U.S. Army Corps of Engineers
Sea Level Tracker User Guide

Sea Level Rise with USACE SLC Scenarios for Key West, FL
Active and compliant tide gauge
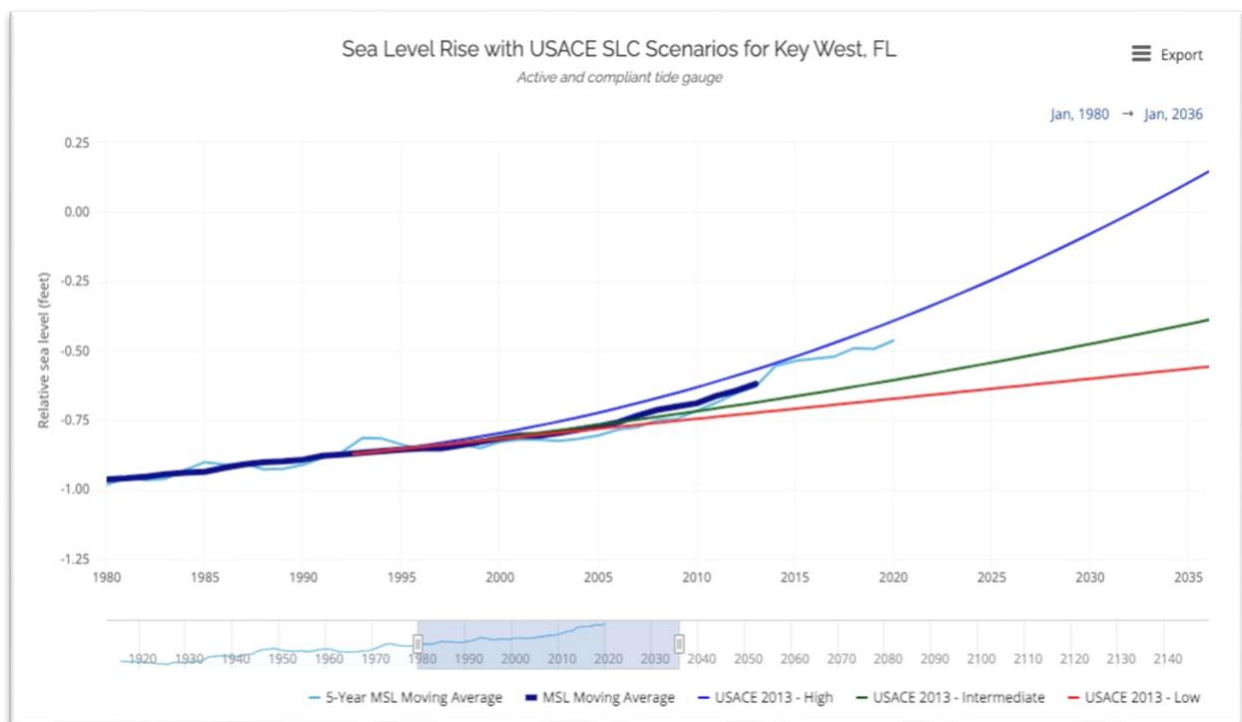
User Guide

Version 2.0

Updated December 2022

U.S. Army Corps of Engineers, Washington, DC

Climate Preparedness and Resilience Community of Practice

Abstract:

Sea level change (SLC) has been a persistent trend for decades in the United States and elsewhere in the world. Observed and reasonably foreseeable global sea level rise is likely to continue beyond the end of this century. In most locations, global sea level rise results in local relative sea level rise. For these locations, these changes have already caused impacts, including flooding and coastal shoreline erosion to the Nation's assets. In other locations, (e.g., Pacific Northwest and Alaska), vertical land movement means that local relative sea level is falling. While this may seem to be a benefit, the impacts in these locations can be just as severe as elsewhere, as reduced water depth can adversely impact navigation. Moreover, along the U.S. Atlantic Coast alone, almost 60% of the land that is within a meter of sea level is planned for further development. Effective infrastructure and development decision-making requires adequate information on the potential rates and amount of SLC. Decision-makers often ask, "What is the current rate of SLC, and how will that impact the performance and reliability of my infrastructure or the current and future residential, commercial, and industrial development?" To better empower data-driven and risk-informed decision-making, the U.S. Army Corps of Engineers (USACE) has developed the Sea Level Tracker. The Sea Level Tracker is a user-friendly web application that visualizes the dynamic nature and variability of coastal water levels at tide gauges, allows comparison to projected SLC scenarios, and supports simple exploration of how SLC has or will intersect with local elevation thresholds related to buildings and infrastructure (e.g., roads, power-generating facilities, dunes). Taken together, the tool enables users to align sea level rise scenarios with existing and planned engineering efforts, estimating when and how the sea level may impact critical infrastructure and planned development activities.

Preferred Citation:

Introduction

Sea level change (SLC) has been a persistent trend globally for decades (Parris et al., 2012; Hall et al., 2016; Sweet et al., 2017). Change is expected to continue beyond the end of this century, which will cause significant impacts to the Nation's assets already located at or near the ocean (e.g., Sweet et al., 2014; Sweet and Marra, 2016). In most locations, global sea level rise results in local relative sea level rise. For these locations, these changes have already caused impacts, including flooding and coastal shoreline erosion to the Nation's assets. In other locations, (e.g., Pacific Northwest and Alaska), vertical land movement means that local relative sea level is falling. While this may seem to be a benefit, the impacts in these locations can be just as severe as elsewhere, as reduced water depth can adversely impact navigation. Moreover, along the U.S. Atlantic Coast alone, almost 60% of the land that is within a meter of sea level is planned for further development. Accordingly, SLC poses significant risk over the lifetime of infrastructure located in affected coastal areas.

Given its mission areas of navigation and flood and coastal risk management, the U.S. Army Corps of Engineers (USACE) has been aware of the impacts of changing sea levels to shoreline erosion and stability and flooding (e.g., USACE, 1979). UASCE has released formal guidance (e.g., USACE, 1989; USACE, 2013a; USACE, 2013b; USACE, 2014) to incorporate "the direct and indirect physical effects of projected future SLC across the project lifecycle in managing, planning, engineering, designing, constructing, operating, and maintaining USACE projects and systems of projects." Now, all current and future coastal projects must account for the impacts of changes in local mean sea level (LMSL) throughout a project lifecycle. The Sea Level Tracker is designed to support the required analysis and to empower deeper exploration of SLC more broadly.

Specifically, the Sea Level Tracker allows users to visualize observed changes in sea level and to compare trends to projected changes per USACE Engineer Regulation (ER) 1100-2-8162 and Engineer Technical Letter (ETL) 1100-2-1. The tool shows the historical, observed changes in mean sea level (MSL) as measured and reported by the National Oceanic Atmospheric Administration (NOAA), mapped against SLC projections from sources such as USACE, NOAA, and the Coastal Assessment Regional Scenario Working Group (CARSWG). Taken together, the tool enables the comparison of actual SLC with SLC projections (as described in ER 1100-2-8162), along with observed monthly water levels and the computation of SLC trends based on historical data. In addition, the tool allows users to map these trends and projections against elevation levels that represent critical thresholds for infrastructure or other elevations of interest to the user. Finally, the tool enables users to visualize the indirect impacts of SLC on extreme water levels (EWLs) as calculated by USACE and NOAA. Working together, these components can help users align SLC scenarios with existing and planned engineering efforts, estimating when and how the sea level may impact critical infrastructure and planned development activities.

