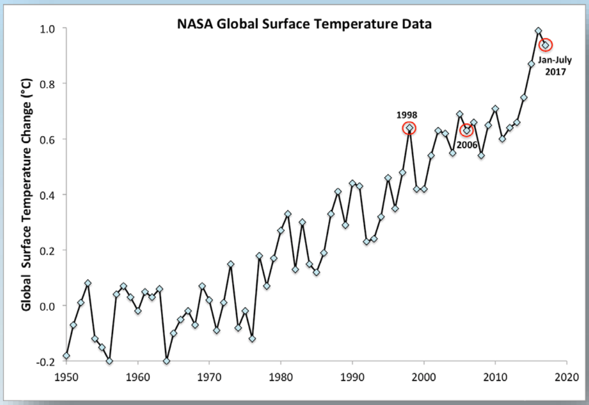
The Massachusetts Coast Flood Risk Model

Modeling Overview and Frequently Asked Questions

Background

Massachusetts' coastal communities were settled during a time when sea levels were remarkably stable. For centuries, natural and built infrastructure such as salt marshes, dune communities, seawalls and bulkheads have allowed people to live, work and play at the edge of the ocean with well-understood, manageable risks of flood damage. However, increases in global temperatures have resulted in 16 of the 17 warmest years on record occurring from 2001 to 2017. People born after 1980 have never experienced a cooler-than-average year. As global temperatures rise, so do sea levels (melting ice sheets, expansion of water), and the Mid-Atlantic and Northeast US coasts are experiencing faster-than-average sea level rise. As seas rise and storms impact our coastlines, communities need access to the most comprehensive information to determine when, where, and how much to invest to decrease potential damages from coastal flooding. The Massachusetts Coast Flood Risk Model (MC-FRM)[1] helps property owners, planners and policy makers consider ways to cost-effectively build resilience and plan for the expected changes.



Change in average global surface temperatures 1950-2017 (0.0 = historic average temperature; courtesy NASA).

Flooding in Boston during Storm Grayson (January 4, 2018).

[1]Funding for the development of the MC-FRM was provided by the Commonwealth of Massachusetts.

What is special about the MC-FRM?

Sea level rise (SLR), combined with storms, has commonly been evaluated with a “bathtub” approach that simply increases the water surface elevation and compares that to topographic elevations of the land (i.e., fills the land up like a bathtub). When incorporating the effects of storms, the bathtub approach assumes the ocean stays perfectly flat. Anyone who has been to the coastline understands that the ocean is not a flat body of water during a storm. Water is aggressively being moved in various directions by waves, winds, and currents. As such, the bathtub approach does not account for critical physical processes during a storm, including waves, winds, and overtopping, and is unable to represent the dynamic nature of flooding. In many cases, the bathtub approach predicts flooding where none will occur, while misidentifying dry areas that would actually flood. Even some models that appear to be more complex only model the water levels up to the shoreline, then use bathtub approaches over land, ignoring important processes of over land flow. These models also tend to be low resolution, lacking details that can have a significant impact on the movement of water. The MC-FRM simulates the physics-based flow of water not only in water bodies, but also over land; including the time-varying, physical movement of water as it propagates inland. The MC-FRM also includes wave run-up and overtopping flow, and the physical based spreading inland of that water, in areas where waves intermittently overtop major coastal structures (e.g., seawalls, revetments). Areas with critical infrastructure and/or complex landscapes need to consider dynamic modeling of the changing climate and storms in order to ensure proper siting, design, and construction of significant investments.

Accurate storm surge probability modeling requires detailed representation of the physical processes (beyond a bathtub model), as well as high resolution inundation predictions based on a combination of sea level rise and storm surge. When simulating hurricanes and nor’easters, the MC-FRM dynamically includes the expected impacts of tides, waves, wave run-up and overtopping, storm surge, winds, and currents over a range of storm conditions and at high spatial resolution.

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What makes the MC-FRM more accurate than other inundation models and flood maps that have been created for the region?

