Multidimensional Hydrodynamic Framework for Modeling Compound Inundation in Coastal Watersheds

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Compound Inundation Team for Resilient Applications

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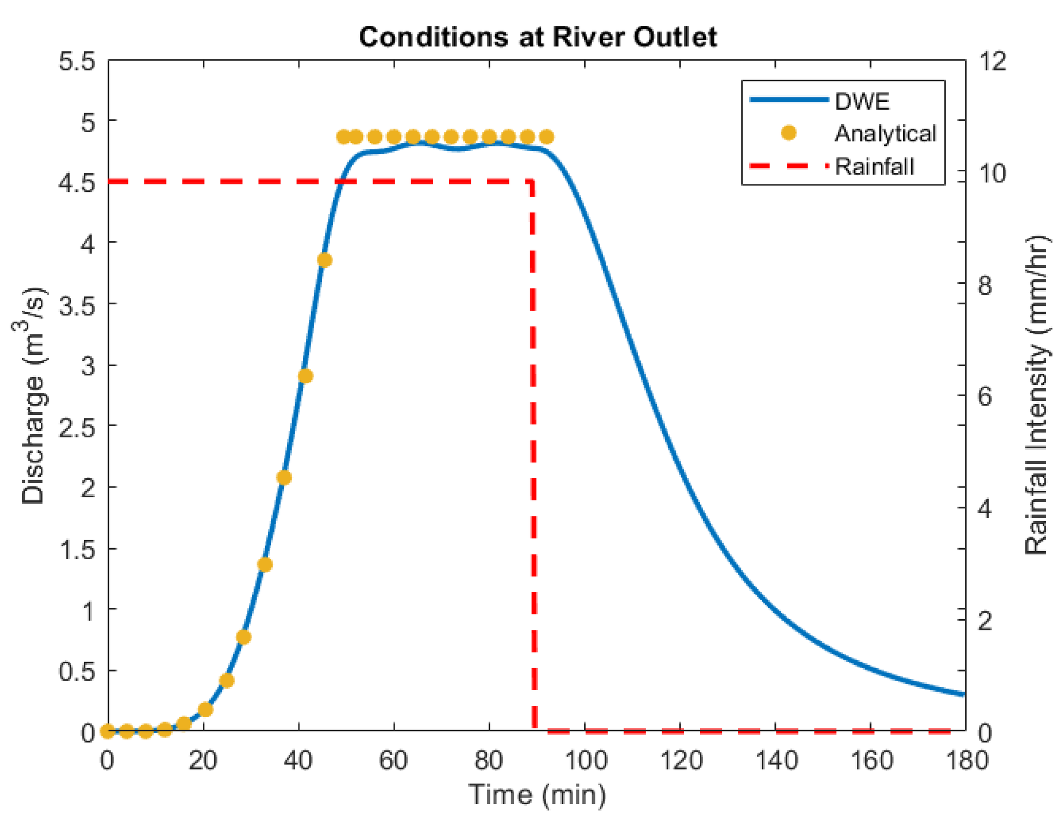
Motivation

Floods are extremely destructive and affect many people each year, such as Hurricane Ian in 2022, which was responsible for over 150 deaths and over $112 billion in damage (NOAA, 2023). Approximately 52% of the U.S. population lives in coastal watersheds (NOAA, 2013). Coastal watersheds are vulnerable to flooding hazards from both intense rainfall and coastal storm surge (Bilskie and Hagen, 2018, Comer et al., 2017, Silva-Araya et. al, 2018). Floods can emerge from several driving forces such as pluvial, fluvial, or coastal flood drivers (Bacopaulos et al., 2017, Serafin et al., 2019). When inundation occurs from a coastal flood driver and an additional pluvial or fluvial flood driver, it is considered a compound flood event. With the effects of climate change, coastal watersheds are expected to be subjected to additional flood stressors, such as sea level rise.

Overview

We developed a coupled overland and river model for modeling compound flooding using the kinematic wave approximation on inland sections of an unstructured mesh, and the diffusive wave approximation on riverine sections. A finite element method is used for spatial discretization and a Crank-Nicolson scheme is used for time discretization. A wetting and drying algorithm is implemented for improved efficiency in the model. Pluvial conditions and tidal conditions are implemented as source terms in the river model.

