Efficient Computation of Flooding Scenarios for the Coast of Maine

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Abstract

We describe an efficient algorithm for computing flood maps caused by overlapping sea-level rise (**SLR**) and storm surges, based on the method used by the second New York City Panel on Climate Change (**NPCC2**) [1]. Our algorithm can handle efficiently large datasets. As a case study, we present results for Lincoln County in Maine, using a 2m-resolution raster digital elevation model (**DEM**) obtained from LiDAR data, totaling 919 million points. Our algorithm overlaps FEMA's 1%-annual-chance storm base-flood elevation (**BFE**) map with an arbitrary level of SLR in less than 100 seconds, and produces results that are very close to the results obtained using the same method in ArcGIS, which runs for hours.

Background and Related work

In 2017, the United States experienced a record-tying 16 weather-related disasters where overall costs reached or exceeded $1 billion [2]. Extreme sea levels and storm events have increased since 1970 mainly as a result of rising mean sea level, which is predicted to further rise by up to 3ft by 2100 [3]. The immediate effect of SLR is coastal inundation, which impacts wetlands, shoreline erosion and displaces population.

SLR flood mapping: Mapping SLR inundation uses a digital elevation model (DEM) of the terrain to determine what part of the coast gets flooded when the sea-level rises by a certain amount. The simplest and most commonly used SLR flood model assumes the coast is static, that is, it will not change as a result of the water level rising and the water will not infiltrate in the ground.

Storm flood mapping: Storms cause coastal flooding due to storm surges. Presently, areas at risk of storm flooding are given by FEMA's BFE maps which depict the flooded areas as well as the elevation to which floodwater is anticipated to rise (the storm surges) during a base flood event (e.g. 1%-annual chance or 1-in-100-years flood; 1-in-500-year flood).

SLR + storm flood mapping, combined effect: With the sea-level predicted to rise, storms will bring the flooding further inland. Accurate prediction of future storm flooding must combine BFE flood maps with rising sea levels produced by global warming.

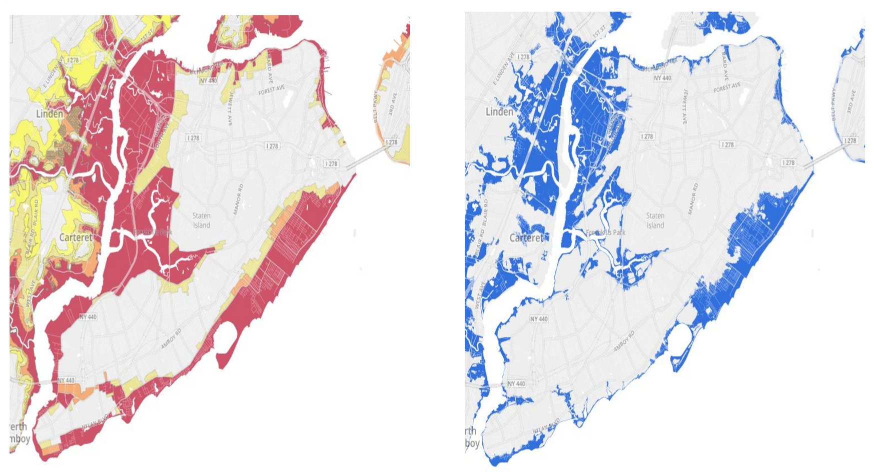

Figure 1: The predicted flooding (left) vs actual flooding (right) of Hurricane Sandy [4]

Since the devastation of Hurricane Sandy, NPCC2 [1] developed a protocol that uses the BFE map as a base model for storm flooding and combines it with SLR using a static approach. The process is designed to be implemented in ArcGIS via a sequence of steps (ArcGIS does not have a designated flood function): interpolate the BFE map, label all cells with elevation below SLR+BFE; compute the connected components of these cells, and remove the components that do not connect to the sea.