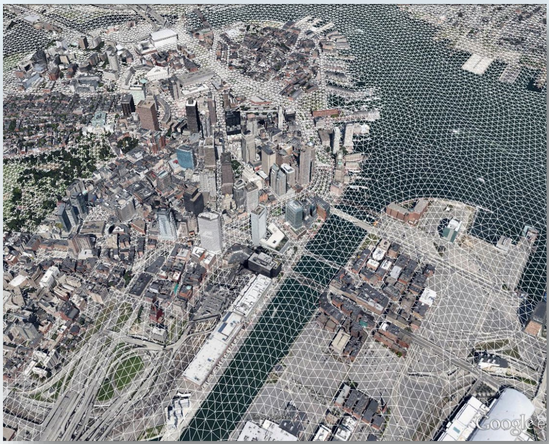
The MC-FRM is a more accurate representation of flooding risk because it is (1) a dynamic model that includes the critical processes associated with storm induced flooding (winds, waves, wave-setup, storm surge, wave run-up and overtopping, etc.), (2) calibrated to historical storm events that impacted Massachusetts with observed high water data and measurements, (3) high enough resolution to capture flood pathways in complex urban topographies, (4) a model that includes both hurricanes and nor'easters under changing climate conditions, and (5) able to capture the net effect of varying storm types, magnitudes, and frequencies.

How do the MC-FRM results relate/compare to the FEMA Flood Insurance Rate Maps (FIRMs)?

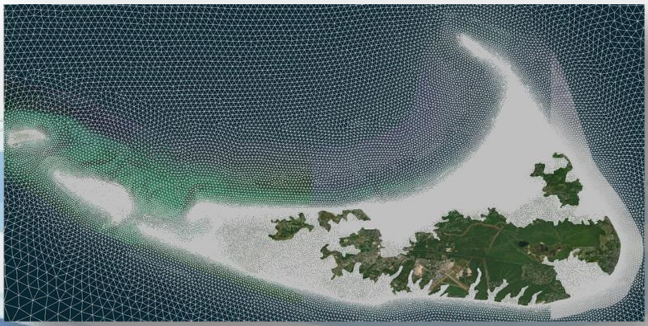
The MC-FRM is focused on present and future flooding projections based on a robust set of storm events, while FEMA results estimate present flood risk based on single historical based event. The methods used to produce the FIRMs are substantially different and FIRMs have a completely different purpose. ***They should not be directly compared.***

What is the resolution of the MC-FRM model grid?

In order to turn complex mathematical equations into high resolution maps, the MC-FRM uses a detailed modeling mesh, in which every intersecting point represents a specific set of data where the model equations are solved. Flood risk data are calculated as frequently as every ten (10) feet in populated areas on land. This provides more localized and accurate data for flood risk analysis and planning.



Example of the high-resolution MC-FRM modeling mesh for Boston (above) and Nantucket (below).



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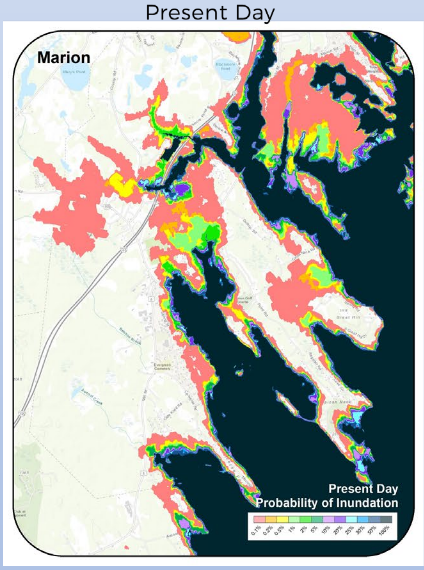
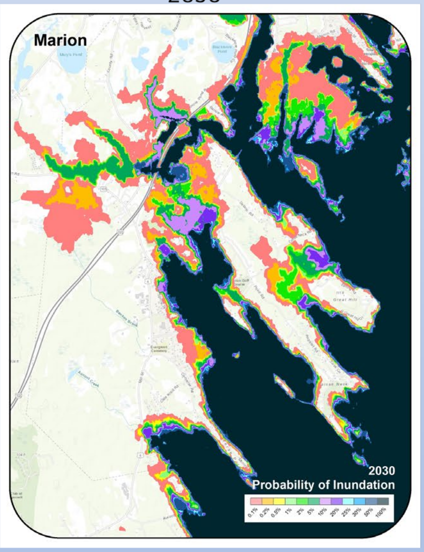
The MC-FRM is a probabilistic model. What does that mean?