Model Validation



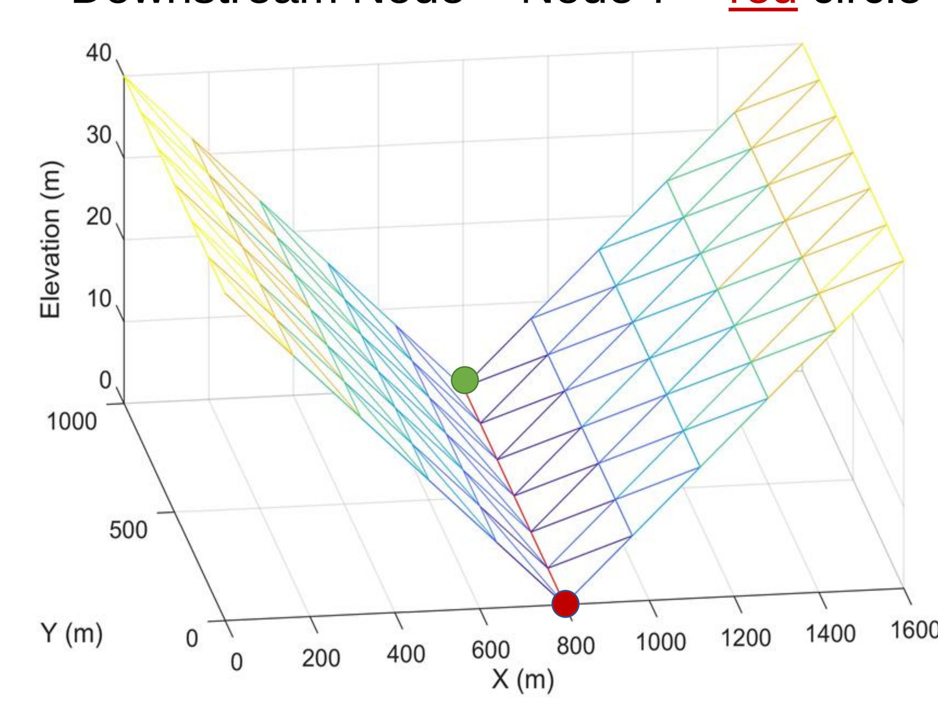
Analytical V-Catchment case Wooding (1965):

Timestep = 180 s
3 hour simulation
S_{0x}= 0.05 (overland)
$S_{0x} = 0$ S_{0y}= 0.02 (river only)
River width = 20 m
Rainfall:10.8 mm/hr for 90 min
Manning's n (river) = 0.15
Manning's n (overland) = 0.015

