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ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Developing Next-Generation Cal-Adapt Features to Support Natural Gas Sector Resilience

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Cal-Adapt's design and functionality have been developed with insights from a variety of beta testers and our helpful technical advisory committee members, who provided valuable feedback throughout several iterations of project updates. These individuals represent scientists and climate experts, planners and technicians, and leaders in development of local climate policies, as well as interested participants from the general public. We gratefully thank current and past members of the technical advisory committee for their feedback and insights, which greatly improved the climate data visualizations on Cal-Adapt.

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

Developing Next-Generation Cal-Adapt Features to Support Natural Gas Sector Resilience is the final report for Contract Number PIR-17-012 conducted by Nancy E. Thomas of the Geospatial Innovation Facility at the University of California, Berkeley. The information from this project contributes to the Energy Research and Development Division's Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

Energy sector operations, management, and planning all require quality-controlled, high-resolution information on projected climate and weather-related risks to maintain safe, reliable, and affordable energy for California's current and future populations. California's energy infrastructure, including facilities and pipelines that store, transmit, and distribute gas, is vulnerable to weather events that may differ significantly from historical records as a result of changes in the climate. Understanding projected climate-related risks is critical to energy sector resilience and planning.

This project developed next-generation enhancements to the Cal-Adapt web application (https://cal-adapt.org), which integrates research results from California's Fourth Climate Change Assessment and expands the capabilities of the web application to provide actionable information on energy infrastructure and climate-related vulnerabilities and resilience to gas sector stakeholders. Improved climate data visualizations, enhanced features, and guidance materials developed through this research support investor-owned utilities, public agencies, nonprofits, and others to more fully understand the local risks of climate change in California to both plan for and adapt to future conditions.

Keywords: Cal-Adapt, adaptation, resilience, climate projection, extreme weather, GIS, interactive web application, data visualization

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Background

The Cal-Adapt web application was first released to the public in 2011 as a web-based resource that showcased innovative climate change research produced by California's scientific community, as recommended in the 2009 California Climate Adaptation Strategy. A second version of the web application was developed and launched as part of California's Fourth Climate Change Assessment, with funding from the California Energy Commission.

The Cal-Adapt web application is used by various organizations to support planning for climate adaptation and resilience. California's legislature has recognized Cal-Adapt as a key resource to support local hazard mitigation efforts, and the application has helped California move forward on climate policy by providing easy access and exploration of the high-resolution, regionally downscaled climate projections sanctioned by the state for use in its energy sector climate adaptation efforts.

Project Purpose and Approach

Cal-Adapt's web application allows the exploration of peer-reviewed data that shows how climate change could affect California, at both state and local levels. The data is available through downloads, visualizations, and Cal-Adapt's application programming interface for research, outreach, and adaptation planning.

This research focused on developing next-generation enhancements to the Cal-Adapt web application, which integrated research results from the Fourth Climate Change Assessment and expanded the capabilities of the application to provide actionable information on energy infrastructure and climate-related vulnerabilities and resilience to gas sector stakeholders. This project was a next step in the web application's evolution to present the latest scientific data and further support stakeholders in understanding climate-related impacts relevant to local decision making. The application's design and functionality were developed in collaboration with a broad spectrum of beta testers and advisory committee members, who provided valuable feedback throughout several iterations of project updates.

The Cal-Adapt development team implemented a user-oriented research approach and collaborated closely with the California Energy Commission, the state's large investor-owned utilities, the technical advisory committee, state agency partners, and other energy-sector stakeholders to ensure that data visualization tools delivered information that met stakeholders' current and planned climate data needs. The technical advisory committee included members who represented climate data users such as investor-owned utilities, the California Independent System Operator, the California Public Utilities Commission, the Department of Water Resources, the Governor's Office of Planning and Research, and Emergency Services. The team gathered stakeholder insights through an ongoing online survey, numerous workshops and webinars, and focused interviews. Regular discussions with key stakeholders provided critical feedback during tool development and beta testing. Iterative development of custom tools made it possible to present initial tools to stakeholders, gather feedback, and refine tool design.

Key Results

The new advances to the Cal-Adapt web application included expanding the data infrastructure to enable additional data preprocessing; developing new data features that improve the functionality of existing data tools; developing new data and visualization tools, which enable exploration of expected future climate changes; and developing a tool that provides near-real-time weather information to put extreme temperatures in the context of historical observations at select California meteorological stations.

This project:

- Improved usability and accessibility by making high-resolution and high-fidelity data available to gas sector stakeholders and other users.
- Explored expected future climate changes visualizations and tools, tailored to specific concerns of gas sector stakeholders that support the planning and protection of energy infrastructure.
- Developed tools and workflows that generate climate-related parameters needed by investor-owned gas utilities for resilience planning.

Knowledge Transfer and Next Steps

An important component of this research was ongoing engagement with key gas-sector stakeholders such as investor-owned utilities. Additional outreach and collaboration included knowledge transfer and training events that were free and open to the public and were designed to share project information and foster adoption of best practices for using climate data. The project team reached out to key stakeholders in Winter 2023 to better understand how tools and data were used by investor-owned utilities and other energy-sector users, and to help identify how lessons learned through this project could guide efforts already underway with California's Fifth Climate Change Assessment (Fifth Assessment).

Key lessons learned during this research can be used by the state to help guide future efforts as California proceeds with the Fifth Assessment. Key lessons learned follow.

- Research undertaken as part of this grant helped identify both data infrastructure and underlying cloud architecture needs required to host, process, and analyze the greatly increased data volume planned under the Fifth Assessment.
- Collaboration between climate scientists, web developers, state agencies, and potential users is critical in developing data visualizations and climate tools that are both statistically rigorous and meet stakeholder needs.
- Stakeholder outreach and user testing should be iterative, frequent, and ongoing to ensure that developers are building the "right" tools. Even powerful cutting edge

climate visualizations tools will not be useful unless they can be easily integrated into current and existing workflows.

- The need for guidance materials should be carefully considered. The time and effort required to develop this guidance should be accounted for in project planning. Stakeholders consistently pointed out the importance of high-quality and easy-to-use guidance materials.

Cal-Adapt is evolving from a single, stand-alone web application to a broader enterprise that includes Cal-Adapt's analytics engine, which is crucial for bridging the gap between growing data resources and energy-resilience applications. The expanded Cal-Adapt enterprise will provide essential visualization, analytical, and computational resources that support a broad range of energy-sector stakeholders using large climate datasets to guide their decision-making and planning processes.

CHAPTER 1: Introduction

Energy-sector operations, management, and planning all require quality-controlled, high-resolution information about projected climate and weather-related risks to maintain safe, reliable, and affordable energy for California's current and future populations. California's energy infrastructure, including facilities and pipelines that store, transmit, and distribute gas, is vulnerable to extreme weather events that can differ significantly from historical patterns. Understanding projected climate-related risks is critical to energy-sector resilience and planning.

The Cal-Adapt web application is a collaboration of state agency funding programs, university, national lab, and private-sector researchers. Free public access is offered to explore peer-reviewed data that show how climate change could affect California. Cal-Adapt's users include energy-sector stakeholders, infrastructure managers, municipal planners, community-based organizations, state agencies, scientists, climate experts, educators, and interested members of the public.

Cal-Adapt was released to the public in 2011 as a web-based resource to showcase the innovative climate change research being produced by the scientific community in California, which follows recommendations in the 2009 California Climate Adaptation Strategy (CNRA, 2009). The second version of Cal-Adapt was developed by the University of California, Berkeley's Geospatial Innovation Facility (GIF), with funding from the California Energy Commission (CEC). It was launched as part of California's Fourth Climate Change Assessment (Fourth Assessment). This version included updates and enhancements that increased its ease of use, information value, interactive visualizations, and data accessibility (Thomas et al., 2018). Cal-Adapt's web application design and functionality were developed in collaboration with a variety of beta testers and advisory committee members, who provided valuable feedback throughout several project updates.

Cal-Adapt has been recognized by California's state agencies and identified in legislative and regulatory policy as a key resource providing easy access and exploration of high-resolution, regionally downscaled climate projections, which have been sanctioned by the state for use in climate adaptation resiliency and planning. For example, Cal-Adapt was named in Senate Bill 379 (Jackson, Chapter 608, Statutes of 2015) as a state resource that supports local hazard-mitigation efforts. Cal-Adapt can also help energy utilities prepare for and adapt to climate change by providing critical climate data to investor-owned utilities (IOUs) for energy-sector planning, as recognized by the California Public Utilities Commission (CPUC, Decision 20-08-046). The 2019 Integrated Energy Policy Report (CEC, 2020) describes Cal-Adapt as an important tool for improved stakeholder engagement by providing better information for infrastructure planning and decision-making, which are critical for meeting California's 2030 greenhouse gas reduction mandate.

