

Sea Level Affecting Marshes Model (SLAMM) for Coastal Long Island Sound:

Using a Web Mapping Application Data Viewer
to Examine Predicted Land Cover Change for **2055**

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Project Background

Tidal marshes are dynamic ecosystems that provide significant ecological and economic value. They are also among the most susceptible ecosystems to climate change, especially sea level rise (SLR). To help identify potential responses to such change, the Connecticut Department of Energy and Environmental Protection (CTDEEP), the New England Interstate Water Pollution Control Commission (NEIWPCC), the New York State Department of Environmental Conservation (NYSDEC), EPA's Long Island Sound Study (LISS), and the New York State Energy Research and Development Authority (NYSERDA) contracted with Warren Pinnacle Consulting, Inc., (WPC) to apply the Sea Level Affecting Marshes Model (SLAMM) to the Connecticut and New York coasts of Long Island Sound.

A variety of factors affect a marsh's fate, including its elevation relative to the tides, frequency of inundation, salinity of tidal flood waters, amount of vegetation on the marsh surface, land subsidence, marsh substrate, and the settling rate of suspended sediment on the marsh surface. Therefore, a simple comparison of current marsh elevations to future projections of sea level does not adequately predict wetland vulnerability to accelerated rates of sea level rise. SLAMM considers many of these factors to predict the response of marshes and other intertidal resources to predicted rates of SLR. SLAMM is not a hydrodynamic model designed to consider variables such as three-dimensional water flow, channel scour, sediment transport, or flow-velocity reductions due to irregular seafloor topography and tidal

flow constrictions such as tide gates. Rather, SLAMM is a two-dimensional model in which long-term shoreline and habitat changes are predicted as a function of elevation, tide range, and sea level rise. A fundamental assumption used is that individual wetland types inhabit a range of vertical elevations that is a function of local tide range. SLAMM computes relative sea level rise for each area subject to analysis at different time steps that is offset by both observed and modeled marsh accretion and other factors affecting marsh surface elevation.

When the model is applied, the change from one land-cover class to another (e.g., irregularly flooded marsh to regularly flooded marsh) is determined by comparing the new tidal water elevation and inundation frequency resulting from a future SLR value to the existing land-cover class and then applying a decision-tree and land-cover conversion rules. To better inform users of the SLAMM model about the confidence or reliability of these results, an uncertainty analysis was also applied using a "what-if" type analysis, called a Monte-Carlo simulation, to account for model input uncertainties or variation.

The investigation's final reports and outputs are available at: <http://warrenpinnacle.com/prof/SLAMM/LISS/> and <http://warrenpinnacle.com/prof/SLAMM/NYSERDA/>

Use Considerations

SLAMM Data

As with any modeling exercise, the quality of its predictions is governed by the data used and the performance of the model itself. Accordingly, the project team has attempted to use and report the best available information. Some specific considerations are noted below:

- SLAMM is widely recognized as an effective model to study and predict wetland response to long-term sea level rise (Park et al. 1991) and has been applied in every coastal US state.
- Elevation, land cover, tide range, and accretion/erosion data for coastal Connecticut and New York come from reliable sources that have been researched and vetted by the project team as well as external project advisers. The resulting output was reviewed both internally and by external experts who provided comments and suggestions to improve and clarify the final products.
- SLR presents the most complicated component. Although there is general agreement within the scientific community that sea levels have been and will continue to increase over this century, there is no consensus on the rate or range of rates expected by location. As a result, the project team used the recommendations from a recent review and analysis of sea level rise projections by NYSERDA. This approach provided consistency for comparison of SLAMM results for areas of LIS, and incorporated both lower-end and higher-end projections for short, mid-range, and long-term time-steps previously presented in peer-reviewed scientific literature.

A more detailed description of SLAMM model processes, underlying assumptions, and equations for this effort can be found in the SLAMM 6.2 Technical Documentation (<http://warrenpinnacle.com/prof/SLAMM>). Information on the NYSERDA approach, including the specific SLR cases, can be found at: <http://www.nyserda.ny.gov/climaid>

Park, R. A., Lee, J. K., Mausel, P. W., and Howe, R. C. (1991). "Using remote sensing for modeling the impacts of sea level rise." World Resources Review, 3, 184-220.