- The process is tedious and involves some manual parts (identification of connected components that are not "sea")
- The process is slow on large data, taking many hours to complete

More complex approaches to model storm surges with SLR involve hydrodynamic modeling, such as [5] and [6]. This is computationally intensive and with many sources of uncertainty.

Algorithm

Given a grid DEM, a BFE map, and an arbitrary SLR amount *x*, we give a simple approach to compute what part of the terrain gets flooded if a sea-level rise of *x* overlaps the storm flooding given by the BFE map. The algorithm uses the approach proposed by [1] and has two components:

1. Interpolate the storm flood levels given by the BFE map further inland.
2. Compute flooding by overlapping SLR on top of the BFE storm surges.

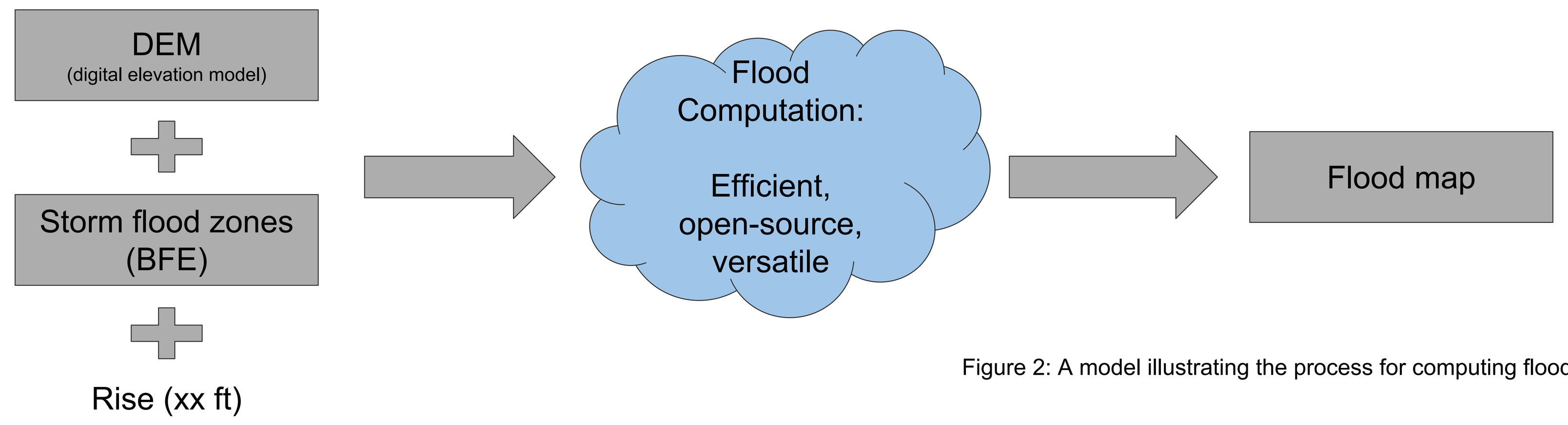

Figure 2: A model illustrating the process for computing flood maps

Flood computation: A point is flooded if:

1) The elevation is below the elevation of the ocean (SLR + BFE storm surge)
2) It can be reached by the ocean via a path of flooded points

Algorithm: We simulate inundation coming from the coast as a one-pass priority-first search. For each point on the coast, determine if point is under water. If so, mark it as flooded, check surrounding, repeat.

BFE interpolation: To simulate inundation we need to interpolate the values of the BFE map inland, to points that are outside the present flood areas but may be flooded in the future. Inverse distance weighting (**IDW**) is commonly used but on polygonal data is computationally-intensive and overall not a good model. We describe a new approach for interpolating the BFE map which retains the continuity properties of IDW but is more efficient. We compare it with a nearest-neighbor (**NN**) interpolation, and with the 5-nearest neighbor interpolation employed by ArcGIS to approximate IDW.