This project focused on developing next-generation enhancements to Cal-Adapt that integrated research results from California's Fourth Assessment and expanded the capabilities of Cal-Adapt to provide actionable information on energy infrastructure and climate-related vulnerabilities and resilience to gas sector stakeholders through:

- Expanding Cal-Adapt's data infrastructure to improve usability and accessibility by increasing the computational power and making advanced user-defined variables available to gas sector stakeholders and other users for data processing, visualization, and downloads.
- Developing expanded data visualizations and new custom tools so that users may explore new high-resolution Fourth Assessment data sets and examine projected climate risks to the gas sector and other assets or regions of interest.
- Outreach and collaboration with key stakeholders including the CEC, IOUs, other gas sector stakeholders, and the technical advisory committee to develop tools, training, and guidance materials that support gas operations, management, and critical planning needs.

New features developed through this research can deliver ratepayer benefits of greater energy reliability and increased safety by supporting gas-sector planning, management, and adaptation. Preserving reliable, safe, and cost-effective operations in the face of a changing climate require integration of projected climate and weather-related parameters into decision making.

CHAPTER 2: Project Approach

The Cal-Adapt web application provides a way to explore peer-reviewed data that shows how climate change could affect California at both state and local levels. Easy public access to this data is provided through downloads, visualizations, and the Cal-Adapt application programming interface (API) for research, outreach, and adaptation planning needs.

Since 2018, Cal-Adapt data hosting and website development have been supported under three separate grants: this award (PIR-17-012), CEC-funded award EPC-17-033 (Building on the Cal-Adapt Platform to Deliver Actionable Information in the Support of Electricity Sector Resilience), and an award funded by California's Strategic Growth Council (Increasing Data Accessibility and Climate Resilience Planning Support Through Cal-Adapt). While each of these awards has a specific focus and tool development targeted to a specific grant, coordination between the different awards enabled cost-efficiency and the leveraging of related products.

For this project, the Cal-Adapt development team used a user-oriented research approach and collaborated closely with the CEC, state IOUs, technical advisory committees (TACs), state agency partners, and other energy-sector stakeholders. Additional collaboration with the broader public also ensured that data visualization tools delivered actionable information and met stakeholders' current and planned climate data needs and workflows. Stakeholder insights were gathered through an ongoing online survey, numerous workshops and webinars, and focused interviews.

The University of California, Berkeley, collaborated with consultant ICF to hold listening sessions and workshops with gas IOUs early in the project, which helped guide subsequent development work. ICF is a consulting company that supports climate change resiliency efforts at several major utilities in California. As part of that effort, ICF worked extensively with downscaled climate data, including data from Cal-Adapt, and processed the outputs according to the custom needs of clients. The information and feedback received during these listening sessions guided website development tasks and priorities.

The University of California, Berkeley, also collaborated with climate scientists from Eagle Rock Analytics during the last phase of the project to reconnect with users. The collaboration was tasked with both determining how Cal-Adapt is currently used and gathering feedback on which additional tools, features, and datasets would be helpful in future iterations of the web application. Semi-structured interviews were conducted in early 2023 with six groups of stakeholders from IOUs, consultants, and state agencies.

During the course of the project, regular discussions with key stakeholders provided critical feedback during tool development and beta testing. Iterative development of custom tools made it possible to present initial tools to stakeholders, gather feedback, and refine tool design. This user-informed development approach is described in greater detail in the EPC-17-033 Final Report (Thomas et al., 2024).

CHAPTER 3: Results

Cal-Adapt helps support California's energy goals by providing actionable information on climate change consequences to California's infrastructure by enabling users to identify local climate-related impacts — such as increased extreme storm risks and extreme weather events. New advances in the Cal-Adapt web application as part of this research include:

- The expansion of the data infrastructure to enable additional data preprocessing.
- Development of enhanced data features and guidance materials that improve the functionality of existing data tools.
- Development of new data and visualization tools that enable exploration of expected future climate changes.
- Development of a tool that provides near-real-time weather information for extreme temperatures.

Expansion of the Data Infrastructure

The usability and functionality of the core Cal-Adapt web architecture were enhanced, including augmentation of the computational power available within Cal-Adapt through leveraging big-data technologies. In addition, many new features were added to the API, including statistics that characterize and explore the extreme events used as building blocks for the new data visualization tools developed in this project.

Enhanced Cal-Adapt Web Architecture and Functionality

As part of this research, the development team expanded the functionality of the Cal-Adapt web architecture and API to enable additional data preprocessing that further customized datasets prior to download, adding functionality for characterizing and visualizing extreme events. Much of the effort involved in this task happened behind the scenes, so users were not aware of major site changes. Back-end code enhancements that improved access to California's Fourth Climate Change Assessment (Fourth Assessment) climate data included:

- Addition of features within the Data Download tool to include preprocessing of data including:
    - User-defined (in addition to common pre-defined) boundary options.
    - Temporal aggregation: daily, monthly, annual, decadal, seasonal, water-year options available, depending upon variables.
    - Spatial aggregation: defaults to mean, but additional options for maximum, minimum, and total calculations.

- Expansion of the code base and additions of API query parameters to define and characterize extreme events, making it possible to:
    - Calculate exceedance probabilities.
    - Calculate estimated return levels for pre-defined return periods (2-, 5-, 10-, 20-, 50-, 100-year), with 95 percent confidence intervals.
    - Request return levels for any user-supplied return period, with 95-percent confidence intervals.
    - Find extremes for a particular day of the year, as well as for 30-year climatologies (studies of the climate and specific variables over a given reference period).
    - Query event duration to consider multiple days when defining an extreme event.
    - Query variable specific distributions following extreme value theory (Coles, 2001) including generalized extreme value (GEV) for temperature, generalized Pareto distribution for precipitation, and inverted Weibull distribution for wind speed.
        - Fit a GEV distribution over block maxima (annual maximum value).
        - Use a peaks-over-threshold approach where the probability distribution of exceedances over a pre-defined threshold is modeled using a generalized Pareto distribution.
- Providing access to the localized constructed analogs (LOCA) variable infiltration capacity model (VIC) variables through the API and data download tool. The Cal-Adapt team worked with California's IOUs and other stakeholders to determine which VIC variables were of most interest. Variable infiltration capacity is a hydrological model that provides projections for a suite of hydrological parameters (Pierce et al., 2018).
- Improved dynamic mapping capabilities for map animations (as seen within the snowpack and wildfire risk tools) and for spatial distributions of change and change anomalies that drive the maps of projected change tool.

The Cal-Adapt web application is cloud-based and runs on Amazon Web Services (AWS). The application was built on top of a Python-based Django web framework, along with supporting libraries including the Geospatial Data Abstraction Library (GDAL), NumPy, and SciPy.

Researched Methods to Scale Up to Leverage Big Data

The Cal-Adapt team explored the use of AWS Lambda distributed cloud computing resources and integrated Amazon S3 storage to speed up the dynamic spatial subsetting, temporal aggregations, and summarization of high-resolution climate datasets. Distributed computing partition tasks are among a collection of nodes that handle the workload in parallel. The research team also tested and compared efficiencies of different data formats for storage and hosting within Cal-Adapt. This included testing NetCDF as a multidimensional storage format within the API against the current high-performance Geotiff format.

The benchmarked comparison indicated that NetCDF was sub-optimal in delivering the high-speed interactivity featured on Cal-Adapt. In addition, a distributed processing workflow did not significantly improve cost-effective performance beyond the current architecture for the existing Fourth Assessment data catalog.

High-speed interactivity performance was near peak capacity, with the current data volume hosted through Cal-Adapt. While Cal-Adapt's web architecture works effectively with the regional downscaled data structure associated with the Coupled Model Intercomparison Project, Phase 5 (CMIP5), future downscaled datasets associated with the Coupled Model Intercomparison Project, Phase 6 (CMIP6), will have higher spatial and temporal resolution, which require much larger storage and computing options, including a shift to distributed cloud compute workflow.