Use Considerations

Web Mapping Application

The web mapping application was built from an Environmental Systems Research Institute (ESRI) ArcGIS Online template using Mozilla Firefox 31.0 and is freely available to the public. It has been opened and used in desktop versions of Internet Explorer (11.0.9600.17801). Access through other browsers or mobile devices may or may not respect the full functionality of the desktop versions.

The application can be accessed from the following locations:

- The CTDEEP mapping site: <http://tinyurl.com/CTNYSLAMMCompare-2055>
- The ESRI ArcGIS Online website, (www.arcgis.com/home), by searching for “CT NY SLAMM”
- The EPA LISS website SLAMM page: www.longislandsoundstudy.net/slam

About the SLAMM Comparison Application

About

The application is designed to allow users to view and compare the following four SLAMM data sets for the coastal areas of Long Island Sound in both Connecticut and New York.*

1. Land cover changes prior to any future sea-level rise predictions (i.e., initial conditions circa 2010)

The initial conditions were generated by running the SLAMM model with current environmental input data and calibrating the results with the most recent wetlands mapping data (National Wetlands Inventory data for CT and NY) and aerial photography.

2. Land cover changes from a “low-end” prediction of sea-level rise by 2055

The predicted changes shown here assume a Rapid Ice Melt Maximum of 1.72 meters of SLR by 2100, corresponding to 0.74 meters (just under 2.5 feet) of SLR by 2055.

3. Land cover changes from a “high-end” prediction of sea-level rise by 2055

The predicted changes shown here assumes a Rapid Ice Melt Maximum of 1.72 meters (5.64 ft) of SLR by 2055.

4. The likelihood of the existence of coastal marsh by 2055

The Likelihood layer depicts how we might expect coastal marsh to be distributed in 2055. (Here, coastal marsh is any of the following land-cover classes: regularly flooded marsh, irregularly flooded marsh, transitional marsh, and tidal-fresh marshes.) Rather than displaying results for a particular set of assumptions, such as the two specific SLR scenarios listed above, this layer depicts the results from multiple model runs using different combinations of various environmental variables. *These results can then be analyzed to illustrate the distribution of how likely coastal marsh may be present at a given time, regardless of any specific SLR assumption or variation in the value of other model input variables.*

* The SLAMM modeling process generated a variety of predictions based on several scenarios of SLR. For more information on these and the overall SLAMM development effort for LIS, please consult the final reports available at:

<http://warrenpinnacle.com/prof/SLAMM/LISS/> and <http://warrenpinnacle.com/prof/SLAMM/NYSERDA/>