The purpose of this manual is to provide guidance on how to use Version 2.0 of the Sea Level Tracker, released in December 2022. The document includes the following: (1) a discussion of the technical concepts incorporated into the tool and (2) guidance for user interaction. This user guide does not cover all possible situations that one may encounter while using the tool, and Sea Level Tracker is not a substitute for professional engineering judgment.
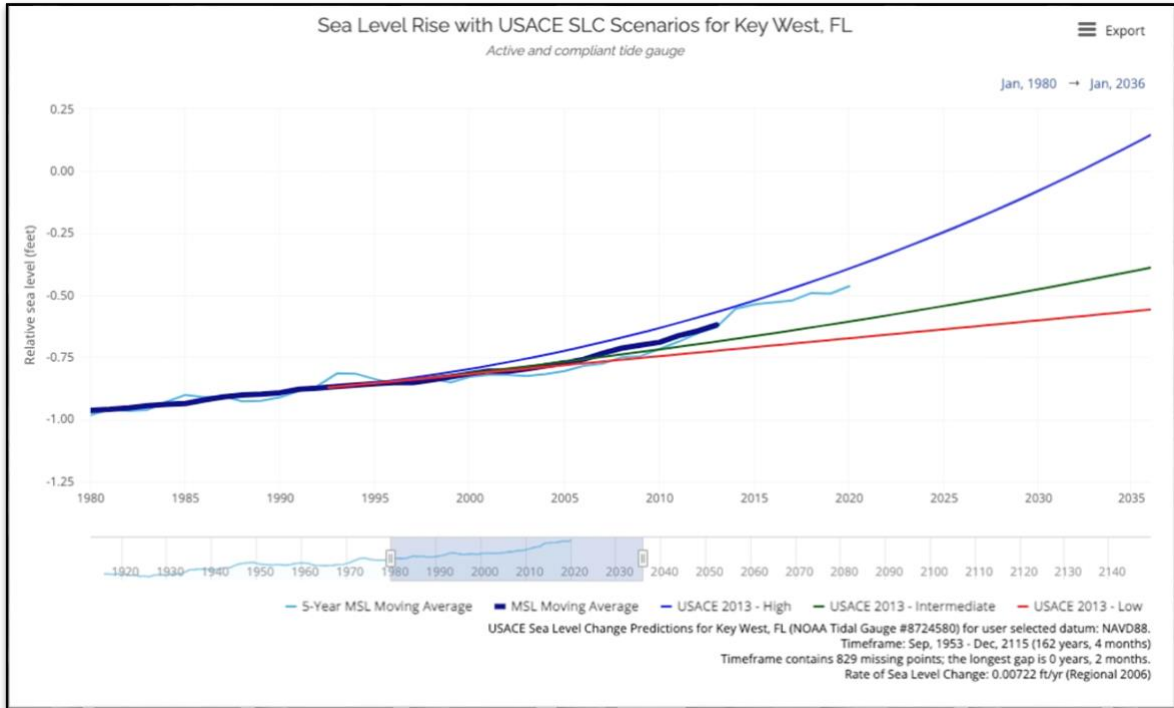
Figure 1: The Sea Level Tracker Analyzing Key West, FL (8724580) Using the NAVD88 Datum

Accessing the Tool

The Sea Level Tracker is available at: http://climate.sec.usace.army.mil/slr_app/.

1 Technical Background

As a comprehensive platform, the Sea Level Tracker combines authoritative tide gauge data from NOAA, well-established projections of sea level, and a statistical toolbox into one web application. The following sub-sections provide a foundational understanding of the tool, its inputs, and the analysis it enables. This document is designed to support use of the tool but does not provide comprehensive technical documentation. Users and readers are encouraged to explore the references included at the end of the document to develop a deeper understanding of the science and engineering theory behind the Sea Level Tracker. In addition, further research is recommended for users intending to use analytic outputs for future planning or in engineering decision-making.

1.1 General Capabilities of the Sea Level Tracker

This Technical Background section covers (1) general tool capabilities, (2) user inputs for the visualizations and data tables, and (3) the high-level scientific and engineering background that supports the USACE SLC projections. As a deployed application, the Sea Level Tracker enables the comparison of actual SLC with SLC projections from sources such as USACE, NOAA, and CARSWG (as described in ER 1100-2-8162), while quantifying and visualizing observed water levels and SLC trends based on this historical data. To enable higher-order analysis, the tool can map these trends and projections against existing threshold elevations for critical infrastructure and other local elevations of interest. The tool also provides easy access to EWLs calculated by NOAA and USACE. All these components, working together, can help users align various sea level rise scenarios with existing and planned engineering efforts—estimating when and how the sea level may impact critical infrastructure and planned development activities.

In practice, the Sea Level Tracker aims to foundationally address two defined needs:
1. Show actual MSL vs. the projected SLC scenarios plainly.
2. Visually represent the observed rate of sea level change at a user-selected location.

To offer data-driven insights, the tool relies on an interactive user interface with four main sections:
1. ***Data Entry Panel:*** Within six unique data entry panes, the user can configure the elements they wish to visualize and explore within the application. On the first pane, the user selects the location, gauge, and vertical reference datum to be analyzed, as well as the SLC rate that is a foundation for the calculated SLC scenarios. On the subsequent panes, the user configures characteristics of the primary visualization and its underlying data, including data sources to visualize, moving averages of historical data, trend lines, extreme water levels (EWLs), and critical elevations for comparison.
2. ***Location Map:*** For a more visual experience, the user can select a location and gauge on the map for analysis. This tab helps the user to maintain geographic context during the analysis and allows the user to explore nearby locations and gauges with ease. The user can alternatively select NOAA grid points to see NOAA projections for select areas that without an active gauge.
3. ***Visualization Tab:*** Built to house an easy-to-interpret data visualization, this tab is the primary means of interacting with the user-configured analysis. The generated plot captures the historic hydrologic behavior at the selected location and gauge (based on the selected datum), while presenting historic trends and averages of interest to the user. The final output is configured by the user's selections in the *Data Entry Interface*, and the resulting visualization can be captured as a screenshot or downloaded as an image file (for distribution with embedded metadata).
4. ***Downloadable Report Tab:*** The downloadable report gathers relevant information from the previous tabs and generates a downloadable report that summarizes the inputs and results shown in the Sea Level Tracker. The report is saved as an interactive HTML file that can be opened in a browser and saved as a PDF file.