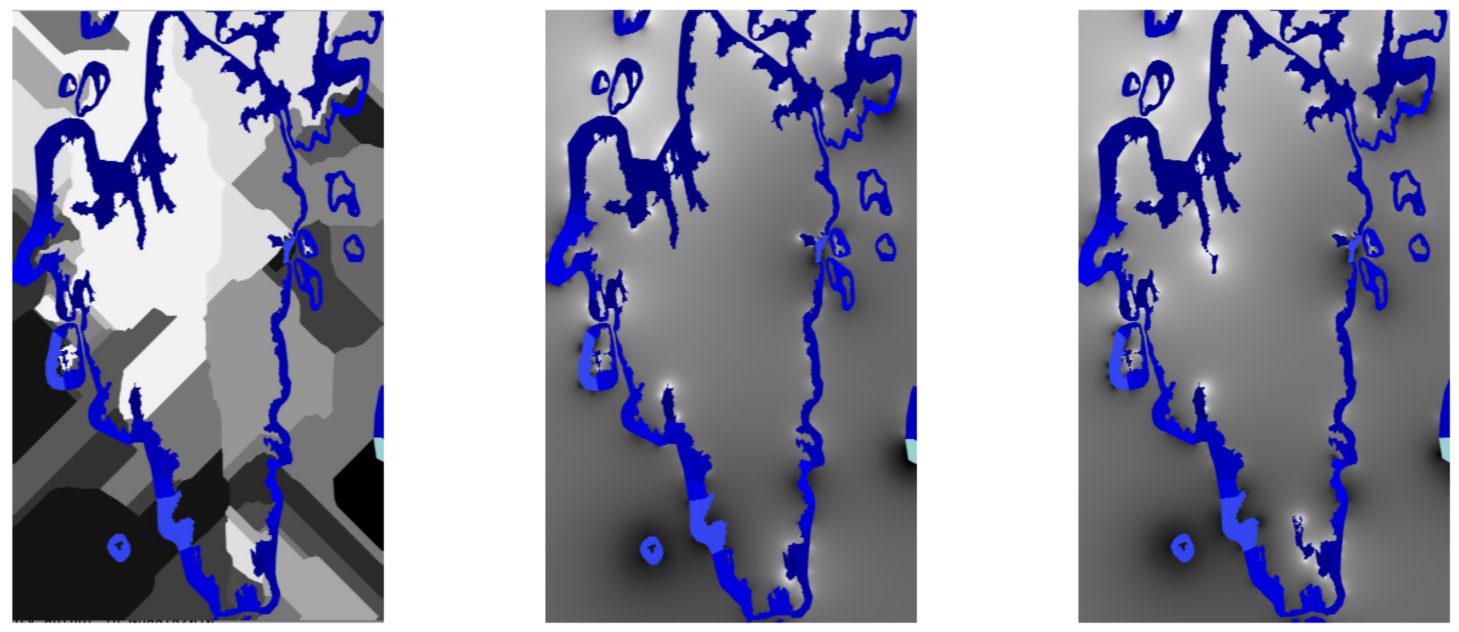

Figure 3: 100-year BFE (blue) on top of interpolated BFE (grayscale) (a) NN (b) approximate-IDW (c) IDW

Case Study: Southport Island in Lincoln County, Maine (2m grid DEM from LiDAR data)

Overlapping 100-year BFE with 1ft SLR

Below we show a closeup of the south-east part of the island. In all maps, the BFE corresponding to a 100-year storm (or: 100-year floodplain) is shown in light blue.
The flood map corresponding to 1 ft. SLR overlapping a 100-year storm is shown in white (when computed by our method with approx.IDW), and dark blue (when computed in ArcGIS with 5-NN) .
Note the differences, which we attribute to the five nearest-neighbor interpolation used by ArcGIS; see below how the flood map is cut due to the jump in BFE values.