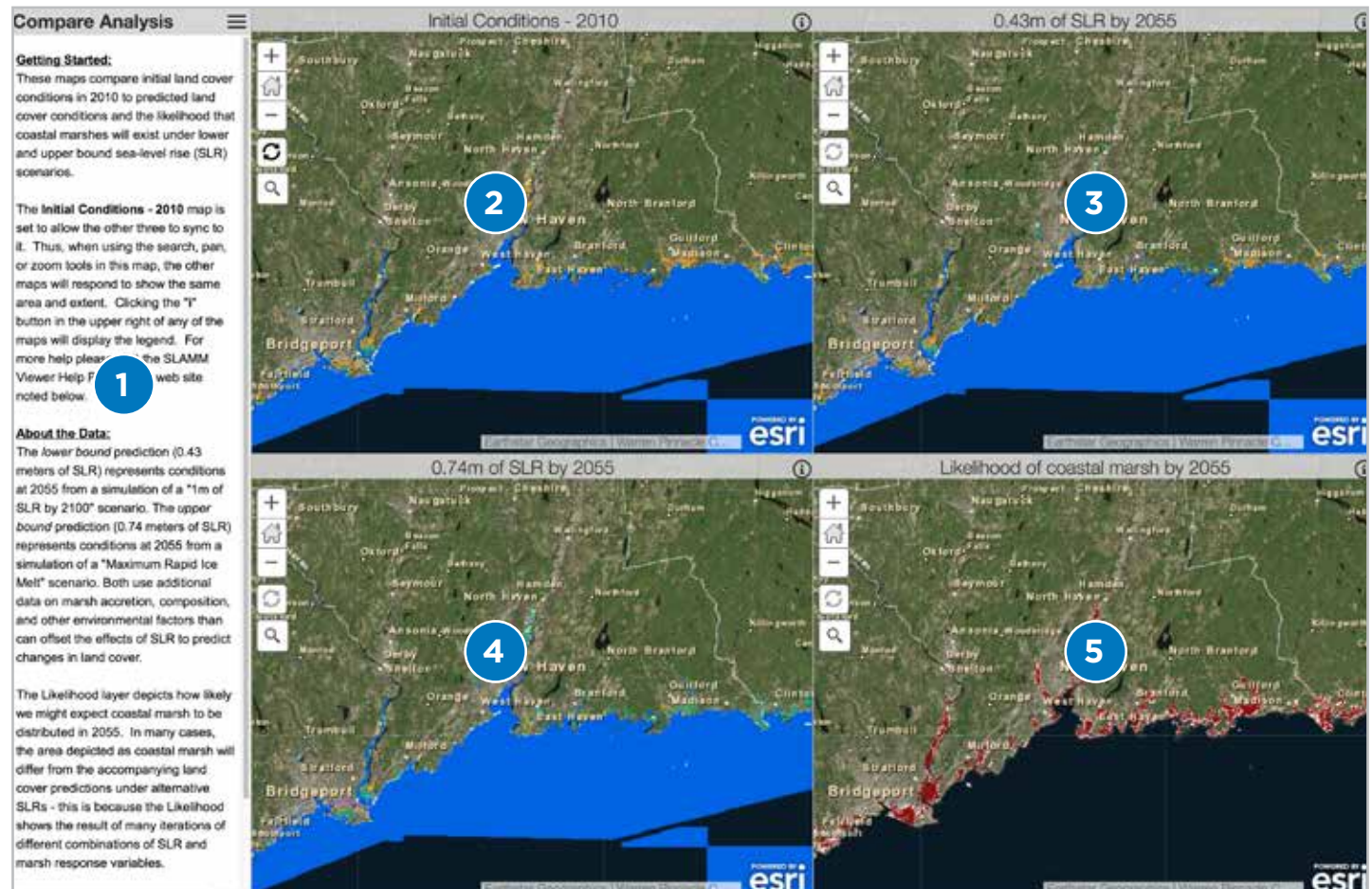
or the NYSERDA ClimAID report at <http://www.nyserda.ny.gov/climaid>

Using LIS SLAMM Comparison Application

Application layout

The application is broken into five sections—one **Info Panel** and four **Map Views**:

- 1 **Info Panel—Compare Analysis:** provides some basic background info on the data and high level instructions
- 2 **Map View—Initial Conditions 2010:** displays actual ground conditions circa 2010
- 3 **Map View—0.43m of SLR by 2055:** shows a predicted “low-end estimate” of land-cover change
- 4 **Map View—0.74m of SLR by 2055:** shows a predicted “high-end estimate” of land-cover changes
- 5 **Map View—Likelihood of Coastal marsh by 2055:** shows the results of an analysis designed to address uncertainty inherent in model input



Using LIS SLAMM Comparison Application

Info panel

The Info Panel section functions simply to provide some basic context for the data and a minimal amount of in-application help. It can be always displayed (the default) or minimized to provide more screen space for the map views.

- 1 Use the icon in the upper right of the Info Panel (three horizontal lines; circled in the figures) to minimize the section from view or to bring it back
- 2 The info panel
- 3 The panel maximized with the map views
- 4 The panel minimized to the far left of the screen. In both cases the icon to toggle between these states is available.

Compare Analysis

Getting Started:
These maps compare initial land cover conditions in 2010 to predicted land cover conditions and the likelihood that coastal marshes will exist under lower and upper bound sea-level rise (SLR) scenarios.

The Initial Conditions - 2010 map is set to allow the other three to sync to it. Thus, when using the search, pan, or zoom tools in this map, the other maps will respond to show the same area and extent. Clicking the "I" button in the upper right of any of the maps will display the legend. For more help please visit the SLAMM Viewer Help Page at the web site noted below.

About the Data:
The *lower bound* prediction (0.43 meters of SLR) represents conditions at 2055 from a simulation of a "1m of SLR by 2100" scenario. The *upper bound* prediction (0.74 meters of SLR) represents conditions at 2055 from a simulation of a "Maximum Rapid Ice Melt" scenario. Both use additional data on marsh accretion, composition, and other environmental factors that can offset the effects of SLR to predict changes in land cover.

