Interactive comment on "Road assessment after flood events using non-authoritative data" *by* E. Schnebele et al.

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Received and published: 13 December 2013

article

Manuscript submitted to *Natural Hazards and Earth System Sciences*
Road assessment after flood events using non-authoritative data
Author responses to Dr. Del Vento (reviewer)

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Our responses are reported below, along with the unabridged comments from Dr. Del Vento.

> This paper describes very interesting new techniques for assessing flood damage using non-authoritative data.

We appreciate Dr. Del Vento's positive comment.

> I recommend to provide more details on how the assessment is done, e.g. how the weights are assigned in a practical example. Also more details about the flowchart of fig. 3 would be useful.

To add more detail, we have revised all of Section 3: Methodology as well as our description of how the road classification is accomplished in Section 4.2.

Section 3.1: Overview

This work is based on the fusion of non-authoritative data and its integration with traditional authoritative sources. Figure 3 illustrates the general methodology where non-authoritative data from multiple sources are combined to produce a spatial and temporal assessment of the disaster. While the precise definition of data fusion will vary by

discipline, for example, in computer science the process of data integration is considered to be the "data fusion"; in this work data fusion refers to the model in its entirety. The methodology consists of a three step process:

1. Non-authoritative damage assessment.

2. Integration with authoritative data for damage assessment.

3. Generation of road damage map.

The model begins with the integration of non-authoritative data (i.e. crowdsourcing and VGI) to create a damage assessment. The step is method-independent and can be performed using any method best suited for a particular combination of data and location. Because this step is not limited to a specific data type, it can easily be extended to integrate additional or different sources. After a damage assessment is created from non-authoritative data, it is integrated with available authoritative data to enhance the damage assessment. This step can be in the form of validation, if "ground truth" data are available, or can consist of an additional integration step whereby authoritative and non-authoritative data are incorporated to fill in gaps in the spatial or temporal data infrastructure. The final step is the classification of roads which may be compromised as a result of flooding. This is accomplished by applying a road network to the damage assessment. Depending on data availability and flood event characteristics, a temporal assessment of the flood event may be generated in addition to the spatial assessment. The specifics for each step as they apply in this paper are discussed Sections 3.2-3.4.

The novelty of this approach is the utilization of non-authoritative data to produce flood and road damage assessments. Although in this work specific crowdsourced data (Civil Air Patrol photos) and volunteered data (YouTube videos, Tweets) are utilized, this methodology can be extended to other sources. The goal of this paper is to illustrate how non-authoritative data can augment existing data and methods as well

as optimize response initiatives by identifying areas of severe damage.

Section 3.2: Non-authoritative damage assessment

We integrate non-authoritative data by interpolating to create a damage assessment surface. The geostatistical technique of kriging creates an interpolated surface from the spatial arrangement and variance of the nearby measured values (Stein, 1999). Kriging allows for spatial correlation between values (i.e. locations/severity of flooding) to be considered and is often used with Earth science data (Oliver and Webster, 1990; Olea and Olea, 1999; Waters, 2008). Kriging utilizes the distance between points, similar to an inverse weighted distance method, but also considers the spatial arrangement of the nearby measured values. In addition, a kriging interpolator is capable of providing some measure of error associated with the predicted values (Stein, 1999). A variogram is created to estimate spatial autocorrelation between observed values $Z(x_i)$ at points $x_1, \ldots, x_n$. The variogram determines a weight w_i at each point x_i, and the value at a new position x_0 is interpolated as

$$\hat{Z}(x_0) = \sum_{i=1}^{n} w_i Z(x_i). \tag{1}$$

Section 3.3: Integration with authoritative data

For this research, authoritative data in the form of a storm surge map created by FEMA MOTF is utilized to (1) illustrate how non-authoritative data can provide a range of damage estimations enhancing traditional storm surge products and (2) as a comparison of authoritative estimated flood extent. The damage assessment surface created from the non-authoritative data is first limited to the FEMA estimated flood boundary to illustrate how non-authoritative data provide a range of damage values in contrast to the binary assessment (flooded/not flooded) provided by the FEMA MOTF map. Second, the area (m^2) classified as flooded by FEMA is used as a baseline

by which the flooded area (m^2) estimated from non-authoritative sources can be measured against.

Section 3.4: Generation of road damage map

The identification of affected roads is accomplished by pairing a road network with the damage assessment surface. A layer comprising a high resolution road network is added to the damage assessment surface layer. Roads are then identified as potentially compromised or impassable based on the underlying damage assessment. The classification of roads is accomplished in ArcGIS 10 using the clip tool to select roads which are located within each damage class. Depending on the range of damage values as well as the scale of the domain, the classes can then be aggregated to facilitate a reduction in complexity and present a clearer representation. Potentially affected roads could also be classified as a function of distance from the flood source (i.e. river or coastline) or distance from the flood boundary.

Section 4.2: Road damage map

The non-authoritative damage assessment was also utilized to identify areas of potential road damage. Although, for the sake of comparison, the damage assessment was limited to within the authoritative FEMA surge extent area (Figure 2c), for the classification of road damage, the area was not limited to the authoritative extent. The fusion of the non-authoritative data predicted flooding and damage outside the FEMA flood extent boundaries, so the full damage assessment was utilized for the road classification.

The road network from the TIGER/line® shapefile was layered over the damage assessment map. Roads were then classified based on the underlying damage assessment layer by clipping and then segregating roads from the original road network layer (Figure 2d). This yielded 10 individual road classes, with values from 1-10, repre-

senting the original 10 damage classes from the gridded Civil Air Patrol crowdsoured photos and YouTube videos. Roads classified with values between 1-3 were considered to have no damage and were not included in Figure 2d. The remaining classes were aggregated into slight (values 4-6), medium (value 7), and severe (values 8-10) damage. The selection of class assignment was based on how the gridded values from the crowdsourced Civil Air Patrol data set were ascertained. The gridded values were a function of number of photos and their averaged values which originally consisted of three classes ranging from 1-3. Therefore, the final road classifications were also represented as three damage classes.

By using the damage assessment layer along with a high resolution road network layer, roads which may have severe damage can be identified at the street level. This is critically important during disasters when evacuations and response initiatives are paramount. For example, following the Colorado floods of September 2013 over 1000 bridges required inspection and approximately 200 miles of highway and 50 bridges were destroyed [1]. Rapid and directed identification of affected areas can aid authorities in prioritizing site visits and response initiatives as well as task additional aerial data collection.

> I am a strong supporter of open data and reproducible research, so I would also like to encourage the sharing of the data and the code used for this paper, if possible. Even with a very restrictive license (e.g. "code and data is made available only to reproduce the results of the paper and no other purposes") would be very useful.

We are also proponents of open data and reproducible research and would be happy to place the data on-line for others to use.

> In conclusion, I strongly recommend accepting this paper and I suggest some minor improvements, namely increase the in-depth discussion of the technical details on how the technique work.

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[1] http://www.denverpost.com/breakingnews, http://www.thedenverchannel.com/news/local-news/

We thank Dr. Del Vento for his recommendation.

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