Coastal storm events striking an area result in different impacts depending on factors, such as the timing of the storm with the tide cycle, the storm track, radius to maximum wind of the tropical storm, the amount of precipitation, etc. Probabilistic modeling evaluates a statistically robust set of viable coastal storm conditions that produce spatially distributed flood probabilities. The MC-FRM doesn't just simulate one storm or a few storms – the MC-FRM dynamically simulates hundreds to thousands of storms to produce flood exceedance probabilities at high spatial resolution. Using this statistically robust approach, the coastal flood exceedance probability (CFEP) can be defined as the probability of flood water inundating the land surface at a particular location. For example, a building that lies within the 2% CFEP zone would have a 2% chance (50-year return period) of flooding. In other words, there is a 2% percent chance that this location will get wet with salt water during a coastal storm event. Stakeholders can then determine if that is tolerable, or if some action may be required to improve resiliency, engineer an adaptation, consider relocation, or implement an operational plan. Critical assets, such as hospitals and evacuation routes, have different risk tolerances than parklands or parking lots.

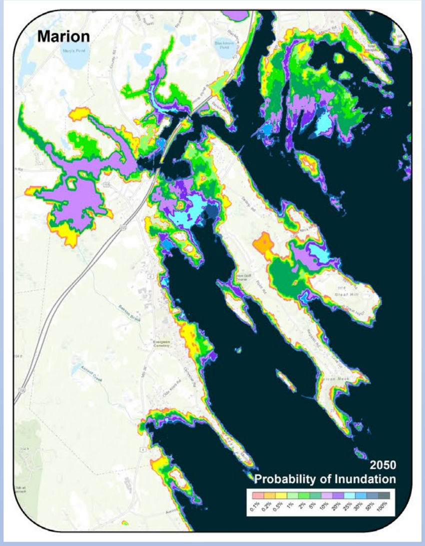
Present Day



2030



2050



By mapping various future years (e.g., 2030 to 2050), individual structures, assets, and areas can be compared to determine how coastal flooding is changing over time. The overall influence of climate change projections can also be evaluated. These maps can also be used to assess flood entry points and pathways and identify potential regional adaptations. In many cases, large upland areas are flooded by a relatively small and distinct entry point (e.g., a low elevation area along the coastline). In cases like this, a more cost-effective and regional solution (rather than evaluating local adaptation options at each building in the area) can be prioritized. A targeted coastal protection project at the flood entry point (e.g., increasing seawall elevation, installing a natural berm, etc.) could protect a whole neighborhood. Maps showing the probability of flooding provide stakeholders the ability to identify areas expected to be flooded, and the probability of flooding. This helps them weigh their tolerance for risk, evaluate when adaptation options may need to be considered, and most importantly, prioritize funding to higher consequence areas.

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What timeframes and sea level rise scenarios are being simulated in the MC-FRM?

MC-FRM scenarios currently include present day, 2030, 2050, and 2070 climate conditions. The sea level rise projections utilized for these scenarios are based on Massachusetts specific analysis (DeConto and Kopp, 2017) and include Antarctic ice sheet projections as of 2017. Sea level rise values vary for the north and south portions of the state. These scenarios are consistent with the projections being used by the Commonwealth of Massachusetts[1].

Location	Relative Mean Sea Level (feet, NAVD88)		
	2030	2050	2070
North	1.2	2.4	4.2
South	1.2	2.5	4.3

Will the MC-FRM results of flooding risk be publicly available?

Yes. MC-FRM flood probabilities and depths will be publicly available through the Commonwealth's Climate Change Clearinghouse.

Are the results of the MC-FRM available for the entire coastline?

Yes. The model includes every Massachusetts coastal city and town potentially influenced by future coastal storm surge-induced flooding during this century. GIS data will be available for download.

Are the results precise enough to be applied to specific buildings or structures?

