FINAL REPORT

University: University of Alabama, Tuscaloosa

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Type of Project (Partners or Cooperative): Partners
Project Title: Development of a U.S. Flood Inundation Map Repository (USFIMR) based on satellite remote sensing analysis
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Section 1: Summary of Project Objectives

Three objectives were outlined in the proposal:

1. Develop a methodology for quasi-automatic flood inundation mapping based on remote sensing imagery

2. Assess the utility of the mapping products in a test case application for hydraulic modeling calibration and validation

3. Compile a flood inundation repository based on reported flood events

Section 2: Project Accomplishments and Findings

Research and development activities focused on (1) developing an accurate and streamlined procedure for mapping flood inundation from readily available satellite imagery, and (2) developing an open, easy to use, and useful online portal to disseminate the flood inundation maps. Research into remote sensing based classification of floodwater focused on two type of satellite sensors: multi-spectral and Synthetic Aperture Radar (SAR). Different floodwater mapping techniques were researched for each type of sensor. We have found that a combination of remote sensing and GIS analysis procedures are needed in order to produce an accurate classification of floodwater. For multi-spectral sensors (e.g. Landsat 8 OLI) we found that supervised classification, where the spectral signature of land cover classes is identified by the operator, was found to be the most accurate (Munasinghe et al., under review). When available image classification was incorporated with, a per- and post-flood change detection analysis. This improved the accuracy of the flood map by eliminating some noise (e.g. cloud shadow). For SAR imagery, a reflectance threshold has to be identified for each image for water classification and a per- and post-flood change detection analysis was found to be critical for eliminating the significant amount of noise associated with SAR analysis. In terms of utility of each sensor type, we found that while multi-spectral imagery is preferable, as water classification is more accurate, and more readily available (primarily for Landsat), given its relatively coarse temporal resolution and the fact that it cannot be used when the area is covered by clouds, it is quite often not a viable source for a flood event of interest. SAR imagery, on the other hand, is advantageous for when a region has a considerable cloud cover, but its availability is limited.

Two major research gaps were identified during the project: floodwater classification under tree-canopy, and floodwater depth estimation. Remote sensing based mapping of floodwater in areas with dense tree cover is a well-recognized problem. In the past, attempts to mediate it was mainly based on remote sensing analysis (e.g. backscatter ratio indices). Similar

approaches were initially attempted in this project but yielded unsatisfactory results. This prompted us to develop a topography-based approach which couple remote sensing water classification with manual topographic analysis, in which the operator will fill the gaps in the remote sensing classified map by manually inspecting the topography of these sites relative to their surroundings. This has led to the development of new collaborations aimed at developing more automated algorithms. Information on floodwater depths is key for a variety of flood event response and analysis efforts. Measuring or estimating floodwater depth is difficult, especially for large flood events. A new methodology was developed, as part of this project, for calculating floodwater depth maps based on flood inundation and DEM layers (Cohen et., accepted).

The overarching goal of this project was to develop a repository that can be used by modelers to develop and test models. To this end, we developed an open and easy to use web-interface. A proof of concept study (Zhang et al., under review) was used to gain insights into the utility of remote sensing flood inundation maps for models' validation and comparison. The USFIMR portal (https://sdml.ua.edu/usfimr/) was launched in September 2016. For each flood inundation map added to the portal, a short description was added through the web-interface as well as links to download the inundation extent shapfile, download a Digital Elevation Model (DEM) file for the regions, and a link to the nearest upstream USGS gauge site. Each layer includes a detailed metadata file. The USFIMR portal was initially based on Google Maps embedded in the Surface Dynamics Modeling Lab (SDML) website. While Google Maps include the needed features for accessing the maps the associated information, it slowed down considerably when multiple layers were added. This is problematic as it considerably hindered user interaction and thus USFIMR usability. In September 2017, we transition from Google Maps to ArcGIS Online, embedded in the same web page. This improved USFIMR upload and navigation time on the website.