Develop New Data Visualizations, Features, and Custom Tools

A main objective of this research was to build new custom tools and data visualizations to support the needs and requirements of gas sector stakeholders to support planning and protection of energy infrastructure. In addition, the team worked closely with the CEC and the science advisor from Eagle Rock Analytics to include more user-driven input and display additional metrics on summary statistics.

Develop New Data Visualization Features

The Cal-Adapt team developed these tools and data visualizations to meet initial user requirements while also ensuring that they are expandable so improvements can be made to better respond to feedback.

User-Specified Thresholds

A major enhancement built in new functionality to incorporate user-specified thresholds for calculating extreme heat days, warm nights, and cooling degree days/heating degree days in the tools. The extreme heat threshold is the maximum daily temperature used to identify an extreme heat day. Typically, extreme heat thresholds are identified based on a location's historical climate since both ecosystems and infrastructure are typically designed for historical climate conditions.

The original tool design used a default threshold definition identified by the CEC, then used that value in subsequent calculations. The default extreme heat threshold temperature is unique to every location and is calculated as the 98th percentile of historical daily maximum temperatures for a location and computed using data from April through October for 1961 to 1990. For locations where extreme heat occurs between April and October, this definition is equivalent to the 99th percentile of historical daily maximum temperature for a location over the entire year.

Through stakeholder engagement, users indicated they needed to enter their own thresholds since different utilities may use unique threshold values depending on what type of asset they are evaluating and in what location. Default thresholds remain and have been expanded to include other common thresholds (for example an extreme heat threshold of 100 degrees Fahrenheit), while additional customization that allows a user-entered value, improves the usability for technical users. The extreme heat threshold temperature is set for every location in the Local Climate Change Snapshot tool and cannot be changed. In the Extreme Heat Tool, users can now either work with the default threshold temperatures or input their own threshold temperatures.

Additional functionality implemented in the Extreme Heat Days and Warm Nights tool allows users to define the parameters of their own heat wave events. Heat waves are periods of sustained, extreme heat that can jeopardize infrastructure, ecosystems, and public health. The default value used in Cal-Adapt is defined as a period of four consecutive extreme heat days or warm nights when the daily maximum temperature is above the extreme heat threshold. Cal-Adapt's tool counts every four-day heat wave as a unique event. So, if extreme temperatures persist for eight consecutive days and nights, that is considered two heat-wave events. The development team added the ability for users to define the number of days that make up a heat-wave event.

Improved Display of Summary Metrics

One piece of common stakeholder feedback was that they require greater understanding of the uncertainty of climate models. This issue continues to be an area of ongoing research in related projects. As part of this research, the Cal-Adapt team worked closely with the science advisor to explore how to present a more complete representation of climate models within the charts across all of the data visualization tools.

The original Quick Stats in Cal-Adapt tools showed the averages of the selected general circulation models (GCMs). The Cal-Adapt team reviewed several optional methods of visualizing additional metrics including providing a table of commonly used statistical summary measures (such as mean, median, and standard deviation) to communicate distribution. A relatively simple option that includes the model range of selected GCMs alongside the average values within the Quick Stats block was identified as the most efficient and understandable approach for users without additional complex explanatory text. This layout and presentation of summary metrics were then implemented across all of the relevant climate tools on Cal-Adapt.

New Data Visualizations and Custom Tool Maps of Projected Change Tool

Many energy sector stakeholders identified the need for Cal-Adapt to include mapping tools that allow users to visualize climate indicators and easily download climate data from Cal-Adapt that can be incorporated within an organization's geographic information system (GIS). In order to better meet these needs, the Cal-Adapt team designed, developed, and launched the Maps of Projected Change tool, which allows users to compare long-term historic climate data with projected future climate estimates in a quick and interactive geographic map display (Figure 1).

Climate data visualized in the tool represent projected changes in long-term, 30-year ensemble averages from 10 LOCA downscaled climate models for three climate variables: annual averages of maximum temperature, minimum temperature, and precipitation rates in California (Pierce et al., 2018). Data is shown for a historical baseline (1961 to 1990) and two future periods: mid-century (2035 to 2064), centered on the year 2050, and end-of-century (2070 to 2099). Data is available for two different representative concentration pathways (RCP): RCP 4.5 (medium emissions scenario) and RCP 8.5 (high emissions scenario).

Users can explore projected absolute values or explore projected changes in value from the historical baseline and select from a list of overlays for different scenarios and time periods. The tool allows users to view data in a single map or create a layered map to compare different scenarios or time periods. The layered view shows two maps layered over each other, with a vertical bar that can be swiped back and forth to reveal different parts of the map. Interactive features include a pop-up box, with data values displayed for an individual grid cell. If a boundary layer is selected, the data value is spatially aggregated over a polygon area. The tool also includes functionality to switch units between the metric and imperial systems.

Users are able to download the maps as images (PNG) or as raster data (GeoTIFF), which can be imported into a GIS program or other analytic environment.

Figure 1: Maps of Projected Change

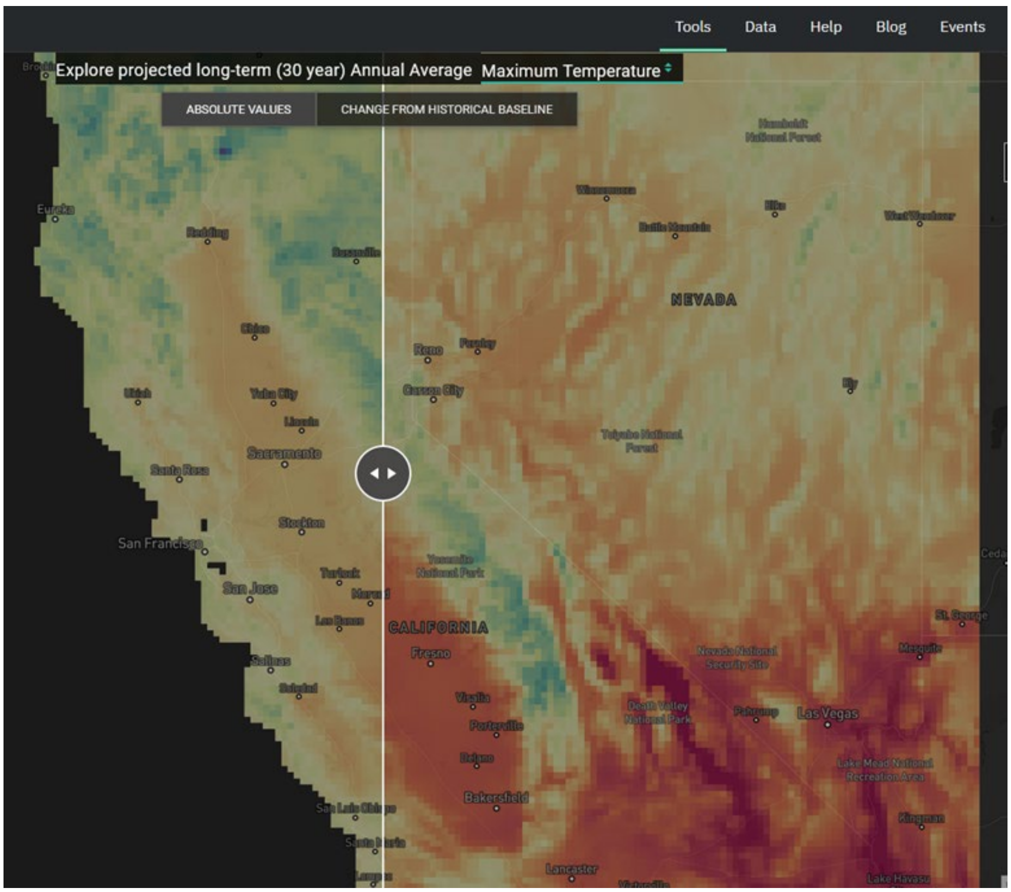


Figure 1 is a screenshot showing projected changes in long-term, 30-year ensemble averages from 10 LOCA downscaled climate models for the annual averages of maximum temperature. Data is shown for Historical Baseline (1961 to 1990) on the left side of the map and End of Century (2070 to 2099) on the right side of the map for comparison. In this example the Representative Concentration Pathways RCP 8.5 (high emissions scenario) is visualized.