Yes. The model predicts the likelihood and depth of flooding at a resolution high enough to be able to analyze individual buildings.

What types of flooding does the model cover?

It simulates storm surge-induced coastal flooding from hurricanes and nor'easters, which differ in speed, direction and duration. The model also includes climate-change induced increases in river discharge from precipitation for major rivers. Upstream freshwater flooding events that have no ocean-based component are not included in the analysis.

[1]https://resilientma.org/changes/sea-level-rise

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What types of storms does the MC-FRM simulate?

The MC-FRM simulates storm surge induced flooding that could occur from both tropical (hurricanes) or extra-tropical (nor'easter) storm events. The intensity and frequency of these storm events change with the changing climate conditions. The model also includes climate-change induced increases in river discharge from precipitation within major rivers. It does not include flooding caused by rainfall that does not drain adequately to a water body, such as ponding in a low spot in a parking lot.

How has the MC-FRM changed from the Boston Harbor Flood Risk Model (BH-FRM)?

The MC-FRM improves upon the BH-FRM in numerous ways. Beyond the inclusion of the entire coastal area of Massachusetts, the MC-FRM also (1) includes updated sea level rise projections consistent with the state standard; (2) expands the storm sets used to include more historical and recent storms as well as hundreds of additional future storms; (3) includes dynamic wave runup and overtopping of coastal structures like seawalls; and (4) adds regular nuisance flooding by projecting future tidal datums.

I'm a town official. How do I use this information?

The MC-FRM provides the public with the best available science-based projections on coastal flooding during this century, helping you understand the level of risk potentially faced by areas within your community. This information can help prioritize adaptation actions across multiple assets throughout a town, therefore allowing more cost-effective, science-based approaches and timing for building resilience.

I'm concerned about a specific property. How do I use this information?

By examining the MC-FRM flood risk projections, property managers can assess the potential timing and depth of saltwater flooding over time for a given location. Buildings and infrastructure exposed to periodic storm flooding—especially in the absence of damaging waves—can be retrofitted to prevent harm. However, every specific property should also consider regional level protection approaches when evaluating risk.

Are dams included in the model?

Major dams, and dam operations, are included in the model.

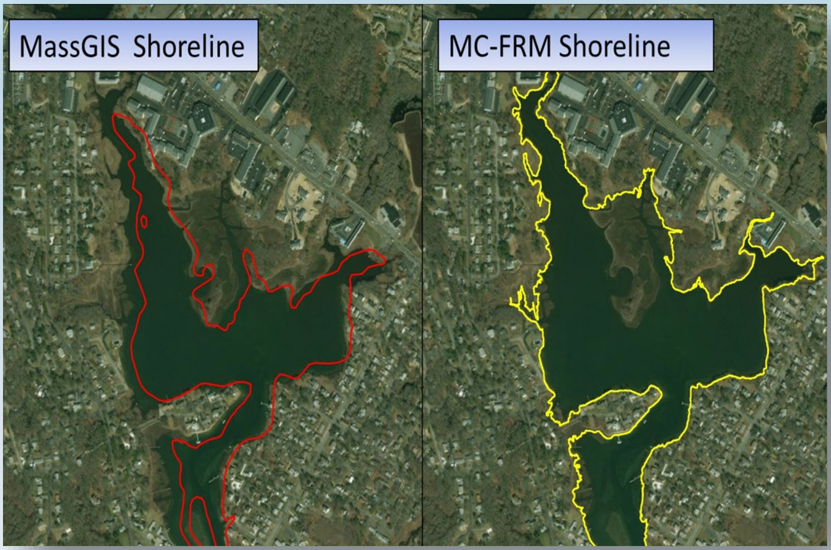
How is the MC-FRM assisting resiliency projects and engineering designs?