5. ***Data Tables Tab***: For deeper inspection, the Sea Level Tracker simultaneously presents the raw data used to populate the visualization tab. Here, all embedded data is at the user's fingertips, where they can filter the selected variables to desired analytical ranges. These tables can be downloaded and saved as a CSV file for distribution.

1.2 Data Used in Sea Level Tracker

As an analytics platform, the Sea Level Tracker does not generate its own data. Rather, the application automatically pulls authoritative tide gauge data from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) Application Programming Interface (API), runs a series of calculations, and returns the described outputs. The CO-OPS API is a flexible retrieval mechanism for direct access to CO-OPS' products, which include historic water levels, predictions, currents, and meteorological observations. The Sea Level Tracker processes the user's selected inputs and sends a request to the API, which returns raw water level data for the user-selected tidal gauge. Therefore, the initial rendering of the selected inputs can take some time, depending on connection speed. More information on querying data through the CO-OPS API can be found here, where the types of information accessible via the API are listed in detail under Resource Types.

As mentioned above, the user can configure the visualization's parameters in the data entry interface. This interface is composed of six panes, each with a unique focus. After configuring the first pane, the user can press the "Submit Inputs" button, which causes the application to process the configured inputs and render the default visualization for the selected location. The Sea Level Tracker will not run unless the first pane is configured, as the elements within this pane configure the CO-OPS API request (though the user can run the tool at any point after configuring the first pane).

1.2.1 Pane #1: Gauge, Datum, and Rate

Figure 2: Data Entry Pane #1

The first pane allows the user to configure the five primary parameters of the Sea Level Tracker. Four of the five parameters are passed directly to the CO-OPS API, and accordingly, will directly impact the raw historical data (gauge, datum, and unit selection). The location elements are converted to a gauge identification number, which is correlated with historical data provided by NOAA and presented with the tool's outputs. For ad hoc analysis, users can use the gauge identification number to directly query the API on their own. The datum value and unit parameters are also passed to the CO-OPS API. For some gauges, not all datum options are offered by NOAA, and accordingly, these choices are removed from the dropdown menu.

Finally, the user can select a SLC rate on the first pane. These values are extracted from NOAA as well, but not directly from the API. They can be accessed here, while the regional rates are sourced from Technical Report NOS CO-OPS 065, "Estimating Vertical Land Motion from Long-Term Tide Gauge Records." These rates are used to calculate the continuous SLC projections in the tool.

1.2.2 Pane #2: Data Sources

The second pane allows the user to select the sea level curve projections they wish to display. The user can choose any number of available projection scenarios from the dropdown menus in this tab. These scenarios are described in more detail in Section 1.3.

Furthermore, when certain sources are chosen, additional inputs will appear in the pane. For example, when the point-in-time NOAA 2022 scenario is chosen, extra options will appear to toggle data interpolation and confidence intervals.

Figure 3. Data Entry Pane #2

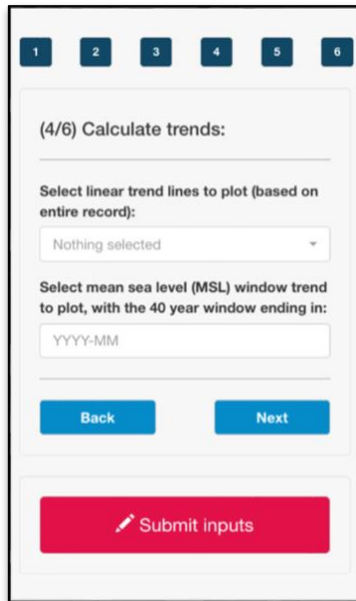## 1.2.3 Pane #3: Moving Average Water Surface Scenarios and Monthly Means

The third pane allows the user to select the measures of historical data to include as a monthly mean or a smoothed, moving average. By default, the 19-year midpoint MSL moving average is selected. The 19-year period is tied to the Metonic cycle. The user also has the option of adding the 5-year midpoint MSL moving average, as well as the raw monthly mean values for any of the water level measures. The monthly values are pulled directly from the API when the Sea Level Tracker requests the data using the "monthly mean" parameter documented here. These values are the basis for all the moving averages calculated in the tool.

Note that moving averages are cropped when there are no non-missing values in the averaging window. Gauges with missing values will require a brief "burn-in" period as the moving averages are smoothed over time. This often appears as irregularities or sudden increases or decreases in the data.

Figure 4: Data Entry Pane #3
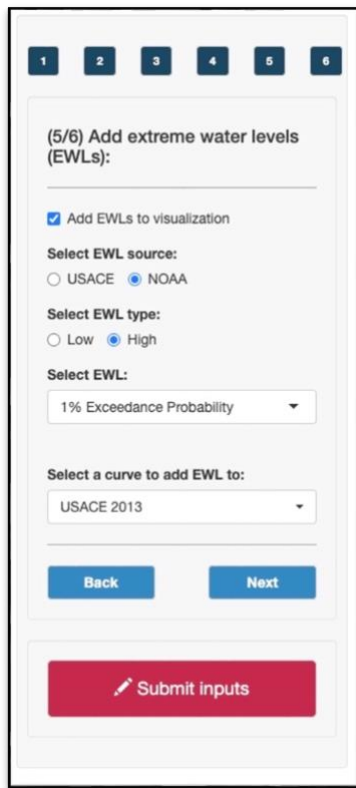
1.2.4 Pane #4: Linear Trend Lines

Figure 5: Data Entry Pane #4

The fourth pane allows the user to select trend lines to plot and visualize in the tool. Trends are calculated using a best-fit linear model, where both the y-intercept of the line and the linear coefficient are pulled from the regression fit. For the primary linear trend lines, these models are optimized to fit the entire period of record for the gauge. If the user wishes to reduce the period used when calculating these values, the user can define a 40-year window, where the entered date is the final month in that measured window. Alternatively, the user can use the time filters below the graph to compute trends on a custom range of data. For these customized periods of record, all calculated trends are based on MSL.

As specified in ER 1110-2-8162, a 40-year period of record is recommended to develop sea level trends, and accordingly, the users are not allowed to generate trends with fewer than 40 years of data.

1.2.5 Pane #5: Extreme Water Levels (EWLs)

Figure 6: Data Entry Pane #5

The fifth pane allows the user to add EWLs to the resulting visualizations. The EWLs are statistically derived water levels based on the probability of an extreme hydrologic event or storm as calculated by NOAA and USACE. These probabilities can be interpreted as approximately the inverse of the rarity of an event, such that a 1% exceedance probability corresponds to the most extreme water level expected over a 100-year period and a 5% exceedance probability corresponds to the most extreme water level expected over a 20-year period, for example. The user can select the SLC source(s) to which the EWL is applied. The EWL curves are measured with respect to the datum selected in Pane #1.

There are two methods for calculating the selected exceedance probability: the generalized extreme value (GEV) probability distribution function, which is used by NOAA, and the percentile function, which is used by the USACE. Both measures are statistically valid, but they are based on different analytic approaches and produce different results. For more information, EWLs and their associated implications are detailed in this technical report.