The Likelihood layer depicts how likely we might expect coastal marsh to be distributed in 2055. In many cases, the area depicted as coastal marsh will differ from the accompanying land cover predictions under alternative SLRs - this is because the Likelihood shows the result of many iterations of different combinations of SLR and marsh response variables.

The interface shows a 'Compare Analysis' section with a hamburger menu icon (three horizontal lines) in the top right corner. Below the text are four map panels arranged in a 2x2 grid. The top-left map is titled 'Initial Conditions - 2010'. The top-right map is titled '0.43m of SLR by 2055'. The bottom-left map is titled '0.74m of SLR by 2055'. The bottom-right map is titled 'Likelihood of coastal marsh by 2055'. Each map panel has a legend icon in the top right corner. The info panel is on the left side of the screen, and the maps are on the right side.

Using LIS SLAMM Comparison Application

Map Views


The four map views are designed to show the user different variations of SLAMM data, along with a legend that describes the symbology (color schemes.)

Each map view has the same set of view controls that change its own scale and extent. However, the four map views can also be synced together, making it possible to easily see changes in data for the same area. By default, the Initial Conditions – 2010 map view is the primary view. Using any of the view controls in this map view will automatically sync the other three map views to display the same extent and scale.


Map Views Controls

In the upper left corner of each map there are five control buttons. Each map has the same five, and all behave as described

 **Zoom In:** Clicking on this button will zoom the map in by a preset factor, allowing you to see smaller areas in greater detail.

 **Default Extent:** Clicking on this button will return the map out to a predefined extent, showing the entire study area for Long Island Sound. (This is a good way to reset things if you get lost.)

 **Zoom Out:** Clicking on this button will zoom the map out by a preset factor, allowing you to see larger areas but in less detail.

 **Sync:** Click on this button in any map view to control how the other maps sync. By default this is set for the Initial Conditions map. A map view with a **black** sync symbol (as opposed to a greyed-out symbol) indicates that particular view is the primary view controlling the other three.

 **Search:** Clicking on this button will open a box where you can enter an address or place-based name to locate.

In addition to these controls, using your mouse by holding down the left mouse button and dragging your cursor will allow you to pan around the map (i.e., drag the map view around to reposition the extent).

Using combinations of the panning and zooming controls will allow you to manually move around the extent of the map at varying scales.

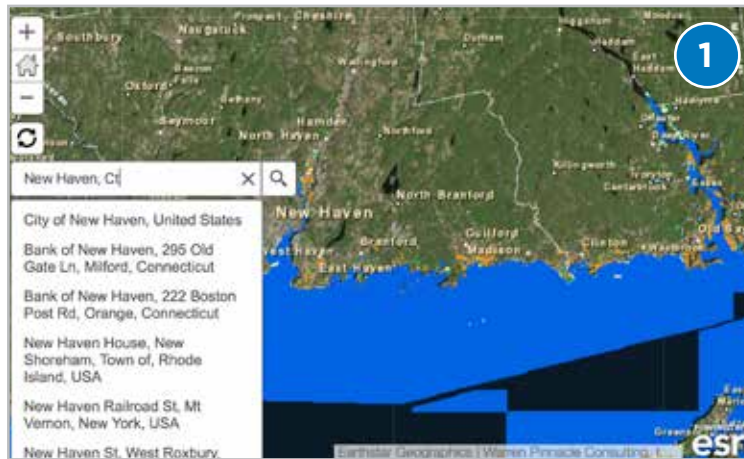
NOTE: In order to have all four map views move in sync, you **MUST** pan and zoom in the primary map view (by default, the Initial Conditions – 2010 map view).