The MC-FRM results, at a site-specific scale, provide a breadth of information useful for informing decisions as to where protection may be required, selecting potential adaptations, planning, and assisting with engineering design. The high-resolution model results offer detailed information at an individual building and parcel level for assessment of existing or developing sites. While potential inundation probability and depths may be manageable under current risk levels, this may change over the service life of the asset. The dynamic model can also provide flood pathways to the site, which gives an indication of how long the flooding is expected to last for a given probability level. In many cases, this is important for determining economic impacts related to out-of-service time frames. Understanding the volume of water and flood pathways gives another layer of information that helps inform design and consideration of local and/or regional adaptation measures. The flood pathway insight allows stakeholders to consider local measures (e.g., raising the elevations of the buildings on the parcel, flood proofing structures, local on-site berms or walls), and regional approaches (e.g., berms, tide gates, flood walls, etc.) to control the source of flooding for a region that may co-benefit other properties.

Towns, communities, and stakeholders throughout the Commonwealth of Massachusetts can use, and have already been using, MC-FRM results to complete comprehensive vulnerability assessments, develop engineering adaptations, and design resilient green, gray, or hybrid solutions. The probabilistic results have given communities the ability to prioritize adaptations and start to build resilience in fiscally manageable ways. Communities and landowners can take action to manage projected imminent risks, while waiting for more certainty when dealing with long-term climate change projections that may not have near-term impacts.

What about non-storm based flooding or flooding that will occur just due to sea level rise?

The MC-FRM results are also being used to define the present and anticipated future (e.g., 2030) mean high water shorelines across the state, resulting in a marked improvement over some current shorelines. These shorelines also provide an indication of where nuisance (daily) flooding can be expected in the future climate.



How does wave run-up and overtopping impact flooding?

In addition to the numerical simulation of the physical flow of water directly over land, the MC-FRM also incorporates dynamic wave run-up and overtopping to determine the volume of water that is thrown over coastal structures during storm events. The MC-FRM accounts for this volume overtopping coastal structures for each wave during the storm event and models the flow of this water behind the structure as it propagates inland or is returned to the ocean. This volume of water is incorporated into the dynamic results of over land water movement that is already simulated in the model.

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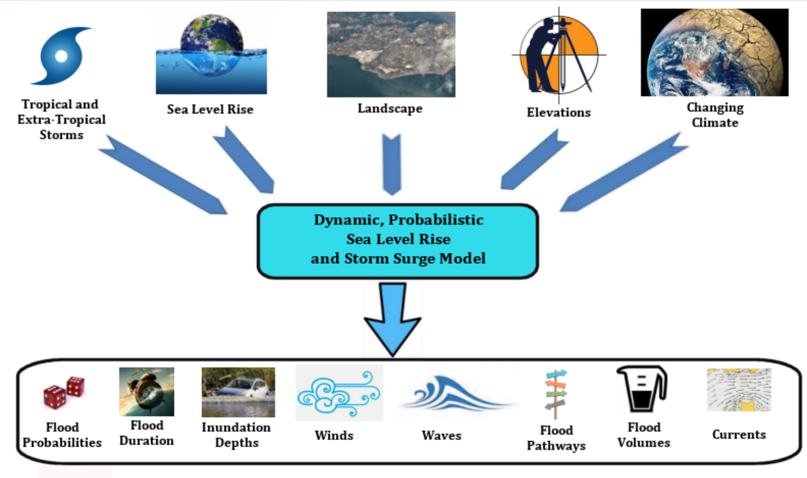
What are the products from the MC-FRM?

MC-FRM products for the Commonwealth include data for every community in Massachusetts that could be impacted by coastal flooding this century. Data products include the probability of flooding in each year (present day, 2030, 2050, and 2070) and water depths associated with the 1% (100-year), 0.5% (200-year), and 0.1% (1000-year) annual exceedance probability levels. Additionally, the water surface elevations associated with the 5% (20-year), 2% (50-year), 1% (100-year), 0.5% (200-year), 0.2% (500-year), and 0.1% (1000-year) annual exceedance probability levels are provided.



Overarching approach using dynamic probabilistic modeling to create the MC-FRM. Outputs provided by the dynamic model provide the ability for a more comprehensive assessment.

These water surface elevations include the effects of tides, storm surge, and wave setup. Further outputs include wave heights and distributions, wave action water elevations, and full tidal datums. Projected wave action water elevations are flood elevations that are calculated from the MC-FRM results by including the site-specific projected wave crest amplitudes above the water surface elevations.