1.2.6 Pane #6: Critical Elevations for Comparison

The sixth pane allows the user to add user-defined, critical elevations for comparison with the visualized outputs. These elevations can be used as a benchmark for both the measured historical water levels and for the SLC projections and extreme water levels for future years.

The tool allows the user to enter a value and define a name for the defined elevation (as it will appear in the tool for the user's records). The tool will also transform the entered elevation between metric and English units, allowing for consistency with the user's unit selection on the first pane.

This pane allows for customization of the final analysis, helping decision-makers align various SLC projections with existing and planned engineering efforts. While the Sea Level Tracker is not a prediction engine, adding defined elevations can provide insight into how SLC may impact critical infrastructure and planned development activities under various risk scenarios (e.g., a one-in-100-year storm occurring under a moderate SLC scenario 20 years into the future). For more information, the implications of SLC are discussed in this technical letter.

Figure 7: Data Entry Panel #6

1.3 Sea Level Change Scenarios

At any location, changes in local relative sea level (LRSL) reflect the integrated effects of global mean sea level (GMSL) change, plus local or regional changes of geologic, oceanographic, or atmospheric origin. Therefore, when constructing local SLC projections, analytic tools must consider global and local effects. The Sea Level Tracker captures both effects, integrating the local (or user selected) relative SLC rate into its projections.

1.3.1 Continuous Scenarios

The Sea Level Tracker offers scenarios from three different sources: USACE, NOAA, and CARSWG. Each source has a set of scenarios: USACE has Low, Intermediate, and High scenarios, NOAA has Low, Intermediate-Low, Intermediate-High, and High scenarios, while CARSWG has Lowest, Low, Medium, High, and Highest scenarios. All the scenarios originate from 1992 in the Sea Level Tracker. Currently, this is the most robust starting point for the SLC scenarios, as 1992 is the center year (or midpoint) of the NOAA National Tidal Datum Epoch (NTDE) of 1983–2001. It is this epoch that is used to define the various tidal datums (Mean High Water, for instance, and local MSL) and it is expected that the average

of the 19 years of hourly readings from each tide gauge will be zero on or about June 30, 1992. This attempts to index the projections to the actual average water surface of the current NTDE (83-01). It is also at this point that the tidal datums are related to the appropriate geodetic datums such as NAVD88.

All sea level scenarios rely on the following formula (USACE 2013):

$$y = \alpha t + \beta t^2 \qquad (1)$$

In (1) above,
- α is the local sea level rate, which is selected by the user in the Sea Level Tracker.
- t is a measure of time, calculated as the difference between 1992 and the date at which the user is generating an estimate.
- β is the coefficient used for different acceleration scenarios global sea level rise.

As shown above, variations in the sea level scenarios result from changes in β. For the low-rise scenario, acceleration of global sea level rise is assumed to be zero. As a result, (1) simplifies to (2) below, which is the linear relationship between the selected local sea level rate and time. Adjusting this parameter (the local SLC rate) can result in significant variation in all three scenarios.

$$y = \alpha t \qquad (2)$$

In the accelerating sea level rise scenarios, β is a positive, non-zero value that results in a quadratic curve. These values can be found in Table 1. Due to the increased polynomial factor on time in this component of (1) above, all three scenarios result in reasonably similar estimates in the near future, but their estimates diverge significantly further into the future.

Table 1: Beta Parameter Values for Continuous Projections

Source	Scenario	β Value
USACE, 2013	Low	0
USACE, 2013	Intermediate	2.71E-05
USACE, 2013	High	1.13E-04
NOAA, 2012	Low	0
NOAA, 2012	Intermediate-Low	2.71E-05
NOAA, 2012	Intermediate-High	8.71E-05
NOAA, 2012	High	1.56E-04
CARSWG, 2016	Lowest	0
CARSWG, 2016	Low	2.71E-05
CARSWG, 2016	Medium	7.00E-05
CARSWG, 2016	High	1.13E-04
CARSWG, 2016	Highest	1.56E-04

1.3.2 Point-in-Time Scenarios

In addition to the continuous projection curves, NOAA offers point-in-time SLC projections on a decadal basis. For each decade, NOAA gives projections for several GMSL scenarios and gives the 17th, 50th, and 83rd percentiles for each scenario. The 50th percentile value is visualized as the MSL in the app, and the 17th and 83rd percentiles are represented as the "Likely Range" of MSL in the app. In addition to NOAA projection for active gauges, these NOAA sources provide projections for grid points around these gauges. Each grid point is identified by its latitude-longitude pair. In areas where grid points are present, they are spaced by one degree of latitude and/or one degree of longitude. These scenarios are mapped to a 1992 base year using the sea level change rates and offset values provided by NOAA in the source data.

The Sea Level Tracker offers two iterations of these point-in-time projections: NOAA 2017 and NOAA 2022. Notable differences between the two sources include the following:
- NOAA 2022 includes projections for each decade until 2150. NOAA 2017 includes projections for each decade until 2100, then gives projections for 2120, 2150, and 2200.
- NOAA 2022 gives projections for 5 GMSL scenarios: 0.3m, 0.5m, 1.0m, 1.5m, and 2.0m. Each scenario's value represents the GMSL rise by 2100 in that scenario. NOAA 2017 gives projections for these 5 scenarios along with projections for the 2.5m scenario.
- NOAA 2022 offers projections for grid points that are centered on whole-value latitude-longitude pairs (e.g., 26.0, –82.0). NOAA 2017's grid points are centered in between these pairs (e.g., 26.5, –82.5).

1.3.3 Local Scenarios

Finally, several local scenarios are supported in the Sea Level Tracker. Each local scenario displays projections for a small subset of active gauges. There is some variation in the granularity of the data between local sources, and all local sources contain point-in-time projections for just a handful of years between now and 2100. These scenarios are mapped to a 1992 base year using the user-selected sea level change rate. See Table 2 below for a full list of supported local sources.

1.3.4 Scenario Documentation

Table 2: Scenarios used in the Sea Level Tracker

Name	Location(s)	Link
USACE, 2013	All gauges	https://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1100-2-8162.pdf
NOAA, 2012	All gauges	https://cpo.noaa.gov/Serving-Society/News/ArtMID/8270/ArticleID/1443/Global-Sea-Level-Rise-Scenarios-for-the-United-States-National-Climate-Assessment
CARSWG, 2016	All gauges	https://www.hsdl.org/c/abstract/?docid=792698
NOAA et al., 2017	All gauges and gridpoints	https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf
NOAA et al., 2022	All gauges and gridpoints	https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report.html
Maryland, 2013	All Maryland Gauges	https://ian.umces.edu/publications/updating-marylands-sea-level-rise-projections/
Maryland, 2018	All Maryland Gauges	https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/Sea-LevelRiseProjectionsMaryland2018.pdf
NPCC, 2015	All New York Gauges	https://nyaspubs.onlinelibrary.wiley.com/doi/full/10.1111/nyas.12591
NPCC, 2019	All New York Gauges	https://nyaspubs.onlinelibrary.wiley.com/doi/10.1111/nyas.14006
NYC, Part 490	All New York Gauges	https://www.dec.ny.gov/regulations/103877.html
New Jersey, 2019	All New Jersey Gauges	https://www.nj.gov/dep/climatechange/data.html
NRC, 2012	Select West Coast Gauges (Los Angeles, CA; Newport Beach, CA; San Francisco, CA; Seattle, WA)	https://nap.nationalacademies.org/catalog/13389/sea-level-rise-for-the-coasts-of-california-oregon-and-washington

2   Interacting with the Sea Level Tracker

The Sea Level Tracker is designed to be analytically robust, yet intuitive to use. The application is composed of multiple panels, each with a unique functionality. This section of the User Guide aims to direct the user through the application and address any potential questions the user may have on interactions with the tool. Future iterations of the guide will address any ad hoc questions and concerns that are not addressed in Version 2.0.