Using LIS SLAMM Comparison Application

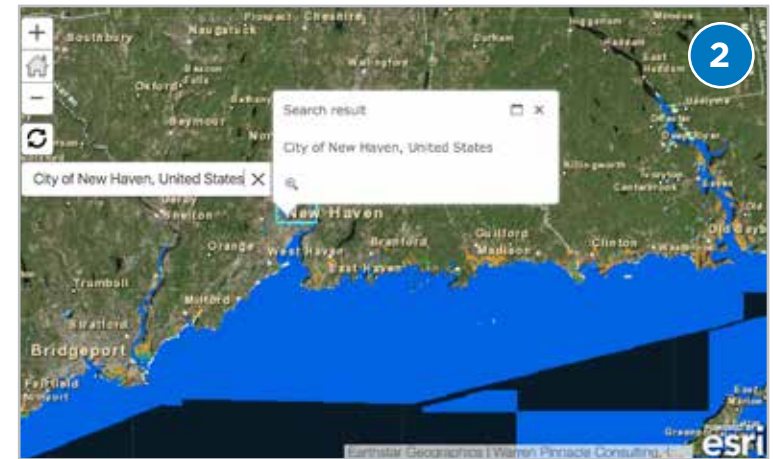
Map View Controls (ct'd)—Using the Search Control

Instead of manually moving around the map view, you can search for and go to an exact location instead. Click on the Search control (magnifying glass), and enter some location information in the resulting search box. This could be a specific address or a more general place name. As you enter your information, a drop-down list of potential options will be generated. If appropriate, you can select an option from this list by clicking on it, or hit enter to apply the search term you entered.

To clear out the result of a search entirely (i.e., remove place markers and result windows from the map view), click the Search control and then click the “X” on the right side of the search box.



1 Entering “New Haven, CT” into the search box generates a list of options that can be selected.



2 Selecting the “City of New Haven” option adds a **place marker** (a blue and white pin) and a **result window** (white box) to the map view and zooms in to the location. Using the “magnify icon” in the lower left of the result window will zoom in further. (You can also use the standard zooming tools described earlier.) The result window can be expanded and contracted by the “maximize” icon to the left of the “X” in the upper right. You can close the result window by clicking its “X” icon in the upper right. (The place marker, however, will remain on the map.)

Using LIS SLAMM Comparison Application

Displaying the map legend

After using the map view controls to display a particular area or specific location, you can open a legend frame to see what the map symbology (color scheme) means. The legend frame can be displayed by clicking the information icon “i” in the upper right corner of the grey title bar of any of the four map views.

Clicking the information icon can toggle the legend frame on or off for any map view, and multiple map views can have legend frames displayed at the same time. (By default, these are initially turned off to maximize viewable map space.) Due to the number of land-cover classes symbolized (there are 18 different types of land-cover classes that SLAMM presents), you may need to use the scroll bar on the right side to move up and down to see all the values.

NOTE: In order to display a legend, the map view must be zoomed into a minimum amount. If the icon is clicked and the text “No legend” appears, use the zoom or search controls to zoom the map view in until it does.

- 1 The information icon on the “Initial Conditions–2010” title bar. All other map views have the same icon in the same location.



- 2 A map view with the SLAMM land-cover classification legend frame displayed. Notice the scroll bar on the right side of the frame that can be moved up or down to see additional classes and color schemes. The legend frame not only identifies the land cover, but also reiterates the SLR conditions (0.74 m by 2055) and provides the model scenario used (2055 Rapid Ice Melt Maximum).



Using LIS SLAMM Comparison Application

Displaying the map legend (ct'd)

Three of the four map views (“initial conditions-2010” and the two specific SLR scenarios) all have the same legend format, as they are showing the same type of data, albeit at different times and under different scenarios. The fourth map view (Likelihood of coastal marsh by 2055) has a different legend, as it is displaying a fundamentally different data set.

NOTE: In many cases, the area depicted as coastal marsh will differ from predictions based on a specific scenario. This is because the Likelihood shows the result of many iterations of different combinations of SLR by 2055 and marsh response variables.