A total of 46 maps were added to the USFIMR; 35 were classified at the SDML and 11 at the Dartmouth Flood Observatory (DFO; co-PIs on this project). Some flood events yielded multiple map layers as we intentionally only included one river reach per map. As an open repository, USFIMR does not track the number of views or downloads. We did receive a number of requests to generate flood inundation maps from across the world. These include, for example, researchers and practitioners from the Institute for Environmental Studies in Amsterdam, University of North Carolina, NCAR, and the Global Flood Partnership.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

This project addresses a need by the NWC to develop and test flood predictions. It addresses the fact that readily available observed flood inundation extents data is lacking. With the National Water Model (NWM) now generating streamflow data for more than 2.8 million streams in Continental USA, USFIMR can be seen as an instrumental and complementing effort for validation of predicted flooding scenarios. NWC efforts on developing a hyper-resolution national flood prediction system is increasingly focusing on flood inundation mapping using hydrology/hydraulic models. Scientists within the NWC has already started using USFIMR for model validation. It was also featured in the 2017 NWC Summer Institute as a resource for projects. The 2016 NWC Summer Institute, where the USFIMR model validation proof-of-concept began, demonstrated the need for flood inundation observational data for model comparison and analysis.

Section 4: Benefits and Lessons Learned: University Partner Perspective

Two graduate students were funded by this project. Bradford Bates was the first graduate research assistant working on this project. He developed much of the mapping procedure and web-interface. He received a full-time job at the NWC after 6-months on the project! Bradford was replaced by Dinuke Munasinghe, which led the initial flood classification study as a participant at the 2016 NWC Summer Institute. Dinuke continued the development and

repository building efforts. He was assisted by an undergraduate research assistant, James Misfeldt. James was responsible increasing the size of the repository and the transition from Google Maps to ArcGIS Online. The involvement of three students in this one-year project is a considerable benefit to the PI's research group and the University as a whole.

The project helped foster collaborations between the PI and co-PIs as wells as with the NWC. The PI has been a Research Theme Leader in the last three NWC Summer Institutes, and this project contributed considerably to his involvement in this program. This project also helped foster collaborations between the university and the NWC, which is a high priority for the university. The PI leads the UA-NWC Water Research Group which main goal is to promote collaborations between the University of Alabama faculty and students and the NWC scientists. This project emphasized the importance and benefit for the university and the NWC from such collaborations.

This project yielded a number of new research directions that we intend to advance in coming years. These include the further development and application of the floodwater depth estimation tool for USFIMR and DFO and the development of a better 'under-canopy' classification methodologies.

Section 5: Publications and Presentations
Three journal papers are currently under review:

Munasinghe, D., S., Cohen, Y., Huang, Y., Tsang, J., Zhang, Z., Fang, Intercomparison of Satellite Remote Sensing Techniques of Flood Inundation Mapping, *Journal of American Water Resources Association*

Cohen, S., G. R. Brakenridge, A. Kettner, B. Bates, J. Nelson, R. McDonald, Y. Huang, D. Munasinghe, and J. Zhang, Methodology for Estimating Floodwater Depths from Remote Sensing Flood Inundation Maps and Topography, *Journal of American Water Resources Association*

Zhang J., Y., Huang, D., Munasinghe, Z., Fang, Y., Tsang, S., Cohen, Comparison of Flood Inundation Mapping Techniques between Different Modeling Approaches and Satellite Imagery, *Journal of American Water Resources Association*

Four presentations were given:

Cohen, S., 2017. The U.S. Flood Inundation Map Repository (USFIMR). CUAHSI Hydroinformatics Conference, July 2017 – Tuscaloosa AL, USA.

Cohen, S., G. R. Brakenridge, A. Kettner, B. Bates, J. Nelson, R. McDonald, Y. Huang, D. Munasinghe, Zhang J., 2017. Methodology for Estimating Floodwater Depths from Remote Sensing Flood Inundation Maps and Topography. *Global Flood Partnership Conference, June 2017 – Tuscaloosa AL, USA*.

Munasinghe, D., Cohen S., Bates S., Brakenridge G. R., Kettner, A., The U.S. Flood Inundation Map Repository (USFIMR): Methodology and Future Development. *Global Flood Partnership Conference, June 2017 – Tuscaloosa AL, USA*.

Munasinghe, D., Zhang, J., Huang, Y., Cohen, S., Fang, N., Tsang, Y., 2016. Comparison of Flood Inundation Mapping Techniques between Different Modeling Approaches and

Satellite Imagery. *Alabama Water Resources Conference, September 2016 – Orange Beach, USA.*

Section 6: Summary of University/Operational Partner Interactions and Roles

The project team included the PI (Sagy Cohen) from the University of Alabama, two co-PIs from DFO (Robert Brakenridge and Albert Kettner), and two co-PIs from the NWC (Barbara Rasaiah and Juzer Dhondia). The PI supervised the three student research assistants working on the project and manage the project finances and workflow. The DFO team provided technical support and maps that were included in the repository. The NWC co-PIs provided technical guidance at different stages of the project, including the establishment of standards for metadata and data storage.