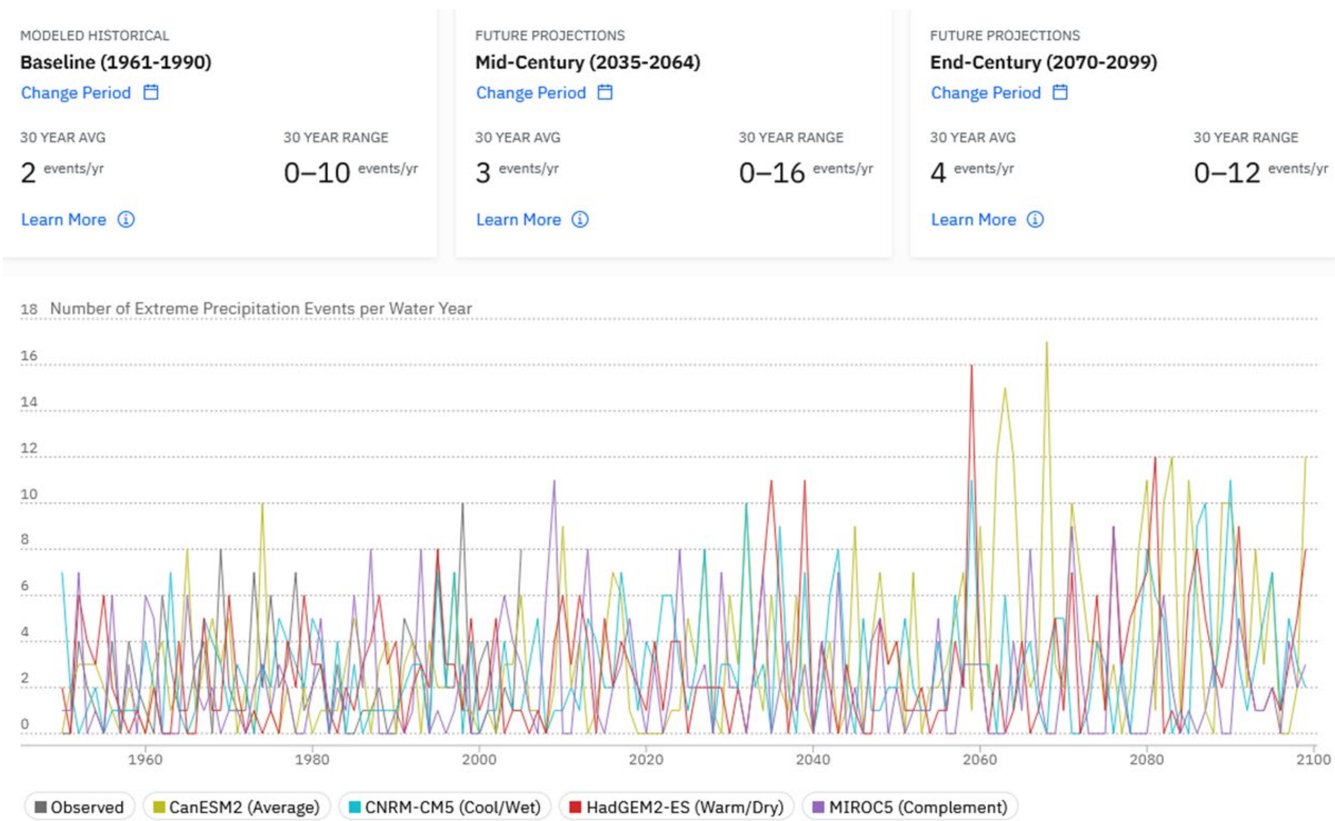
Source: Cal-Adapt, 2023

Extreme Precipitation Events Tool

Infrastructure and energy systems designed for historical extremes may not be prepared for the extreme events associated with a changing climate. Extreme events are impactful and cause a majority of damage and loss and expected changes in the frequency of extreme events have planning implications. Energy sector stakeholders therefore require information on extreme events to effectively improve planning and design for future climate conditions.

Under the direction of Cal-Adapt's science advisor, the Cal-Adapt team developed the Extreme Precipitation Events tool to explore and better understand the intensity and frequency of extreme precipitation events, which are significantly different from typical weather at specific locations and times of year (Figure 2). Extreme precipitation events can lead to flooding, mudslides, and other damaging events. In a changing climate, the intensity and frequency of such events will also change across California. This tool allows users to visualize how climate models can predict how extreme precipitation events will change over this century.

Figure 2: Projected Changes in the Number of Extreme Precipitation Events Under RCP 8.5, for Santa Barbara County



Source: Cal-Adapt. Data: LOCA Downscaled CMIP5 Climate Projections (Scripps Institution of Oceanography), Gridded Observed Meteorological Data (University of Colorado Boulder), LOCA Derived Products (Geospatial Innovation Facility).

Figure 2 shows results from the Extreme Precipitation Events tool for Santa Barbara County under a high emissions (RCP 8.5) scenario. The visualizations allow users to examine how extreme precipitation events are likely to change in a warming climate over locations of interest. For this location the visualization reports an extreme precipitation 2-day rainfall total of 1.26 inches. Historically, Santa Barbara would experience two events per year of that magnitude but by the end of the century could experience extreme high precipitation events on average four times a year.

Source: Cal-Adapt, 2023

Statistical Methods

The Extreme Precipitation tool allows users to understand and explore how often extreme events are likely to occur in the future, and how intense these events could be. This tool relies on a different set of statistics from those found elsewhere on Cal-Adapt; in this tool the extreme value theorem (EVT) is used to produce information about the "tails" of the distribution, or the most impactful precipitation events.

EVT is a statistical method used for describing rare events (Coles, 2001; Wilks, 2011). There are several ways to apply EVT to precipitation data including fitting a GEV distribution over block maxima (annual maximum value) and the peaks-over-threshold approach where the probability distribution of exceedances over a pre-defined threshold is modeled using a generalized Pareto distribution. This tool explores extreme events in California using a peaks-over-threshold approach.

Data values that exceeded a high predefined threshold, by default the lowest value from annual maximum values in the historical period (1961 to 1990), were extracted from a 30-year daily time series. If there are back-to-back events, only the largest event is included. A generalized Pareto distribution was applied to this partial duration time series. Shape and scale parameters for the distribution were estimated using the maximum likelihood method. Return levels for selected return periods were estimated from the fitted model. Confidence intervals at the 95 percent level for each return level were estimated using the profile likelihood method, where sufficient ($n > 100$) events existed.

Terminology

- **Threshold Value:** The extreme threshold sets the conditions for which a precipitation event is considered "extreme". By default, the threshold is set to the lowest annual maximum precipitation accumulation in the historical record (1961 to 1990). Other alternative threshold values (90th, 95th and 99th percentiles) are based on commonly used quantiles over the historical record. Selecting too high a threshold (in arid locations) or too low a threshold can decrease the reliability of the estimates.
- **Event Duration:** Event duration is the number of days over which precipitation contributes to a single event. Changing this value will change the extreme threshold.
- **Return Period:** The return period estimates the average time between extreme events. This is sometimes worded as a "1 in X years" event.
- **Return Level (Intensity):** The return level is the estimated amount of precipitation expected to be exceeded once every return period. It is effectively the inverse of the return period. Instead of wondering how often an extreme precipitation event will occur, users instead consider a once-in-a-given time period: What would an extreme precipitation event look like? The return level is similar to the accumulated precipitation threshold but is estimated from the underlying statistical distribution of modeled precipitation data in future climate scenarios. By contrast, accumulated precipitation thresholds are calculated from historical observed values.

Tool Design

By default, Cal-Adapt calculates extreme values of precipitation over a 2-day period and defines an extreme event as the lowest value from annual maximum values in the historical period (1961 to 1990). Users can override these defaults by selecting a new "event duration" (number of days over which precipitation accumulates), or by selecting a different "threshold" value that corresponds to either the 90th, 95th or 99th percentiles. The tool displays the extreme events that exceed the threshold, in different ways.

Users can select from four available indicators which explore different characteristics of extreme precipitation events. The intensity chart shows the estimated intensity of precipitation events (Return Level) for a selected period (Return Period) and how it changes over the historical (1961 to 1990), mid-century (2035 to 2064), and end-century (2071 to 2099) periods. The other charts display the frequency of these events, their timing, and the longest stretch of consecutive extreme events.

The Extreme Precipitation tool was designed to address the following questions:

1. What will extreme events look like in the future?
2. How many extreme events will occur each water year?
3. When in the year will extreme events occur?
4. How long will extreme events last?