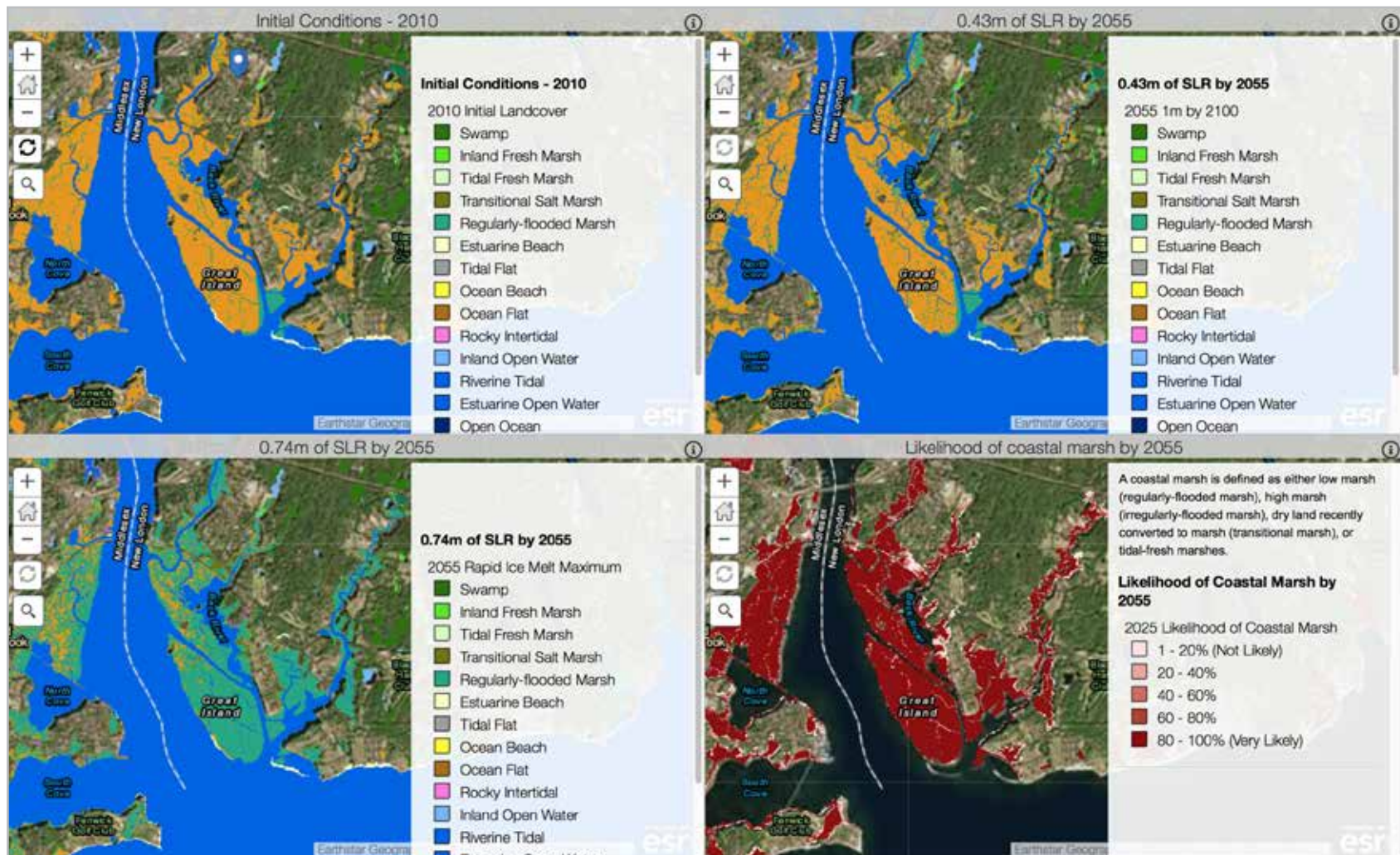


A Likelihood map view with the legend displayed. Darker colors correspond to higher likelihoods, i.e., that a coastal marsh was present in a predominant number of models. This allows users to get a sense of the extent of marsh in the future without having to select any one set of conditions.

Analysis with the SLAMM Comparison Application

Example

The four map views can be used in unison to explore and examine the effects SLR may have with respect to marsh composition and extent. The following shows a zoomed-in view of an area in Old Lyme, CT, on the eastern shore of the lower Connecticut River.

