**Ellicott City Disasters II**

*Enhancing a Statistical Flood Risk Model to Continue Improving Early Warning Systems and Public Safety in Ellicott City, Maryland*

**Project Team**

***Project Team:***

Alina Schulz (Project Lead)

Scott Cunningham

Jonathan Donesky

Matthew Pruett

***Advisors & Mentors:***

Dr. John Bolten (NASA Goddard Space Flight Center)

Dr. Sujay Kumar (NASA Goddard Space Flight Center)

Perry Oddo (NASA Goddard Space Flight Center)

Callum Wayman (NASA Goddard Space Flight Center)

Brian Cleary (Howard County Storm Water Management Division)

***Past or Other Contributors:***

Terra Edenhart-Pepe

Julio Peredo

Caroline Resor

Callum Wayman

**Project Overview**

***Project Synopsis:*** In 2016 and 2018, Ellicott City, Maryland was the victim of two severe flood events that destroyed lives and property. This project enhanced an existing machine learning flood severity model and supported the risk mitigation efforts of the Howard County Office of Emergency Management (OEM). The model combined NASA Earth observations with publicly available meteorological and streamflow data to recognize conditions indicative of flood events that threaten public safety and make stage height predictions in Ellicott City. The results will be leveraged during the third term project to integrate the model and socioeconomic data into an actionable risk scorecard already in development by OEM. This will support customized operational decision making in Ellicott City and the surrounding areas.

***Abstract:***

As flooding events in the United States grow in frequency and intensity, the use of technological advancements and applied science are increasingly necessary for effective flood monitoring and warning systems. The NASA DEVELOP Ellicott City Disasters II project investigated the use of machine learning for applications in flood risk detection to support the improvement of early warning systems. To strengthen the efforts of the Howard County Office of Emergency Management (OEM) in building a more robust flood monitoring system, the project improved the original statistical flood risk model, FLuME (Flood Learning Model Environment), programmed by the first DEVELOP term The enhancements incorporated an additional six years of precipitation and soil moisture data from the North American Land Data Assimilation System (NLDAS), modeled using Aqua Advanced Microwave Scanning Radiometer for EOS and Tropical Rainfall Measuring Mission TRMM Microwave Imager. These Earth observations were supplemented by stream gauge data from the OEM and the US Geological Survey. The resultant flood risk model FLASH (Flood Learning Environment and Severity Assessment Hub) was trained to evaluate input variables and predict stage height in Ellicott City in real time. The addition of an advanced deep learning framework known as long short-term memory improved the model’s ability to capture relationships between variables. To assess the effectiveness of the new model, FLASH produced a model efficiency metric of 0.99, a significant improvement over the 0.85 value produced by the previous model. The project assisted the OEM in pursuing the integration of open data and NASA Earth observations into a threat matrix capable of informing near real-time decision making.

***Keywords:***

remote sensing, flash flooding, machine learning, neural network, long short-term memory (LSTM), emergency management

***National Application Areas Addressed:*** Disasters, Urban Development, Transportation & Infrastructure

***Study Location:*** Howard County, MD

***Study Period:*** January 2011 to December 2019

***Community Concerns:***

* Ellicott City, MD has suffered from increasingly frequent and damaging floods in the past decade, experiencing two 1000-year flood events over the course of three years.
* Current emergency management protocols hold the potential to integrate additional data and technology to respond to rapidly forming threats.
* Post-storm repairs and flood mitigation projects will cost the city over $113 million.
* Preemptive action could save lives and millions of dollars in property damage.

***Project Objectives:***

* Improve existing statistical flood risk model with use of Long Short-Term Memory (LSTM) machine learning framework to provide stage height predictions
* Utilize additional *in situ* data from project partners to contextualize model outputs and improve model accuracy
* Conduct sensitivity analysis to determine the impact of each input variable on overall model performance

***Previous Term:*** 2019 Summer (GSFC) – Ellicott City Disasters

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Howard County Government, Office of Emergency Management** | Mike Hinson, Acting Emergency Management Director | End User | No |
| **Howard County Government Storm Water Management Division** | Brian Cleary, Project Manager | Collaborator | No |
| **NOAA, National Weather Service, Baltimore-Washington Weather Forecast Office** | Christopher Strong, Warning Coordination Meteorologist | Collaborator | No |

***Decision-Making Practices & Policies:***

The Howard County OEM develops and maintains emergency management plans that encompass emergency response as well as disaster recovery, mitigation, and protection. The OEM also provides guidance to governmental and emergency response agencies on the development of disaster management plans. OEM staff conduct countywide planning, training, and exercise programs to help the county prepare for natural and man-made emergencies. In addition, OEM staff manage and coordinate the County's Emergency Operations Center (EOC) during times of emergency management activation. Currently, the OEM makes decisions using WebEOC emergency management technologies, such as cameras and live updates from the National Weather Service and Maryland Department of Transportation. However, the OEM has the capacity to integrate NASA Earth observations into the existing emergency response framework. More specifically, Ellicott City’s “Safe and Sound” plan features the development of a threat matrix that stands to benefit from the use of near real-time data integration into flood severity predictions.

