Coupling watershed and coastal processes in built environments to forecast storm-induced hazards

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Hurricane Harvey (August, 2017) and Hurricane Florence (September, 2018) are two examples of large storm and flooding events that directly impacted large built, coastal environments. Hurricane Harvey is an example of the direct impact of a storm along a urban as well as developed coastline, while hurricane Florence affected built, but less urban communities along the Carolina coastline. In these storm events, the runoff resulting from intense and long-lasting rainfall converged with increased water levels and flows from oceanic origin. Although the hazards associated with runoff/increased water levels and flows from open water have been extensively analyzed separately, interactions between these two important hazard generating phenomena in built environments remain elusive.

One of the lessons learned from recent hurricanes is that we need to combine/couple hydrological and oceanic processes in order to correctly forecast the resulting flows and flooding processes. This becomes all the more complicated by the impervious cover that pervades urban ecosystems, due to shifting hydrologic regimes compared to historical records. The scale at which the interaction between the runoff and oceanic flows should be modelled at the watershed scale. At the scale of the built environment, these processes should be modelled and analyzed at scales of cap. 1-10 m, since local infrastructure, such as roads, buildings and structures can modify the flow locally and have basin scale consequences. This aligns closely with the parcel scale, which is convenient for extending analyses to address social inequities in hazard susceptibility. Furthermore, such hazards exacerbate the risk of terrestrially-derived pollutants and nutrients to downstream freshwater and marine habitats, as well as coastal habitats such as coastal wetlands, beaches, and floodplains.

Approach

This project leverages existent river runoff and watershed models and applies them to the built environment. These models have the capability to quantify precipitation and overland flow and can be used to assess how man-made impervious structures and engineered drainage systems impact flooding during above average flooding events.

The models used will be well-established, open-source, high-resolution codes developed by hydrodynamic and oceanographic communities. They will be adapted for the specific challenges posed by the built community, and will resolve individual structures and their influence on water flow and wave propagation. Modeled watershed processes will include meteorological forcing (winds, heat fluxes, precipitation), local watershed modeling and flow routing, including drainage and retention, sediment, contaminant, and nutrient transport and changes in landscape (morphodynamics and collapse of infrastructure). Prior to the application of these models in a forecast mode, these will be verified with measurements collected in specific benchmark cases (e.g. Harvey, 2017) and design future data collection efforts directed towards a multidisciplinary verification of the model.

Real-time forecasts from operational riverflow models will provide upstream boundary conditions.The coastal models will be forced by high-resolution meteorological models, with ocean boundary conditions, and will resolve tides, storm surges, infragravity and incident waves, wave setup, wave runup, sediment transport, and morphological evolution. Effects of vegetation, natural and built features will be either resolved or characterized with spatially and temporally varying friction coefficients. The influence of tide and surge propagation through inlets or engineered structures like storm-surge barriers, and the inundation upland landscapes of will emerge from the coupled watershed - coastal model solutions.

Impact

The project domain will be at the watershed scale, but the model will resolve built structures (numerical grid scale of ~meters) and produce output at the parcel scale. Parcel-scale resolution will allow results to be assessed by individual property owners, and to be integrated up to larger units like neighborhoods, political subdivisions, or infrastructure or emergency response units. This will allow analysis from engineering, geographic, and socioeconomic perspectives.

The proposed work will identify locations where infrastructure (both green and grey) could be designed to facilitate desired physical processes — locations where water retention structure could be built, or locations where enhanced draining should occur. Best practices for the design of infrastructure could also be examined using scenarios. In addition to informing infrastructure and landscape design meant to alter hydrodynamics, this work will identify how pollutants from upstream and urban landscapes enter coastal habitats.

Mitigation strategies for coastal hazards often include built defenses such as flood gates. Closing flood gates gates can have the unintended effect of exacerbating flood risks of upland watersheds if precipitation is intense (at the expense of mitigating flooding from an ocean/bay). Linking watershed and coastal models will inform policy decisions and tradeoffs when mobilizing flood defenses such as flood gates.

The results of this work will be relevant for disaster response (by providing real-time information on flooding and contaminant pathways for use by emergency management personnel) and recovery (inform land use planning and adaptation strategies that mitigate vulnerability from flooding and contamination, inform emergency management plans/routing).

Integration with CoPe Framework

<u>Coastal Processes</u>: This project focuses on various aspects of hydrological and meteorological hazards, both upland and from open water, and their implications for built ecosystems at or near the shoreline. These include storm surges and tides, wind and waves, high river flows and stormwater management, and coastal protection strategies.

<u>Human Dynamics</u>: The joint study of upland hydrology and tidal/wave/wind disturbance from open waters here is novel because many aspects of human dynamics will be studied. These include, protection of property, public safety, influence of, and on, infrastructure, as well as the

implications of these hydro-meteorological forces on the resistance and resilience of coastal ecosystems and the services they provide.

Broadening Participation: Nearly all built and/or urban ecosystems support communities with differential susceptibility to environmental disturbance. As the project's resolution is at the parcel scale, predictions/impacts of the work can be extended appropriately to parse social inequity. The consequence is an explicit broadening of participation of otherwise neglected social groups.

Built Environment: This project addresses aspects of the built environment directly as it (1) focuses on hazards from upload and the open water in concert on coastal areas, and (2) focuses on the risks by studying risk to people, infrastructure, and ecosystem services in urban places through different disciplinary lenses.