What Are Extreme Events Going to Look Like in the Future? By clicking on the "Intensity" indicator, users can explore how much precipitation will be considered extreme during three periods: historical (1961 to 1990), mid-century (2035 to 2064), and late-century (2070 to 2099). Colored dots show the median extreme event in four climate models, surrounded by grey bars that cover the 95-percent confidence interval. If the values (in inches, shown on the left) increase, this shows the need for planning of more extreme precipitation events; a decrease in value suggests future climates will have less intense extreme events.

Users select the return period they are interested in from the dropdown menu above the graphic. Return periods correspond to the value shown on the tool by stating, "an event of this magnitude will occur once every X years, where X is the return period selected." The tool allows users to select 2-, 5-, 10-, 20-, 50-, or 100-year intervals, which show how impactful precipitation events correspond, from fairly common to extremely rare.

How Many Extreme Events Will Occur Each Water Year? In a warming climate, California is expected to oscillate between dry and wet periods, so understanding how frequently high-intensity events occur (and also how much these may change between years or decades) is instructive. The "Frequency" indicator returns the number of extreme precipitation events per water year. If users are interested in making an assessment for a fixed point in the future, such as, for example, 2050, it is recommended that users look at the 15 years before and after 2050 to best capture the variability of the climate at that point in time.

When in the Year Will Extreme Events Occur? Shifts in the seasonality of precipitation have big impacts on water storage, wildfires, and agriculture. Clicking on the "Timing" indicator brings up a graphic representation of when impactful precipitation events may occur. Shorter wet seasons are expected across much of the state, indicated in this tab by larger, wider white regions during the year.

How Long Will Extreme Events Last? Long-lasting heavy precipitation events have different impacts when compared with shorter, more intense events. Heavy precipitation events in sequence are associated with catastrophic impacts in flood-prone regions across California. The "Maximum Duration" indicator shows the longest length of consecutive days above a threshold.

Why Is Data Sometimes Missing? Confidence intervals are not calculated when the number of extreme events are too few to accurately gauge uncertainty. Confidence intervals are omitted when there are fewer than 100 extreme events during the period. This ensures that the underlying statistical distributions used to model uncertainty and return intervals are robust.

User Advisory

The Extreme Precipitation tool broadly informs potential changes in extreme precipitation intensity and frequency across a wide range of environments and climate zones. On a local scale, different statistical assumptions (using annual maximal values rather than partial duration time series, fitting techniques for distribution parameters, and choices of extreme value distributions) may be more appropriate. Users are encouraged to ensure that the empirical fit of the applied distribution is acceptable to their end uses before using estimates produced from this tool.

Aggregating results by county is an option, though users should, if possible, avoid this approach since many large counties have different climate zones; aggregating across multiple climate zones distorts any climate signal in the process.

Extreme Weather Tool

A new tool was developed that allows users to explore extreme weather — temperature and wind speed — for past and current conditions, using a quality-controlled dataset for historical hourly weather observations, curated by the state's energy sector for 38 weather stations across California (Figure 3). Unlike other Cal-Adapt tools, the Extreme Weather tool presents near-real time weather information rather than projected climate data. This project funded the development of extreme minimum and maximum temperatures within the tool, while the addition of the wind-speed variable was funded under a related CEC-funded project (EPC-17-033).

Figure 3: Extreme Weather Tool: Weather Station at San Francisco International Airport

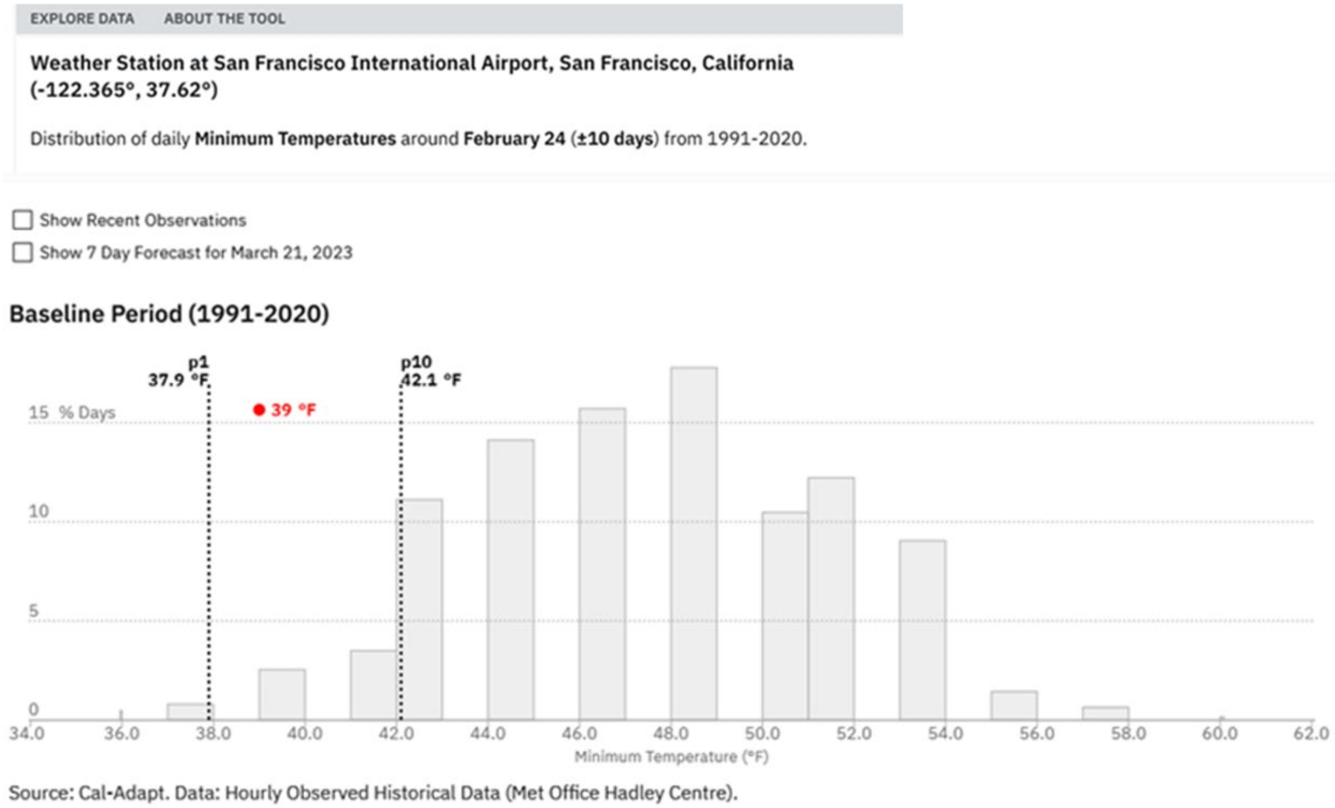


Figure 3 shows the distribution of daily minimum temperatures around February 24, 2023, at the San Francisco International Airport's weather station. On February 24, 2023, San Francisco had a low of 39 degrees Fahrenheit (3.9 degrees Celsius), the lowest temperature recorded in six years. This value was entered into the Threshold tab to better understand how extreme these low temperatures were, related to the historical record.

Source: Cal-Adapt, 2023

The Extreme Weather tool was collaboratively developed with the CEC and the Cal-Adapt science advisor. The historical hourly weather observations were curated, and the dataset was included for download on Cal-Adapt, along with an explanatory guide to help potential users of the hourly dataset (Doherty and Evan, 2020).

Input Data Sources

The hourly observed historical data consist of 39 weather stations across the state, each with an observation period (from 1973 to 2022) from the Hadley Centre Integrated Surface Database (HadISD) global record. Stations identified in this database were chosen based on their high-quality temperature data. Due to the observing techniques, the instrumentation used, and similarities in quality assurance/quality control protocols, it's likely that data for dew point and mean sea level pressure will be of similar quality, though this has not been fully assessed. Only 38 of the original 39 stations are presented within the Extreme Weather tool since the Monterey station was archived by HadISD on December 31, 2020.

The near-term weather forecast included in the tool is from the National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service. The National Weather Service is an agency of the federal government that provides weather, water, climate forecasts, and warnings for the United States, its territories, adjacent waters, and ocean areas. The Near-Term forecast provided by the National Weather Service focuses on large-scale temperature and precipitation patterns for the following seven days.

Recent weather observations presented within the Extreme Weather tool are from NOAA's National Center for Environmental Information, which is the federal agency that manages one of the world's largest archives of atmospheric data. The Global Historical Climatology Network-Daily dataset integrates daily land-surface observations from around the world. The station dataset includes observed maximum and minimum temperatures, total precipitation, snowfall, and depth of snow on the ground.