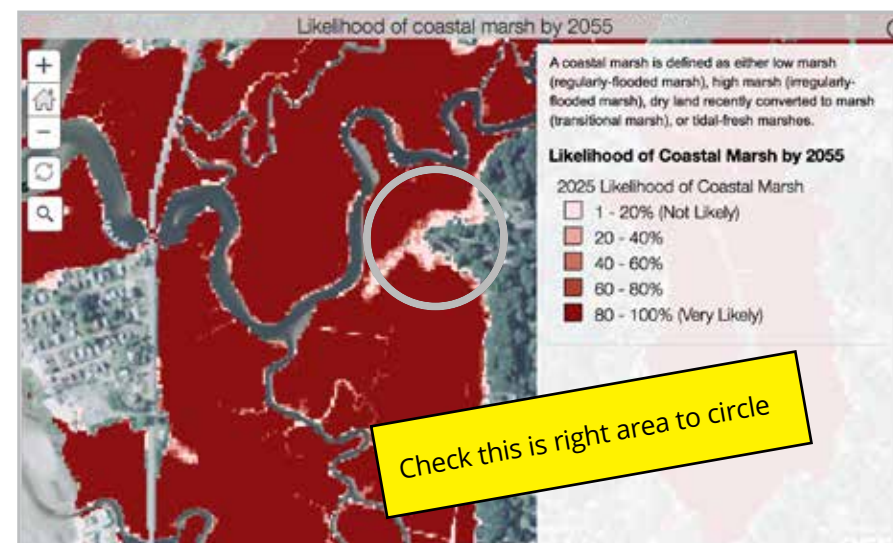
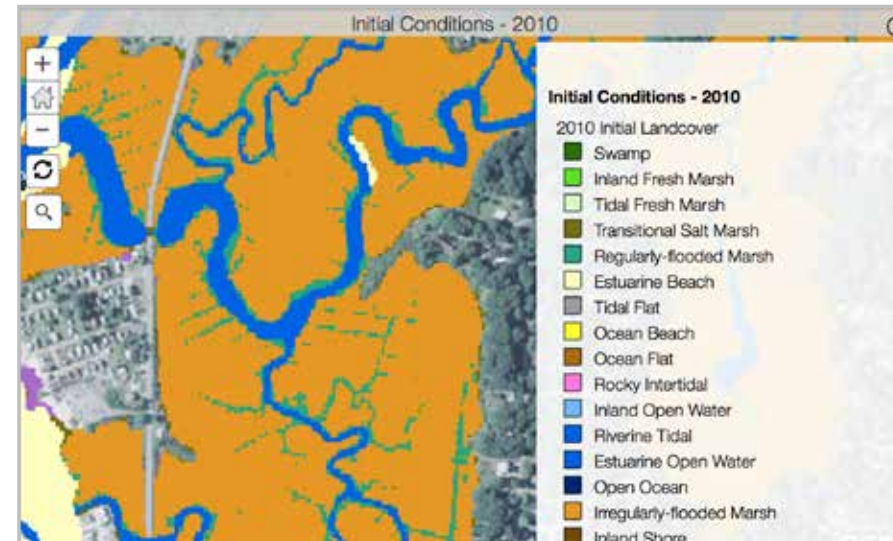


Analysis with the SLAMM Comparison Application

Example (ct'd)

From the four map views, we can make the following observations:

- The *Initial Conditions* map shows an area dominated largely by irregularly flooded marsh, with small areas of transitional and regularly flooded marsh.
- With $0.43m$ of SLR, the amount of transitional marsh increases (the marsh is migrating beyond its original boundaries) and small areas of irregularly flooded marsh are becoming more regularly flooded.
- With $0.74m$ of SLR, the area has dramatically changed from a largely irregularly flooded marsh to a largely regularly flooded marsh with further expanded areas of transitional marsh.
- By comparing the *Initial Conditions* to the *Likelihood* map, we can get a sense of how likely some of these changes may be.
 - In both scenarios, areas classified as irregularly flooded marsh or regularly flooded marsh are dark red in color, indicating that these are still predicted to be marshes (as opposed to conversion to tidal flats or drowned, for example).
 - In looking for areas of transitional marsh, the Likelihood map can be instructive in identifying areas that are **more likely** to show this migration effect. Areas generally outside the bounds of the original marsh configuration that are darker in color (e.g., circled in the figure right) are more apt to be areas of marsh migration than those with lighter-color areas.



Analysis with the SLAMM Comparison Application

Example (ct'd)

Based on the previous observations, here are some examples of activities that managers or scientists might explore now to prepare for the future:

Can we design studies or collect observations to confirm or deny:

- Predicted marsh transgression extents and/or rates?
- Predicted marsh land-cover composition?

Are there land management assessments or studies to:

- Determine the implication of the ecological effects of certain marshes transitioning between different land cover states?
- Explore the possibility of certain areas even supporting marsh transition?
- Explore the potential for conservation easements, land purchases, or other protective measures where it may be likely to help ensure healthy coastal marsh ecosystems?

ACKNOWLEDGMENTS

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