***Project Benefit to End User:***

The enhanced statistical flood risk model will supplement the emergency management actions of the Howard County OEM by predicting stream height for the main gauge in Ellicott City that governs response efforts. The integration of the model into the threat matrix in development will help standardize decision making and quantify flood predictions. Additionally, the sensitivity analysis will provide conclusive results displaying the correlation of various parameters that historically caused flooding in the region, enabling the partners to integrate these factors into the development of their threat matrix. The model can influence early warning decisions when potential flooding conditions are either present or predicted, allowing the OEM to better direct its resources where necessary.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Aqua AMSR-E** | Precipitation, surface wetness, soil moisture | Precipitation, surface wetness, and soil moisture data will be used to supplement flood risk analyses and add additional parameters to the flood risk model. |
| **TRMM TMI** | Precipitation | Precipitation data will be used to supplement flood risk analyses. |

***Ancillary Datasets:***

* NASA North American Land Data Assimilation System (NLDAS-2) – Near real-time precipitation and soil moisture model comparisons for bolstered modeling capabilities
* United States Geological Survey (USGS) Daily Streamflow Conditions Data – *In situ* measurements for model validation and inputs for prediction
* National Oceanic and Atmospheric Administration (NOAA) & National Weather Service (NWS) – Stream gauge data related to the floods of 2011, 2016 and 2018 in Ellicott City

***Modeling:***

* Flood Learning Model Environment (FLuME) (POC: Callum Wayman, NASA Goddard Space Flight Center) – Original statistical flood risk model produced during the first term; used to help develop FLASH

***Software & Scripting:***

* Python 3.7 – Statistical flood risk modeling
* R 3.5.3 – Statistical flood risk modeling and data plotting
* Esri ArcGIS Pro 2.3 – Raster manipulation and analysis, imagery processing, and map production
* Google Earth Engine API – Data acquisition and manipulation

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| **Flood Learning Environment and Severity Assessment Hub (FLASH) – Ellicott City Improved Flood Risk Model** | Aqua AMSR-ETRMM TMI | An improved flood risk model that includes additional inputs, such as *in situ* stream gauge measurements and precipitation data, as well as the potential to expand the model’s application beyond the Patapsco Watershed, will improve the partner’s ability to mitigate flood damage. | IV |
| **FLASH Tutorial** | Aqua AMSR-ETRMM TMI | The tutorial included a slideshow with step by step instruction for data acquisition and independent model execution to enable the partners to conduct analysis with the most recent data and for future terms to replicate the process. | N/A |

**Project Handoff Package**

***Transition Plan:*** The team held a virtual meeting for the Howard County Office of Emergency Management and Howard County Storm Water Management to hand off materials and present findings. The team shared the enhancements made to the flood risk model and its outputs were discussed. Additional insights from the sensitivity analysis were also presented. The software release process required for FLASH has been drafted and the partners will receive the code when it is complete.

***Software Release Plan:*** FLASH will begin its official software release process during the third term, as suggested by Danny Mangosing. To minimize repetitive software release efforts, all documentation related to FLASH was provided at the end of the second term. The third term has the opportunity to integrate scripting changes into the existing ReadMe’s, tutorials, and documents. Both the first term’s software release POC and the second term’s software release POC can communicate with the partners throughout this process, ensuring that their questions and needs are addressed.

***Project Continuation Plan:*** The third term Ellicott City Disasters project will receive the updated FLASH code incorporating LSTM and the data acquisition and model execution tutorial generated at the end of this term. The final term of this project will finalize the code for the partners, along with the necessary tutorials for data acquisition and model execution. These results will be incorporated into Howard County OEM’s early warning system to enhance public safety in near-real time.

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***Partner POC:*** Brian Cleary, bcleary@howardcountymd.gov

***Handoff Package:***

* FLASH Tutorial
* Technical Paper
* Poster
* Presentation

**References**

Edenhart-Pepe, T., Peredo, J., Resor, C., Wayman, C. (Summer 2019). Ellicott City Disasters: Applying NASA resources to a statistical flood risk model to improve early warning systems and public safety. NASA Goddard Space Flight Center. <https://drive.google.com/file/d/1TPBN5KnsriSNrpXtKkCRCuCge0RDTKjz/view?usp=sharing>

Ganguly, K., Nahar, N., & Hossain, B. (2018). A machine learning-based prediction and analysis of flood affected households: A case study of floods in Bangladesh. *International Journal of Disaster Risk Reduction, 34,* 283-294. <https://doi.org/10.1016/j.ijdrr.2018.12.002>

Kwak, Y.-J., Pelich, R., Park, J., & Takeuchi, W. (2018). Improved flood mapping based on the fusion of multiple satellite data sources and in-situ data. *The Institute of Electrical and Electronics Engineers, Inc. (IEEE) Conference Proceedings*, pp. 3521–3523. Retrieved from <https://search.proquest.com/docview/2130608212?accountid=28155>

Mosavi, A., Ozturk, P., & Chau, K. W. (2018). Flood prediction using machine learning models: Literature review. *Water*, *10*(11), 40. <https://doi.org/10.3390/w10111536>