The tool has two primary pages, which are toggled by user selections on the header bar. The welcome page, or landing page, is designed to offer the user general background information. The level of detail is not meant to fully explain the application or fully support its use; that is the goal of the user guide. Rather, the landing page aims to direct the user to critical supplemental resources and this guide, while providing generic introductory language for a new user.
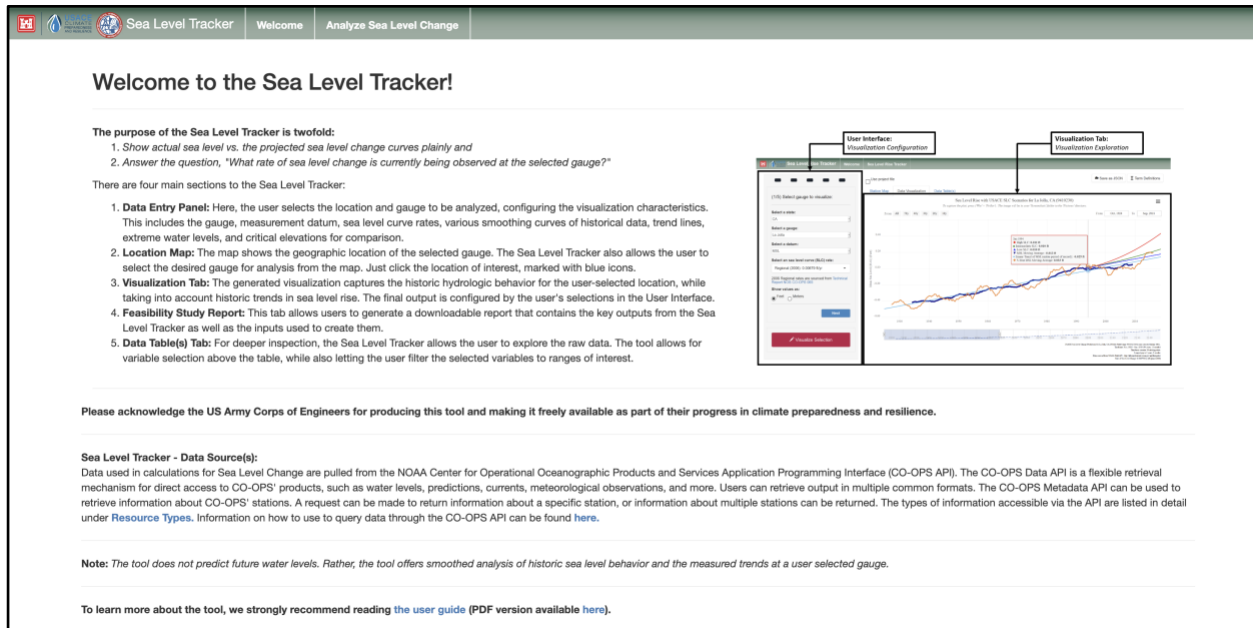
Figure 8: *Welcome Page*

The second option in the header bar brings the user to the page used to run the application, explore analytic outputs, and deliver data-driven insights. The remainder of this section is dedicated to walking through this component of the tool.
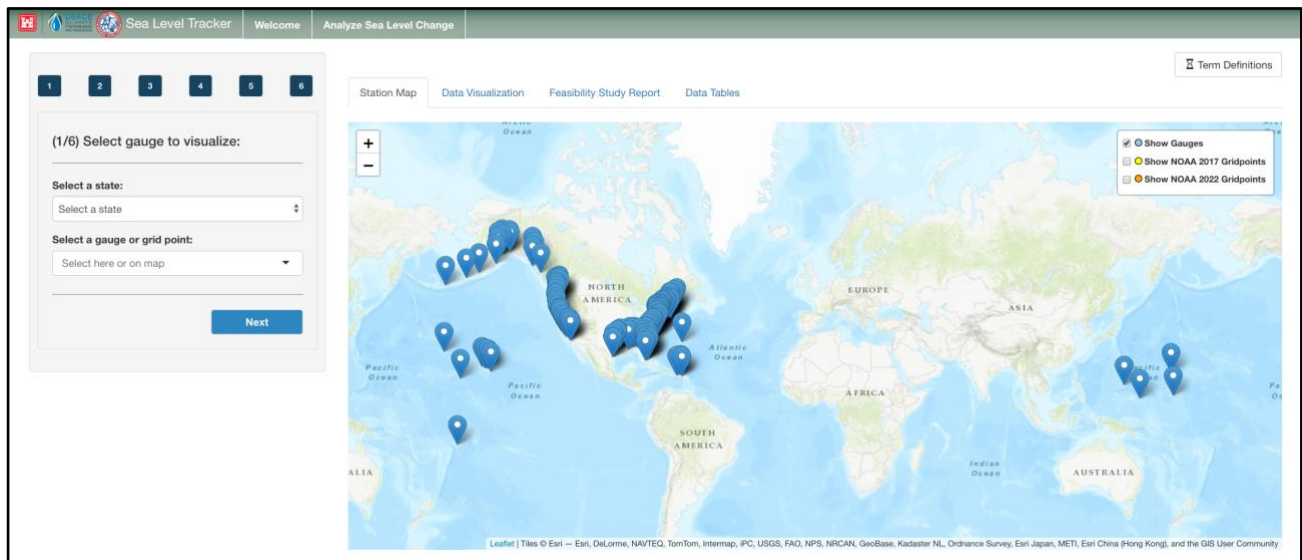
Figure 9: *Analyze Sea Level Change Page*

2.1   Data Entry Panel

On the left-hand side of the application page is the Data Entry panel, composed of six unique panes. The user can move between the panes by selecting the "Next" and "Back" buttons at the bottom of the panel (located above the "Submit Inputs" button). Alternatively, the user can jump between panes using the radio buttons at the top of the panel, which include the pane number and hover-over-titles to improve ease of use. It is recommended that the user explore all six panes, even if the user does not wish to enter parameters on each. (*Note:* For more information on the motivation behind the six panes, see Section 1.2 of this User

Guide.)

