405) 521-2557\kbloss@odot.org	Oklahoma	State Maintenance Engineer
Michael Bonini	mbonini@state.pa.us	Pennsylvania	Research Division Manager
Jeff Brown	jeff.brown@wyo.gov	Wyoming	
Dr. Brian Bruckno	Brian.Bruckno@vdot.virginia.gov	Virginia	
Dr. Silvana Croope	Silvana.Croope@state.de.us	Delaware	TMC Interoperability and Mapping Engineer
Augie Cruz	augie.cruz@dot.ca.gov	California	GIS coordinator for the Div. of Env. Analysis
Caleb Dobbins	bureau58@dot.state.nh.us	New Hampshire	Administrator, Highway Maintenance
Dale Doughty	maintenance.mainedot@maine.gov	Maine	Chief, Bureau of Maintenance and Operations
Andy Doyle	adoyle@dot.ga.gov	Georgia	State Bridge Maintenance Engineer
Matt Dunn	(662)842-1122/medunn@mdot.ms.gov	Mississippi	District Maintenance Engineer
Vince Fairhurst	fairhuv@wsdot.wa.gov	Washington	Office of Emergency Management
Robert Faley	Robert.Faley@state.vt.us	Vermont	District 1 Transportation Administrator
John Farley	jcfarley@ncdot.gov	North Carolina	
Jim Feda	fedajj@scdot.org	South Carolina	Director of Maintenance
Michael Foppe/Tom Blair	Thomas.Blair@modot.mo.gov	Missouri	Maintenance Supervisor - City of Troy
Judy Gates	env.mainedot@maine.gov	Maine	Director, Environmental Office
Dick Gersib	gersibd@wsdot.wa.gov	Washington	Program Manager, Stormwater and Watersheds Division
Jaffar Golkajeh	jgolkajeh@indot.in.gov	Indiana	Manager-Bridge Asset Management & Program Engineering
Susan Gorski	gorskis@michigan.gov	Michigan	State Long-Range Plan, Development of Strategic Plans
Ed Green	egreen@azdot.gov	Arizona	Hazmat/GIS Team Leader
Kevin Griffin	kgriffin@utah.gov	Utah	Director of Maintenance
Mark Harris	mharris@mdot.state.md.us	Maryland	Emergency Response Manager & Grants Coord
Owen Hasson/Tom Blair	Thomas.Blair@modot.mo.gov	Missouri	Incident Management Coordinator - St. Louis
Jerry Hatcher	Jerry.Hatcher@tn.gov	Tennessee	Director, Maintenance Division
Audrey Hidano	audrey.hidano@hawaii.gov	Hawaii	
Duane Hill	duane.hill@state.mn.us	Minnesota	District 1 Engineer
Howard Holland	howard.holland@txdot.gov	Texas	Director of Maintenance
Dave Huft	dave.huft@state.sd.us	South Dakota	Research Program Manager, Division of Planning & Engin.
Lisa Idell-Sassi	dot.iways@alaska.gov	Alaska	Real-Time Systems Coordinator
Dr. Katherine Jefferson	katherine.jefferson@dc.gov	Washington, DC	Associate Director of Transportation Operations
Christopher C. Joncas	cjoncas@dot.state.nv.us	Nevada	Emergency Operations Project Manager
Dave Jones	dave.jones@itd.idaho.gov	Idaho	
Joel Jundt	joel.jundt@state.sd.us	South Dakota	Director, Division of Planning and Engineering
Walt Kerttula	wkerttula@mt.gov	Montana	Disaster and Emergency Services Coordinator

Vince Latino	Vince.Latino@la.gov	Louisiana	Chief of Maintenance
Al Leidner	leidnera@nyc.rr.com	New York	
Kyle Lester	303-512-5218	Colorado	Director Highway Maintenance
Rachel Lewis	614-351-2892	Ohio	Administrator, Office of CADD & Mapping Services
Michael Lonergan	Mike.Lonergan@ct.gov	Connecticut	Bureau Chief, Bureau of Highway Operations
Anthony Lujan	Anthony.lujan1@state.nm.us	New Mexico	Deputy Secretary Highway Operations
Cathy Mather/John Corbin	cathy.mather@dot.iowa.gov	Iowa	Assistant to John Adam
Kristin McHugh	kristin.mchugh@dot.wi.gov	Wisconsin	North Central Region Communications Manager
Bob McWhorter	mcwhorterr@dot.state.al.us	Alabama	Director, ALDOT Office of Homeland Security
Jim Mitchell, PhD	Jim.Mitchell@la.gov	Louisiana	IT GIS Manager, LA Dept. of Transportation & Development
Peter Niles	peter.niles@state.ma.us	Massachusetts	District 1 Highway Director
Beth Petrowske	beth.petrowske@state.mn.us	Minnesota	District 1 Public Affairs Coordinator
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Appendix D: Mentions of Research Project in the Media

Government Computer News (GCN):

Project mines tweets, satellite and drone imagery for disaster response

http://gcn.com/articles/2014/05/02/carbon-scanner.aspx?m=1

By Rutrell Yasin
May 02, 2014

Hurricanes, floods, fires, earthquakes and blizzards can cause massive disruptions to transportation networks and other public safety systems, making it difficult for emergency management workers to know what's happening on the ground when a disaster strikes.