Statistical Method

Extreme value theory (EVT) is a statistical method used to describe rare events (Coles, 2001). There are several ways to apply EVT to weather variables, including fitting a GEV distribution over block maxima (annual maximum value), and the peaks-over-threshold approach where the probability distribution of exceedances over a pre-defined threshold is modeled, using a generalized Pareto distribution. This tool explores extreme events in California, using the block maxima approach.

Annual maximum values of the climate variable from a 21-day window around a specific day of interest were extracted from a 30-year daily time series for the baseline period (1991 to 2020). A GEV distribution for temperature and an inverted Weibull distribution for wind speed were applied to this time series. Distribution shape and scale parameters were estimated using the maximum likelihood method. Exceedance probabilities for different threshold values (return levels) were estimated from the fitted model, with 95-percent confidence intervals.

It is important to note that the Extreme Weather tool was designed to inform estimated probabilities of extreme weather events across a broad range of environments and climate zones. On a local scale, different statistical assumptions (for example, fitting techniques for distribution parameters, choice of extreme value distribution) may be more appropriate.

Users should make sure that the empirical fit of the applied distribution is acceptable to their respective end uses before using estimates from this tool for their planning purposes.

Knowledge Transfer and Next Steps

Cal-Adapt is already used to help organizations plan for climate adaptation and resilience. The related final report from EPC-17-033 (Thomas et al., 2024) includes many examples of how Cal-Adapt has been and is being used by the energy sector and others to help plan for both climate adaptation and resilience.

Web Application Technology Transfer

The Cal-Adapt web application is built on top of the Python-based Django web framework, along with supporting libraries such as GDAL, NumPy, and SciPy. Additional capabilities for spatial querying and manipulating geo-formats are provided by the Django-Spillway package, an open-source library developed at GIF. The combined web framework provides fast and dynamic temporal aggregation of time-series data and spatial aggregation by different vector boundaries.

The Cal-Adapt web application will be transferred to a new host organization, Eagle Rock Analytics. The detailed technology transfer plan used to transition Cal-Adapt to the new host appears in Appendix A. In addition to the technology transfer of the database, web server, services, and data that make up the Cal-Adapt web application, the source code base developed at the GIF that supports the front-end tools and visualizations is also available to be packaged and transferred.

As part of the technology transfer for this project, additional documentation was created for each individual data visualization tool on Cal-Adapt, which records feature requirements, revision histories, links to datasets used in the tool, query parameters and endpoints, and any planned revisions or suggested updates. These documents were invaluable for quickly bringing new developers up to speed on existing tools and features with Cal-Adapt and retain institutional knowledge regardless of which agency or organization may host and serve the web application in the future.

Outreach and Collaboration

Outreach and collaboration activities with key gas sector stakeholders included IOUs, climate practitioners, planners, managers, educators, and ratepayers. These activities included knowledge transfer and training events designed to share project information and promote the adoption of best practices for using climate data.

Stakeholder engagement activities and subsequent feedback through an online survey, workshops, webinars, in-person meetings, and interviews with energy sector and other users, were performed throughout the project. The topics of the workshops and webinars included introductions to the new tools and newly available climate data, how to access the climate data, and, in general, how to work effectively with Cal-Adapt. Because these stakeholder engagement activities covered topics relevant to concurrent agreements, many of the details have already been described in detail in Chapter 2 and Chapter 4 of the EPC-17-033 Final Report (Thomas et al., 2024), including:

- A stakeholder engagement plan.
- Stakeholder engagement activities.
- Tool design, development, and testing processes.
- Website application architecture.
- A collaborative approach.

Input on Overall Web Application Usability

Insights and feedback from the engagement activities follow.

- Cal-Adapt tools and data were helpful for guiding climate vulnerability assessments.
- The data customization possible with Cal-Adapt tools was appreciated.
- Visualization of data and tools on Cal-Adapt was helpful and was a good one-stop shop.
- IOUs often use Cal-Adapt tools for internal education and discussions.
- Having data available in multiple formats (including spreadsheet output) was valuable.
- Climate data on Cal-Adapt was used to lay out, in parts, internally created data (for example, wildfire projections).
- Consultants are often hired to conduct the heavy data processing, and consultants may use the Cal-Adapt API to download climate data and perform additional internal processing.

Key Recommendations for Improvement within Project Scope

Those recommendations addressed:

- A Climate Anomalies Map tool so IOUs can download raster data and upload to their respective systems for improved integration with GIS (Maps of Projected Change tool, improved functionality in the Data Download tool).
- Hourly observed station data (HadISD curated dataset and Extreme Weather tool).
- Historical available observed data being extended closer to the present (GridMET observed meteorological data available through Cal-Adapt).
- Access to hydrological data: interest in rainfall rates, runoff, and soil moisture (VIC variables processed and made available in Cal-Adapt).
- Ability to download data for user-specified regions of interest (user uploaded shapefiles in the Data Download tool feature).

Features and Functionalities of Cal-Adapt That Were Most Valuable to Users

- Climate tools:
    - **Local Climate Change Snapshot:** Tool was supported enthusiastically and identified as useful for quickly looking up climate risks, generating figures in presentations, and as an educational tool both internally and externally for their organizations.
    - The shapefile upload feature was used at state agencies.
        - Interest in census tracts and county boundaries to aggregate statistics to these spatial levels.

    - Climate data were used in air-quality modeling and assessments that require temperature information.
    - Tools that provide access to temperature data and information were useful to users working on environmental justice issues.
    - Tools were used to understand the current locations of the biggest impacted places with respect to heat, drought, and other conditions, to prioritize the flow of funds.
- Data Download/API:
    - Several IOUs have existing workflows that rely on the API, in some cases downloading the complete dataset.
    - Some organizations download climate data through the API to use in land-use models.
    - The API was used to download (using Python, R) data on minimum and maximum temperature (Tmin, Tmax), precipitation, vapor pressure deficit, incoming solar radiation, and day length.
- Guidance:
    - Technical users tended to prefer white paper/methodology write-ups.
    - Semi-technical/non-technical users tended to request more video tutorial content.
    - Some agencies rely on Cal-Adapt to make choices about the GCMs based on the given model descriptions.
    - A state agency indicated that the most useful guidance on Cal-Adapt was in working through the cookbooks and talking with the development team.

Suggestions for Improvements to Web Applications

- Climate tools:
    - Provide more information on cross-variable climate risks (extreme heat, precipitation, wildfire).
    - Include more on compounding climate events (such as the combination of wildfire and flooding caused by precipitation).
    - Provide more data on the interaction between sea level rise and precipitation flooding risk (interest expressed by a state agency).
        - How can models be used in conjunction with each other?
    - Expand community vulnerability and equity data on Cal-Adapt (interest expressed by IOUs).
        - Include healthy places index in addition to the CalEnviroScreen on the Cal-Adapt website.
        - More on community vulnerability information to help meet the California Public Utility Commission's Order Instituting Rulemaking requirements.

    - Provide the option to aggregate data at the county level, available across all climate tools.
    - Incorporate more integrated risk metrics, such as those used by Redfin.
    - Include additional variables of interest, such as:
        - Effective temperature
        - Wind gusts in addition to wind speed
        - Horizontal subsidence
        - Landslides/mudslides
        - Rise in the water table, associated with sea level rise
        - Debris flows and scouring
        - Scour depth on streams
        - Hourly temperature data
        - Maximum ice loading
- Data Download/API:
    - Continue to have programmatic access to downloading data (including cookbook examples), including any new versions of the website.
    - Improve API usability to make it easier to perform spatial aggregation of data, before download.
    - Provide VIC model details, specifically vapor pressure deficit calculations.
    - Improve training and outreach about features that are already available in Cal-Adapt (for example some users are unaware of the ability to upload their own shapefiles).
- Guidance:
    - Develop a more robust frequently asked questions (FAQ) wiki/user support forum for additional help.
    - Provide explicit guidance from Cal-Adapt on how to approach using multiple models to summarize outputs across different models (requested by a couple of state agencies).
    - Provide guidance on how the CMIP6 shared socio-economic pathways compare to RCP 8.5.
    - Deliver guidance on appropriate data use for users using the API.
        - Some analyses based on previous CMIP5 data shouldn't necessarily be directly ported to CMIP6 (in particular evenly weighted averages of all models).
    - Provide descriptions of each GCM such as hot and dry, cool and wet, to help agencies interpret their results and assess which GCMs they should use.
    - Provide direction on when California's Fifth Climate Change Assessment (Fifth Assessment) data is sanctioned by the state and ready to use for planning (requested by IOUs).