At the bottom of the data entry panel at large is the "Submit Inputs" button. This button is present regardless of which pane is currently selected, and no analytic outputs will be calculated before the user presses this button. When pressed, the Sea Level Tracker will take some time to process the data, but it should take no longer than 15 seconds depending on network speed. If the application is taking longer than 15 seconds to process the inputs and the "pending" icon no longer appears over the other panels, it is recommended that the user re-press the "Submit Inputs" button, as a logging issue may have occurred.

2.1.1 Pane #1: Tide Gauge, Datum, and Rate

The first pane allows the user to configure five critical elements of the Sea Level Tracker. Unless these elements are selected and entered by the user, the application will not run.

1. *State:* In this dropdown, the user must select the state of the desired gauge to visualize. The states are alphabetically organized and the subsequent gauge options in the dropdown are dependent on the state selected (i.e., changing the state subsequently changes the possible gauges the user can select).

2. *Gauge:* In this dropdown, the user must select the desired gauge to visualize in the Sea Level Tracker. As mentioned above, the user's options are dependent on the selected state, where the only gauges present in the dropdown are those present within the state selected above.

3. *Datum:* This dropdown only appears after the user selects a location (i.e., both a state and a gauge). Note that the tool's datum options are dependent on the gauge selected, as NOAA does not measure all possible datum values for all gauges available in the Sea Level Tracker. By default, the selected value is the NAVD88 datum, and if it is not available, the MSL datum. A few locations (e.g., Puerto Rico) have established local datums other than NAVD88. For more information and an explanation of each datum, the user is encouraged to click the hyperlink associated with the dropdown in the UI or follow this link.

4. *Sea Level Scenario Rate:* This dropdown only appears after the user selects a location (i.e., both a state and a gauge). Note that the rate options are dependent on the gauge selected, as the tool defers to NOAA on local sea level rates measured at the location in question. By default, the Sea Level Tracker uses the regional rates sourced from this report. All other rates are based on historical data. The user can also enter their own rate by selecting the "Enter custom rate" value in the dropdown, though it is recommended that the user use the predefined values.

5. *Units:* On the first pane, the user can toggle different unit measurements for the tool. Changes to this parameter will impact all analytic outputs in the Sea Level Tracker, as the user-selected value is passed to the NOAA API, adjusting all the foundational data in the application. For the Sea Level Tracker, the default value is "Feet."

2.1.2 Pane #2: Data Sources

The second pane allows the user to choose the data sources that will be displayed in the data visualizations and tables throughout the application. Any number of sources can be selected. Additionally, sources are separated into two dropdowns: one for universal sources and one for local sources.

Universal Sources: Universal sources are data sources that have data available for most or all of the available gauges. This includes the calculated projection mentioned in Section 1.3, as well as the point-in-time NOAA scenarios mentioned in Section 1.3.1.

NOAA Projection Parameters: When a point-in-time NOAA source is selected from the dropdown, two extra options will appear below the Universal Sources dropdown: Interpolate Values and Show Likely Range. Users can enable these features and click the "Submit Inputs" button to have the following appear

on the graph:
- ***Interpolate Values Checkbox:*** When selected, the scatterplot representing the point-in-time scenarios will have dashed lines connecting the data points.
- ***Show Likely Range Checkbox:*** When selected, the point-in-time data points will be surrounded with a colored area representing the "Likely Range" of the sea level values, as defined in Section 1.3.2.

Local Sources: Local sources are data sources that contain projections for a single region within the United States, as detailed in Section 1.3.3. Available local sources can be found in the Local Sources dropdown.

2.1.3 Pane #3: Moving Average Scenarios and Monthly Means

The third pane allows the user to select which measures of historical data he or she wishes to present as moving averages. By default, the 19-year midpoint MSL moving average is selected. On this pane, the user also has the option of adding a 5-year midpoint MSL moving average or the raw monthly averages.

1. ***5-Year MSL Moving Average***: This moving average can be toggled on or off using the checkbox selection at the top of the pane. Currently, the only 5-year moving average the user can add to the tool is based on mean sea level. As a default, this scenario is not calculated or presented as an output.
2. ***19-Year Moving Averages:*** The user can select 19-year moving averages for a particular tidal datum phase by manually typing them into the bar or by entering the cursor into the bar and selecting the desired value from the dropdown. Values can be removed by selecting them in the bar and pressing "Backspace" or "Delete." The user can choose to calculate the 19-year moving average for any combination of the following monthly values: *Highest, MHHW, MHW, MSL, MLW, MLLW, or Lowest.* These options are explained by clicking the "Term Definitions" button in the top right of the application. As a default, the 19-year MSL moving average is selected.
3. ***Monthly Averages:*** The user can select monthly averages by manually typing them into the bar or by entering the cursor into the bar and selecting the desired value from the dropdown. Values can be removed by selecting them in the bar and pressing "Backspace" or "Delete." The user can choose any combination of the following options: *Highest, MHHW, MHW, MSL, MLW, MLLW, or Lowest.* These options are explained by clicking the "Term Definitions" button in the top right of the application. As a default, none of these values are calculated.

2.1.4 Pane #4: Linear Trend Lines

The fourth pane allows the user to select trend lines to plot and visualize in the tool. The user can either fit a linear trend line to the entire period of record or within a defined 40-year period of record.

1. ***Entire Period of Record:*** The user can select linear trend lines by manually entering the desired values into the bar or by entering the cursor into the bar and selecting the desired value from the dropdown. Values can be removed by selecting them in the bar and pressing the "Backspace" key or "Delete" key. The user can choose any combination of the following options: *Highest, MHHW, MHW, MSL, MLW, MLLW, or Lowest.* These options are explained by clicking the "Term Definitions" button in the top right of the application. As a default, none of these values are calculated.
2. ***40-Year Period of Record:*** The user can select any date within the gauge's period of record as the end date for the 40-year window. The start date of this window is 40 years prior to the entered date, on the month. The user should enter this value in the YYYY-MM format. All 40-year linear trends use the MSL value. Future releases of the Sea Level Tracker will allow the user to create 40-year linear trends for alternate values. By default, no 40-year linear trend is calculated.

2.1.5 Pane #5: Extreme Water Levels

The fifth pane allows the user to add extreme water levels (EWLs) as calculated by NOAA or USACE to the analytic outputs. If the user chooses to add EWLs and checks the corresponding box on this pane, the user can configure various parameters of the EWLs.

1. *EWL Source:* By default, the NOAA method is selected for extreme water levels. Using the radio buttons, the user can select the USACE calculation method. For a deeper explanation of these two methods, please review Section 1.2.4 and read the supporting documents included in the reference section below.

2. *EWL Type:* Using the radio buttons, the user can select either low or high extreme water level. The high EWL adds the calculated value to the scenario, while the low EWL subtracts the calculated value from the scenario. By default, the high option is selected, adding the extreme water value to the selected scenario.