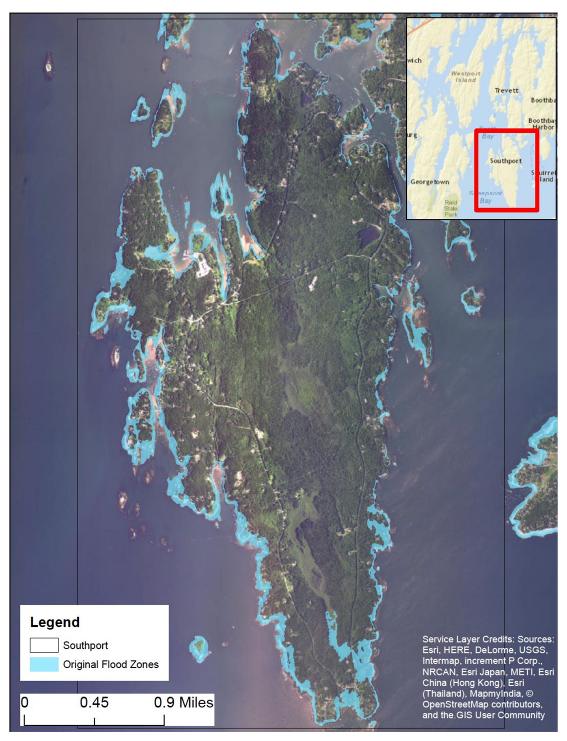

Figure 4: Southport with BFE (100-year floodplain) in light blue

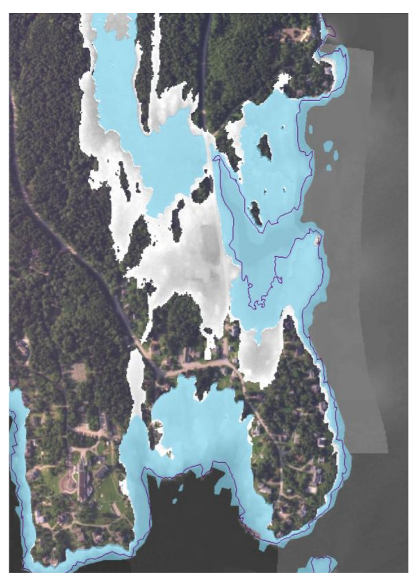

Figure 5: our results in white

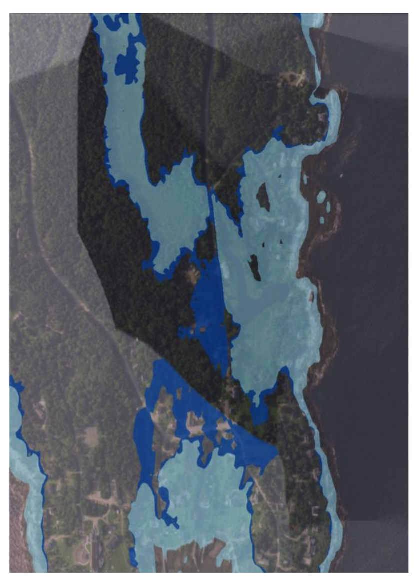

Figure 6: ArcGIS results in dark blue

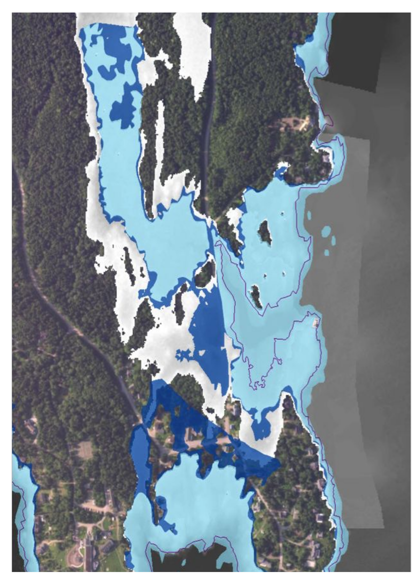

Figure 7: our results (white) vs. ArcGIS (dark blue)