- Organizations and agencies showed an interest in hosting their own data on Cal-Adapt (for example, third-party wind modeling and high-resolution satellite imagery).

Key Lessons Learned

Key lessons learned during this research can be used by the state to help guide future efforts, especially as the state transitions from the Fourth Assessment to the Fifth Assessment.

- Research undertaken as part of this research project identified the data infrastructure and underlying cloud architecture needs required to host, process, and analyze the greatly increased data volume under the Fifth Assessment. Technology generated under the research has become an important building block in the bridge to the next-generation architecture developed for the Fifth Assessment.
- Collaboration between climate scientists, web developers, state agencies, and potential users is critical to developing data visualizations and climate tools that are both statistically rigorous and meet the needs of stakeholders. This collaboration was essential to the development of the Extreme Precipitation Events tool and the Extreme Weather tool, which require scientifically rigorous statistical analyses of climate projections and historical observations.
- Stakeholder outreach and user testing must be iterative, frequent, and ongoing to make sure that developers are building the "right" tools. Even powerful cutting edge climate visualization tools will not be useful unless they can be easily integrated within current and existing workflows. For example, user engagement highlighted the value to users of building an updated Cal-Adapt API that is capable of accessing and analyzing the new CMIP6 Fifth Assessment climate data catalog so that users can easily digest the newest climate data without rewriting all of their own underlying code. One suggestion was to monitor the use of visualizations and data tools on the website (such as by Google Analytics or similar tools), along with stakeholder outreach activities that discuss tool use.
- The need for guidance materials should be carefully considered and the time and effort required to develop this guidance should be sufficiently accounted for in project planning. Stakeholders continually pointed to the importance of high-quality and easy to use guidance materials. Much of the direct knowledge transfer is through guidance documents and content developed by the Cal-Adapt team for the website. The developers went through many iterations and reviews with stakeholders to present complex climate information in clear and descriptive text within all of the data visualizations and tools, which can also be found in the FAQs and in the Glossary. The Cal-Adapt team also developed additional guidance through blog posts, tutorials, and webinars to help walk users through the concepts and tools.

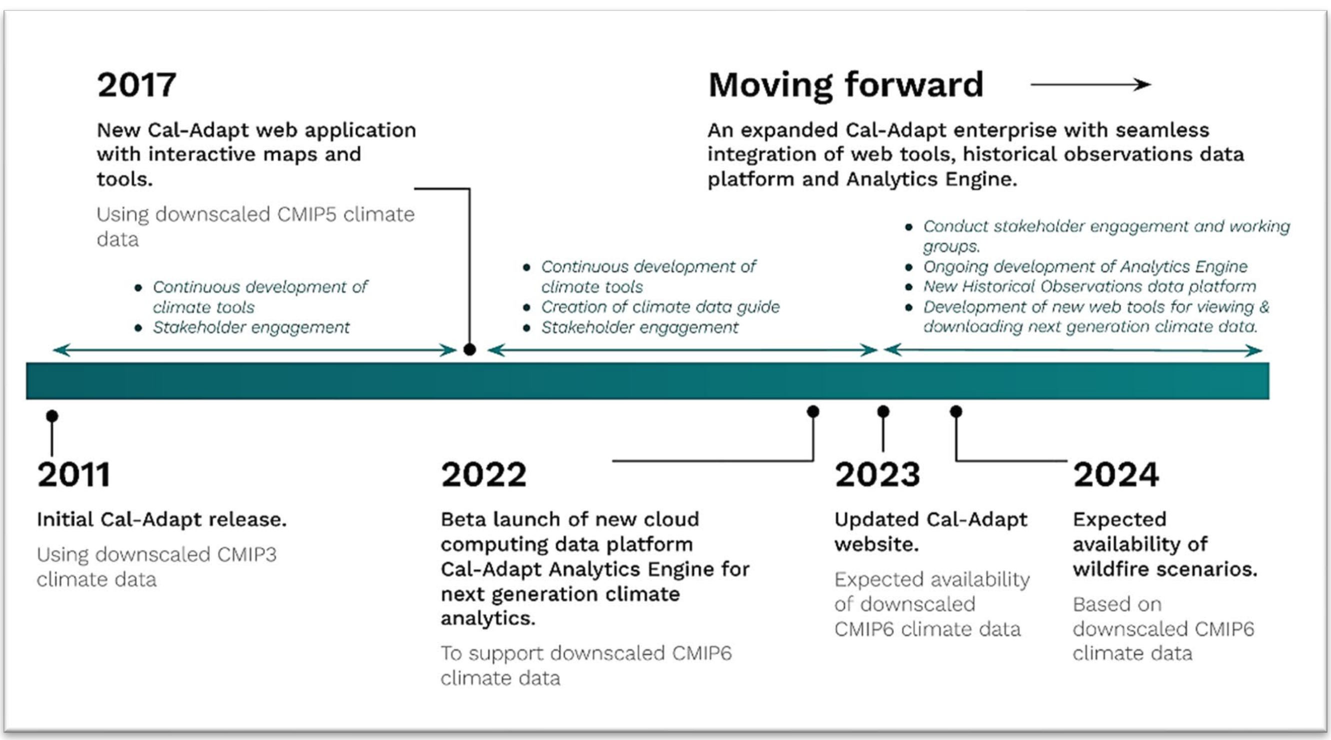
Next Steps: The Evolving Cal-Adapt Enterprise

Cal-Adapt is evolving from a single, stand-alone web application to a broader Cal-Adapt enterprise, which includes Cal-Adapt's analytics engine. The broader Cal-Adapt enterprise expands beyond the capabilities developed for California's Fourth Assessment to support the much larger dataset associated with California's Fifth Assessment. New, higher temporal and spatial resolution data aligned with the latest generation of climate models from CMIP6 used by the Intergovernmental Panel on Climate Change's global sixth assessment report have been generated for use in the Fifth Assessment. The analytics engine offers a more comprehensive and powerful solution for highly technical and data-intensive needs, with a focus on the energy sector (CEC, 2021b). The expanded Cal-Adapt enterprise will continue to provide essential visualization, analytical, and computational resources that support a broad range of stakeholders that use large climate datasets to guide their decision-making and planning processes.

In support of that evolution, as part of this project, a new landing page was built to introduce and explain these changes to Cal-Adapt users. Both newly developed and used content include:

- An updated "About" page content and project roadmap (Figure 4).
- A blog post describing and providing references regarding the expanded Cal-Adapt enterprise.
- A blog post describing access to next-generation Fifth Assessment climate data.
- A page entitled Data Development Grants and Research Projects.

Figure 4: The Cal-Adapt Roadmap



Source: Cal-Adapt, 2023

CHAPTER 4: Conclusion

The climate data visualizations, enhanced features, and guidance materials developed through this research will help energy utilities, public agencies, nonprofits, and others more fully understand and identify local climate-related impacts such as increased storm risks and extreme weather events. The current Cal-Adapt web application (Cal-Adapt 2.0) provides easy access to climate data — with an emphasis on showcasing data products funded by the state of California — through data visualization and download tools that make complex climate data more actionable for users. Cal-Adapt 2.0 was designed for fast, responsive interaction through a web browser that allows users to explore and access climate data, most of which was generated as part of California's Fourth Assessment. With some exceptions, these Fourth Assessment datasets were derived from LOCA downscaled CMIP5 data, with a roughly 6 kilometer by 6 kilometer spatial resolution and daily temporal resolution.

The project team hopes that key lessons learned during this research will guide future related efforts, especially as the state transitions from the Fourth Assessment to the Fifth Assessment.

- Research undertaken as part of this grant helped identify the data infrastructure and underlying cloud architecture needs required to host, process, and analyze the greatly increased data volume planned under the Fifth Assessment.
- Collaboration between climate scientists, web developers, state agencies, and potential users is critical for developing data visualizations and climate tools that are both statistically rigorous and meet stakeholder needs.
- Stakeholder outreach and user testing should be iterative, frequent, and ongoing to make sure that developers are building the "right" tools. Even powerful cutting edge climate visualizations tools will not be useful unless they can be easily integrated within current and existing workflows.
- The need for guidance materials should be carefully considered, and the time and effort required to develop this guidance should be adequately accounted for in project planning. Stakeholders continually pointed to the importance of high-quality, easy-to-use guidance materials.