Difference in flow between analytical and numerical solution = 0.9204%

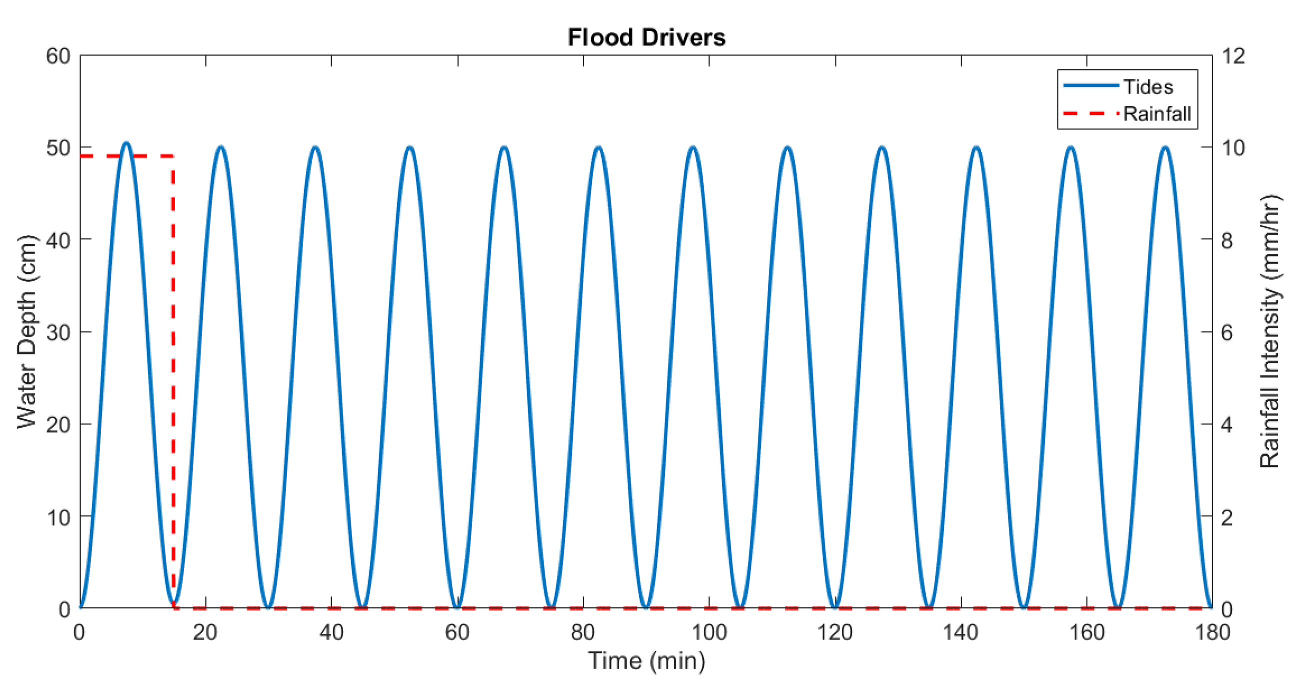
Domain

Upstream Node = Node 1 = green circle
Downstream Node = Node 7 = red circle



Case Study

As a case study, we used the same mesh in the analytical case, but reduced the rainfall duration and introduced a tidal condition as a downstream Neumann boundary condition.



Idealized case study:

Timestep = 5 s
3 hour simulation
Rainfall:10.8 mm/hr for 15 min
Tidal Condition = $0.5 \sin^2 t$