3. *EWL Exceedance Probability:* Using the dropdown, the user can select the desired exceedance probability for the extreme water levels measure. Changing this value adjusts the magnitude of the extreme water value, dependent on the methodology selected in the above radio button. For a deeper explanation of the interpretation of exceedance probability, please review Section 1.2.4 and read the supporting documents included in the reference section below. Be default, the "1% Exceedance Probability" is selected.

4. *Scenario Selection:* Using the dropdown, the user can select a source and scenario to add the EWL value to or subtract the EWL value from.

2.1.6 Pane #6: Critical Elevations for Comparison

The sixth pane allows the user to add critical elevations, or user-defined heights above a defined datum, for comparison with other calculated values. To add values, the user must define a name of the critical elevation in the text entry bars on the pane. Unless the user formally enters both a critical elevation and a name for the critical elevation, the value will not be added. All entered values will appear in the table below on this pane.

1. *To Add a New Elevation:* Enter the height and name for the critical elevation in the boxes, then press "Add elevation." Please ensure each entered elevation has its own unique name and height. Heights are defined with respect to the datum selected in Pane #1.

2. *To Remove a Previously Entered Elevation:* Enter the correct name into the box or select the row in the table you would like to delete, then press "Remove elevation." Selecting the value in the table will automatically populate the name and elevation box for the removal.

2.2 Map Panel

To the right of the data entry panel are four unique panel options. By default, when the user navigates to the application page, the Sea Level Tracker presents the map panel. This panel is used for visual interpretation of the selected location, while also simultaneously functioning as an alternative option to select a gauge for analysis.

If using the map to select a location, the user must first click the map to select a state. When successfully clicked, the data entry panel will be updated with the user selected state. Next, the user must click the desired gauge location on the map. Once a state is selected on the map, the user can select different gauges within that state on the map.

The mapping panel uses the Leaflet and ESRI libraries to visualize global locations. The mapping software is regularly updated and should be representative of current street, landscape, and water characteristics.
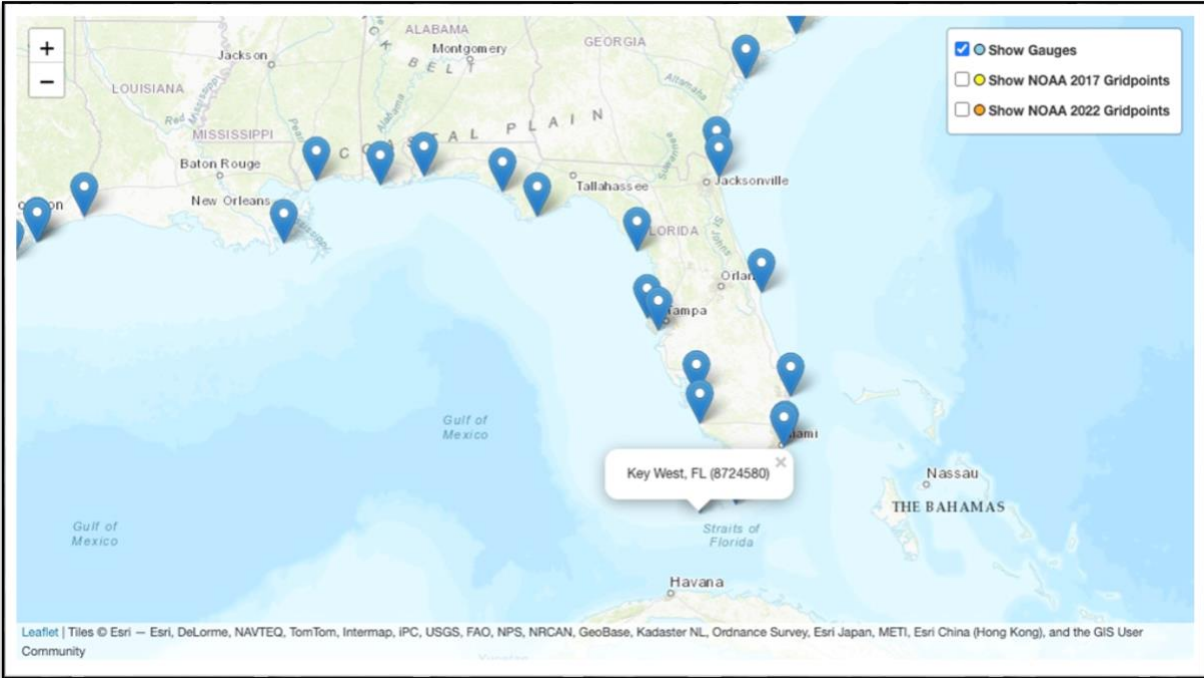
Figure 10: Mapping Panel with Gauges

NOAA Grid Points: The Sea Level Tracker 2.0 now lets the user see point-in-time sea level projections of different scenarios at latitude and longitude-based grid points around the world. The user can view the available grid points by navigating to the top-right corner of the map and enabling either the NOAA 2017 Grid Points or NOAA 2022 Grid Points options via the radio buttons. The 2017 and 2022 NOAA scenarios contains a different set of grid points and are displayed with separate colors. Clicking on a grid point on the map will select it as the source, in place of a gauge.

Figure 11: Mapping Panel with NOAA Grid Points

2.3   Visualization Panel

To the right of the data entry panel are three unique panel options. By default, when the user presses the "Submit Inputs" button, the Sea Level Tracker switches to the Visualization panel. When the user changes the location parameters on the data entry panel, previously generated visualizations are hidden from the UI (though they can be returned by adjusting the data entry panel's location values back to those used during the previous run of the tool). This is done to prevent any confusion between analytic outputs and configured parameters, which could be captured simultaneously by a screenshot.

While all the scenarios and values visualized are configured by within the data entry panel, the user can interact with the visualization in several ways.

1. ***Visualized Period of Record:*** In the top right, the user can select the period of record to visualize by entering both a start date and an end date. Alternatively, the user can click and drag to create a zoom box on the plot itself. This action will define new boundary ranges for the plot, which the Sea Level Tracker will zoom in to. If the user chooses to zoom in this way, he or she can also click the "Reset Zoom" button to return to the original plot frame. Finally, the user can also drag and adjust the window boundaries below the plot. By extending, shrinking, or adjusting these, the user will change the visualized period of record. (*Note:* Although the user can change the window visualized in the tool, none of the scenarios adapt to these changes.)

2. ***Legend:*** A legend appears underneath the x-axis of the graph. This legend will enumerate the scenarios that are plotted. Scenarios in the graph can be hidden by clicking on the corresponding item in the legend.

3. ***Graph Callouts:*** When the user hovers over a scenario in the graph, a callout will appear. This callout will show the SLC value of that curve at the corresponding date.