However, first responders might gain a better understanding of an unfolding emergency from a new crowdsourcing project that uses cloud-based tools to help guide satellites and small unmanned aerial vehicles (UAVs) to trouble spots based on posts from social media.

At the center of the project is a geo-social networking application called the Carbon Scanner, developed by the Carbon Project, a software firm that specializes in "geo-social" networking and cloud computing. The scanner picks up on Twitter hashtags related to natural disasters and produces a map showing the location of the tweets so emergency workers can better pinpoint affected areas.

"It's an alert system that will show where tweets are located and that will hopefully help us define an area where we should be investigating," said Nigel Waters, the project leader and a professor with George Mason's Department of Geography and Geoinformation Science, a project partner. After finding the area of interest, satellite imagery could give emergency operations centers a first look at the extent of damage to infrastructure, Waters said.

The tweet does not need geo-location to be picked up by Carbon Scanner. If it does, that's fine, but the scanner can also detect place names in tweets, such as "flooding at La Guardia Airport" and then put a dot on the map based on that data.

The Scanner mines enough information to get a snapshot of what's going on at a location during a natural disaster, said Jeff Harrison, CEO of the Carbon Project.

Officials can then fuse satellite imagery with pictures and video from a variety of other sources, including Civil Air Patrols, drones, traffic cameras and citizens, Waters noted. The project participants are using satellite imagery from DigitalGlobe, a provider of commercial high-resolution earth imagery products and services.

The project is being funded by a grant from the Transportation Department's Research and Innovative Technology Administration. Its partners include George Mason University and representatives from state and municipal transportation departments in Maryland and Westchester County, N.Y.

The project started off with a focus on satellite imagery data, but feedback from the project's advisory group helped bring in airborne imagery from the Civil Air Patrol as well as from drones, Harrison said. Often, after storms or hurricanes, clouds can obstruct the satellite view of what is happening on the ground. This was the situation when heavy rains and massive flooding hit Colorado in September 2013.

In that case, project participants were able to mine data from Twitter and glean imagery data from drones supplied by a Falcon UAV to get a better picture of the effects of catastrophic flooding that devastated the state from Colorado Springs to Boulder County, Harrison said.

Drones will play a big role in providing more real-time information to emergency responders, Harrison, said, especially as the Federal Aviation Administration works to lift restrictions on their use. What's more, hundreds of small imagery satellites — the size of small refrigerators or big toasters — now being launched by companies such as Skybox and Planet Labs will help government respond to these at trouble spots on the ground, Harrison added.

The Carbon Cloud, which runs on Microsoft's Azure cloud platform, is essential for the rapid mining and processing of thousands of Twitter feeds, Harrison said. "I don't know if this [project] qualifies as big data, but it is pretty big data," he said.

In addition to mining Twitter and imagery data during the Colorado floods, participants in the two year project that ends in August 2014 have conducted a variety of studies assessing damage from Hurricane Sandy, which struck the northeast in 2012; and flooding in Waynesville, Mo., and the city of Calgary in Alberta, Canada in 2013.

Carbon Project Helps Connect Social Media to Satellites http://thecarbonproject.azurewebsites.net/News/Details/22

ALEXANDRIA, VA, 1.9.14 *- The Carbon Project today announced it was selected to work with George Mason University (GMU) to develop cloud-based tools for guiding mapping satellites or small UAVs during natural disasters - based on information from social media posts.*

"Hurricanes, floods, fires, earthquakes and blizzards can all cause massive disruption to transportation infrastructure. The ability of first responders and governments to direct needed resources to an area is often hampered by our ability to see what's happening," says Jeff Harrison, CEO of The Carbon Project. "In this crowdsourcing project, large groups of people provide small bits of information that can give us a better understanding of real-time events. This information is used to help guide satellites or small UAVs onto trouble spots."

The effort developed and deployed a cloud-based application called the Carbon Scanner to assess the impact of natural events on transportation infrastructure using social media, alert on trouble spots and help guide satellites or UAVs to collect imagery for rapid mapping. Project partners include George Mason University, The Carbon Project, commercial companies and community representatives from US state and local governments. The project is funded by a grant from the US Department of Transportation's Research and Innovative Technology Administration (RITA).

"This project has already made good progress in designing, developing and deploying a functioning capability," says Harrison. "We look forward to the second year of the effort and developing new ways to push this valuable information to those who need it."

Appendix E: **Final Article for Submission (Attached separately)**

Appendix F: Final Financial Statements (to be submitted separately)