Gas sector stakeholders frequently emphasized that the value they place on the climate projections available through Cal-Adapt are peer-reviewed and state sanctioned for use by utilities. Data transparency is critical, particularly when sharing information with local communities. As stakeholders noted during recent interviews, some agencies rely on Cal-Adapt to make choices about model selections and look to the website for guidance on using climate models.

As California moves to the Fifth Assessment, it will be critical to provide guidance materials to help make this next-generation, highly complex, higher temporal and spatial resolution information both useful and actionable to a broad set of users. Decision makers, policy makers and members of the public all benefit from the distillation of complex scientific information into easy-to-use information that enhances understanding and enables smart investments and planning.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AMI	Amazon Machine Image
API	application programming interface
AWS	Amazon Web Services
CEC	California Energy Commission
climatology	study of the climate and specific variables over a given reference period
CMIP5	Coupled Model Intercomparison Project, Phase 5
CMIP6	Coupled Model Intercomparison Project, Phase 6
E2C	Amazon Elastic Compute Cloud
EVT	extreme value theory or theorem
FAQ	frequently asked question
Fifth Assessment	California's Fourth Climate Change Assessment
Fourth Assessment	California's Fifth Climate Change Assessment
GCM	general circulation models
GDAL	Geospatial Data Abstraction Library
GEV	generalized extreme value
GIF	Geospatial Innovation Facility (University of California, Berkeley)
GIS	geographic information system
GridMET	*Gridded Surface Meteorological dataset*
HadISD	*Hadley Centre* Integrated Surface Database
IOU	investor-owned utility
LOCA	localized constructed analogs
NOAA	National Oceanic and Atmospheric Administration
R	Programming language for statistical computing and data visualization
RCP	representative concentration pathways
TAC	technical advisory committee
Tmin, Tmax	minimum and maximum temperature
VIC	variable infiltration capacity model

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Project Deliverables

The project deliverables that are part of the key technical tasks, were delivered. As indicated below, a number of the deliverables can also be found on the Cal-Adapt web-application (https://cal-adapt.org):

- Data Download Tools Memo – available at https://cal-adapt.org/blog/data-download
- Next-Generation Cal-Adapt Memo – as described at https://cal-adapt.org/events/webinar-accessing-climate-data
- Cal-Adapt Update Memos (Cal-Adapt newsletters): see blogs at https://cal-adapt.org/blog/
- Land Use/Land Cover and Population Projections Memo
- Extreme Climate Events Update Memo
- New Data Availability Memo
- Workshop and Webinar Presentation Materials and Visuals
- Technology/Knowledge Transfer Plan and Report
- Project Fact Sheets

These project deliverables, including interim project reports, are available upon request by submitting an email to pubs@energy.ca.gov.

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix A: Cal-Adapt Web Application Transfer Brief
(as delivered to CEC for EPC-17-033)

June 2024 | CEC-500-2024-078

APPENDIX A: Cal-Adapt Web Application Transfer Brief (as delivered to CEC for EPC-17-033)

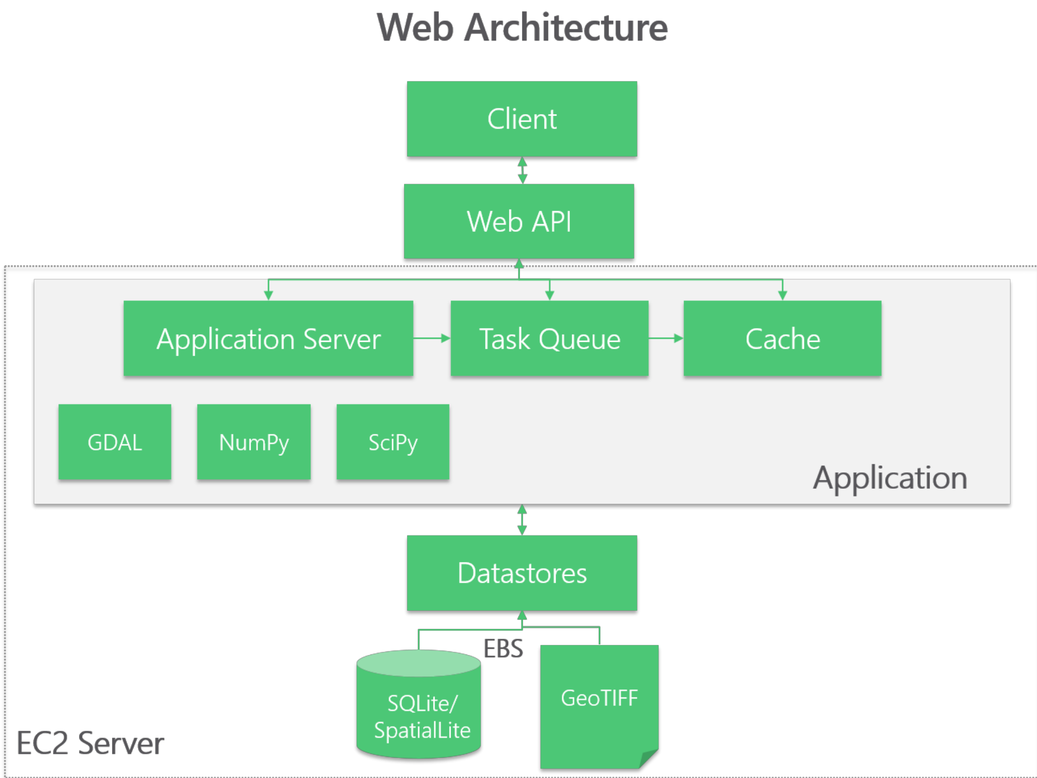
The Cal-Adapt web application is cloud-based and runs on Amazon Web Services (AWS). This application environment allows for a transfer of ownership if required under future Cal-Adapt funding. The Web architecture is as shown in Figure A-1. To transfer site ownership, an image of the production server as an Amazon Machine Image (AMI) could be created within the standard AWS management console. The self-contained AMI includes the database, web server, services, and all static assets necessary to run the entire site. This AMI would be shared with the Amazon account tasked with taking over hosting and management of Cal-Adapt. The AMI could be copied and then launched as a new Amazon Elastic Compute Cloud (EC2) instance. At that point, the Geospatial Innovation Facility (GIF) hosted instance would be deregistered and the Cal-Adapt.org domain transferred to the new owner. The latest source code release developed for generating front-end tools and visualizations could also be packaged or cloned from GitHub and provided for future development.

The hosting, management, and ongoing development of the web application upon transfer will require expertise in Python, JavaScript and some familiarity with Amazon Web Services. Cal-Adapt is built on top of the Python-based Django web framework along with supporting libraries such as GDAL, NumPy, and SciPy. The application stack also includes SQLite with SpatialLite as a database, Nginx as the web server, and Redis as a job queue for asynchronous task handling. Additional capabilities for spatial querying and manipulating geo-formats are provided by the Django-Spillway package, an open-source library developed at the GIF. The combined web framework provides fast and dynamic temporal aggregation of time series data and spatial aggregation by different vector boundaries.

The front-end tools and visualizations featured on Cal-Adapt have been designed to allow users to easily interact with and explore climate change data. The user interface is built using popular JavaScript libraries including Bootstrap, MapBox, and D3. MapBox is an open source mapping platform for custom designed maps. Cal-Adapt uses MapBox basemaps and API for mapping components in climate tools. Upon transfer, the ownership of the Cal-Adapt MapBox account could also be transferred to the new owner. While this is currently within the free service tier, this may change in the future as the popularity and complexity of the climate tools increase. The front-end code is built and packaged using Babel and Webpack.

Cal-Adapt currently runs on a single AWS m4.large EC2 instance type which bills at $0.117 per hour per on-demand instance and utilizes an 857 gigabyte Amazon Elastic Block Storage volume at a cost of $0.12 per gigabyte for a general purpose solid state drive. Current monthly costs for the application average around $220.00, subject to change with varying data volume and usage. In addition, the GIF manages the Cal-Adapt Data Server, which is a 15 Terabyte Ubuntu Linux Dell PowerEdge R730 server hosting primary climate research data, commonly stored in NetCDF format. The machine could be taken offline and shipped to a new location, and the networking, domain name system entry, and links on the Cal-Adapt website would have to be modified for ongoing accessibility to California's climate change research.

Figure A-1: Cal-Adapt Web Application Architecture



Source: UC Berkeley