4. ***Capturing/Downloading the Visualization:*** The user has four options for downloading or saving the configured data visualization.

   a. ***Screen Capture:*** While the web browser with the Sea Level Tracker is the selected window on the user's computer, he or she can press the "Win" and "PrScr" buttons simultaneously to capture an image of the web browser, in its entirety. The image will appear in the default "Screenshots" folder in the "Pictures" directory on the user's computer.

   b. ***Screen Capture—Snipping Tool:*** The user can also use the snipping tool to capture the visualized results. It is recommended that the user include the tooltips in this screen capture for full context.

   c. ***Image Download:*** By clicking the "three bar" icon in the top-right corner of the plot, the user can choose to download the visualization as either a jpeg or a png. It will appear in the user's web browser and in the user's "Downloads" directory. The metadata for the visualization will be included with the download.

   d. ***Downloadable Report:*** Navigate to the Feasibility Study Report panel to download the visualization within the context of a report. See Section 1.3 for more details.
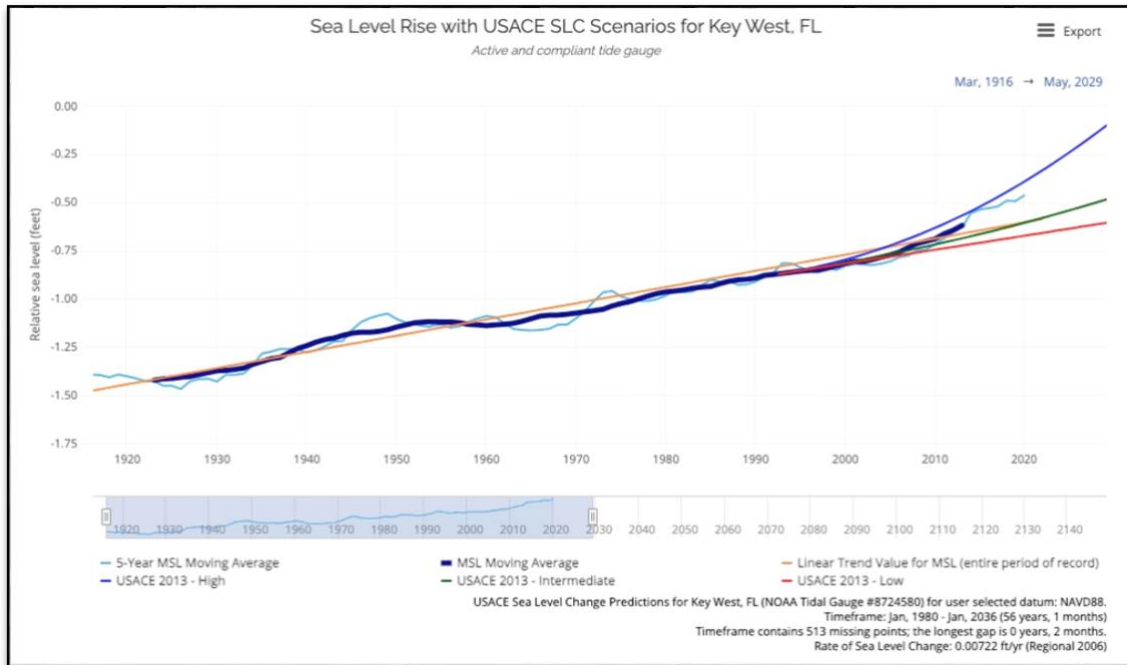
Figure 12: The Sea Level Tracker with 19-Year and 5-Year Moving Averages and a Linear Trend

2.4   Feasibility Study Report Panel

To the right of the data entry panel are four unique panel options. The third panel option is the Feasibility Study Report panel. The purpose of this panel is to let the user download an HTML report that cleanly summarizes the tool's outputs.

Custom Fields: The top of this panel consists of text inputs and dropdowns that allow the user to add customized text to the report. None of these custom inputs are required—an empty field will result in an empty space on the report.

"Generate Report" Button: Press this button to download the report. The report should be downloaded to your browser as an HTML file. Click on the file to open the report in a new window in your browser.

Report: The downloaded report consists mainly of three elements: text information about relevant parameters used such as gauge and relative sea level rise, maps and data visualizations, and a datum visualization.

The downloaded report contains elements from the Sea Level Tracker such as the map and data visualization graph. Note that these elements are interactive and can be zoomed and filtered just as they can in the Sea Level Tracker.

At the bottom of the report, a datum visualization graph can be found. This graph shows the difference in sea level measurements at the different datums offered by the Sea Level Tracker. This graph is accompanied by a table of the full names of each datum. This section reminds the user that the sea level values displayed in the Sea Level Tracker will depend on the datum selected.

To create a printable version of the report, the user can use their browser's provided print function, such as CTRL+P on Windows or CMD+P on MacOS. This should give the option to save as PDF or print.

2.5   Data Tables Panel

To the right of the data entry panel are four unique panel options. The fourth and final panel option is the Data Tables panel. When the user first navigates to the Data Tables panel, they will be presented with a dropdown of available data tables, and a "Generate Tables" button. The user can select any number of tables from the dropdown and then press the "Generate Tables" button to display. Each table should then be displayed in the panel. Note that some tables may be empty, depending on the settings the user chose in the Data Entry panel. For Continuous, Point-in-Time, and Local Scenarios tables, ensure that at least one source of that type has been selected in the Data Sources pane in the Data Entry panel. Each table includes some or all the following columns.

Table 3: Data Table Column Descriptions

Column	Description
Date	The date associated with the historical data or projection.
Decade	The decade associated with the data point.
Year	The year associated with the data point. If Year is empty, the data comes from a source whose resolution is larger than yearly and should not be interpreted as yearly data.
Month	The month associated with the data point. If Month is empty, the data comes from a source whose resolution is larger than monthly and should not be interpreted as monthly data.
Source	The source of the data.
Scenario	The scenario represented from the source data (e.g., low, intermediate, high).
Non-Exceedance Probability	If applicable, shows the probability of exceedance of the sea level value shown.
Averaging Period	If the associated SLC value represents a moving average, Averaging Period denotes the scope of the moving average (e.g., monthly, 5-year period, 19-year period).
Value Type	Denotes the measurement the sea level value is representing (e.g., MSL, MHW).
Sea Level	The sea level value. When using this value, consider the associated Scenario, Non-Exceedance Probability, Averaging Period, and Value Type.

For each of the selected tables, the user can adjust the presented table in several ways. Below each variable name is a filter box. Here, the user can configure a filter or a range for a selected variable, adjusting the data in the table to fit within the desired boundaries. This feature is of particular use for the date columns, allowing the user to quickly navigate to future or historical dates of interest. Alternatively, the user can use the page buttons at the bottom right of the table to move forward or backward in time. Finally, the user can adjust the number of rows that appear on the user interface, though higher numbers will adjust the depth of the user's web browser. The Sea Level Tracker's default value is 20 entries.

For all selected tables, the user can save the raw data in three different ways (presented to the user with three buttons to the top left of the table). The user can either copy the raw data to his or her computer's clipboard, or download the raw data as a ".csv" file or as a ".xslx" Microsoft Excel file. When the user copies or downloaded the data, the entire dataset is extracted, not just the elements visualized in the user interface.

Figure 13: *Data Table Generated in the Sea Level Tracker*

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