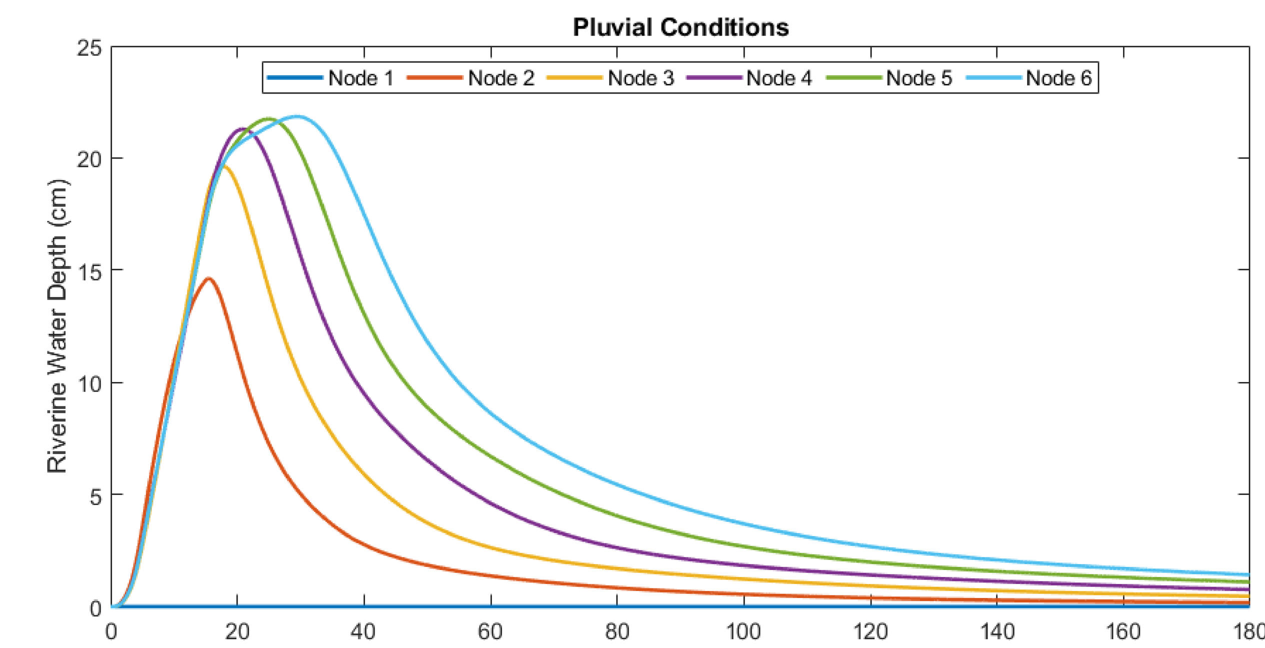
Conclusions and Future Work

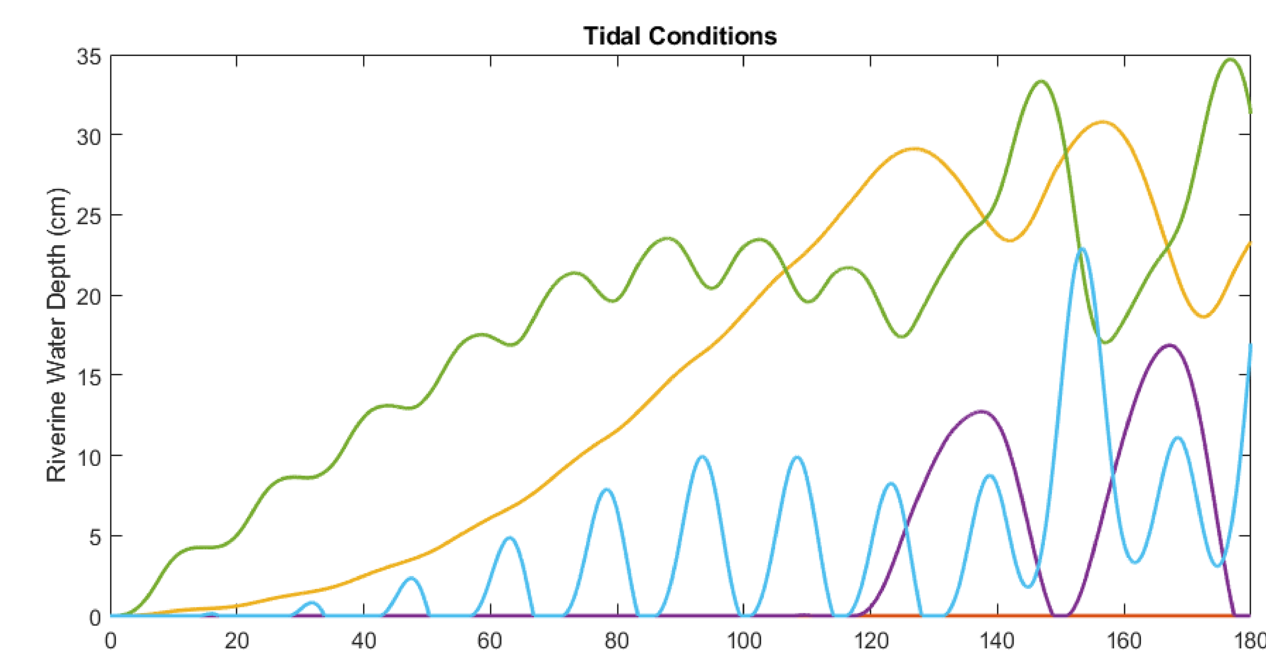
Our results show that compound effects on an unstructured mesh can be captured in the Continuous Galerkin Finite Element framework using the combination of tidal conditions and lateral discharge.

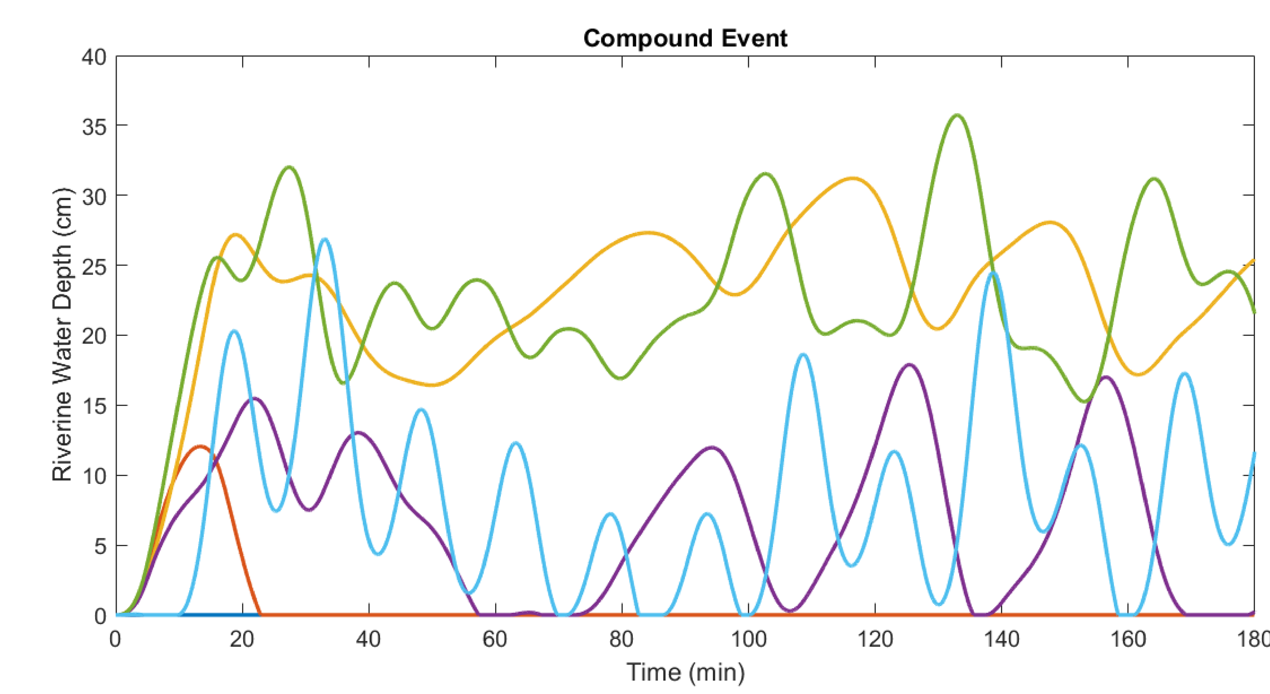
Future work involves:

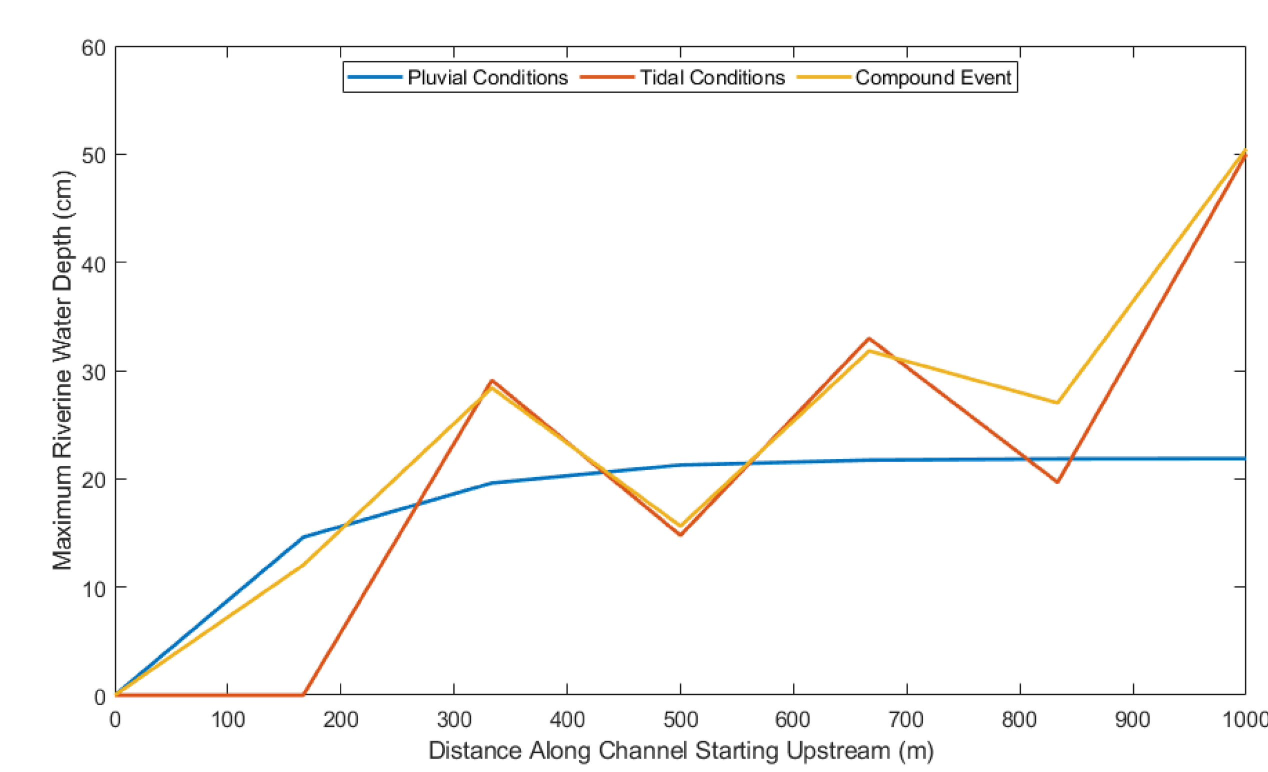
- Running simulations of compound events on more complex meshes
- Utilizing other source/sink terms such as infiltration and out-of-bank flow
- Parallelization and implementation into a hydrodynamic model

Results









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