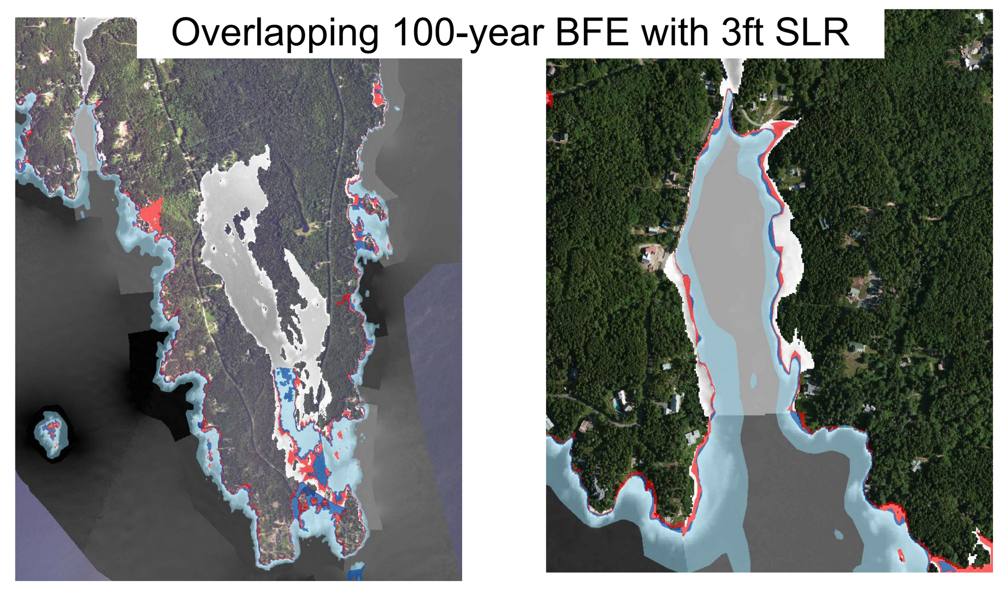

Figure 8: Southport with 3ft SLR on top of BFE (blue). ArcGIS results (red) and our results (white)

Results

Performance: Based on simple and fast algorithm, designed to be efficient on large data. Can handle 1billion-points Lidar dataset. Our approximate-IDW interpolator is significantly faster than IDW (e.g. 86 sec. compared to 9,685 sec. on Southport). NN-interpolation is, as expected, the fastest (1 sec. on Southport, 225 sec. on Lincoln). Approximate-IDW and IDW look visually the same, and significantly different than NN, which retains the BFE region boundaries.

Flood delineation: Figures 7 and 8 show a comparison between our resulting flood maps and the maps developed using ArcGIS. We note overall similarity, with some differences in the low lying area in the south-east part of the island, which our algorithm marks as flooded even at 0ft SLR.

Efficiency: Our code can compute floodmaps, with and without BFEs, in milliseconds for Southport, and in less than 100 seconds for Lincoln County (919 mill. points). This does not include the time to read/write the grids, and to interpolate (which is done separately).

Conclusion

- **Simple:** Two-step process (interpolate, flood), much simpler to use than ArcGIS.
- **Free and open source** (https://github.com/coryalini/slr-bfe-research)
- **Efficient:** e.g. can flood Lincoln county (2m DEM from LiDAR data, 900 million points) in under 3 minutes compared to days in ArcGIS.
- **Versatile:** can model arbitrary sea-level rise on-the-fly, and can combine sea-level rise with BFE and tidal surfaces.
- **Extensions:** Currently assumes BFE grid and elevation grid are given in NAVD88 datum. Our approach can be extended to incorporate any tidal surface (for e.g. can compute flooding due to BFE + sea-level rise on top of MHHW)

References

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