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ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Building on the Cal-Adapt Platform to Deliver Actionable Information in Support of Electricity Sector Resilience

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PREPARED BY:

Nancy Thomas
Geospatial Innovation Facility
University of California Berkeley
Primary Authors

Martine Schmidt-Poolman
Project Manager
California Energy Commission

Agreement Number: EPC-17-033

Kevin Uy
Branch Manager
ENERGY GENERATION RESEARCH BRANCH

Jonah Steinbuck, Ph.D.
Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

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

Cal-Adapt provides a way to explore peer-reviewed data that portrays how climate change might affect California at the state and local level. This project has built on the Cal-Adapt web-application (https://cal-adapt.org) to make such data developed as part of California's Fourth Climate Change Assessment more accessible and actionable for electricity stakeholders.

As a key component of this research, a user-oriented approach was implemented and coordinated closely with the California Energy Commission, the state's investor-owned utilities, a technical advisory committee, state agency partners, and other energy-sector stakeholders to identify what new data services, visualizations, and features would be most helpful for users to plan for and adapt to in a future climate.

In recognition of stakeholder needs, the team redesigned the Cal-Adapt web application to make it easier for new and existing users to learn about climate data, understand the tools and features on Cal-Adapt, and connect with other state resources available for climate adaptation and resiliency planning. Existing Cal-Adapt tools were redesigned to streamline and standardize the user experience of exploring and accessing climate data. A new data download tool was developed that allows users to access some of the available advanced features to customize data extraction without requiring any code. Custom analytical tools were also developed that depict climate-related risks from a range of stressors on California's electricity infrastructure, using data and new understanding from California's Fourth Climate Change Assessment.

The tools provided improved data services and access to new datasets with a focus on wildfire projections, sea-level rise models, and a new extreme weather tool that enables users to explore observed data from specific meteorological stations.

Keywords: Cal-Adapt, Energy Sector Climate Resilience, Climate Services, Climate Tools, Climate Change Adaptation

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Introduction

Electricity sector operations, management, and planning require best-available, peer-reviewed data on projected climate and weather-related risks to provide safe, efficient, and reliable energy for current and future Californians. California's energy infrastructure, including power generation facilities and transmission lines, is vulnerable to climate-related impacts and extreme weather events that may differ significantly from historical records in the future due to the changing climate. Understanding projected climate-related risks that may cause disruption and energy vulnerability is critical for energy-sector resilience and planning.

Research supported by the state of California has provided high-quality, peer-reviewed data and scientific analyses of many climate-related factors including sea-level rise, inland flooding, storms, wildfire, and extreme heat, all of which can be incorporated into energy-sector decision-support and planning through the Cal-Adapt web application. Cal-Adapt provides electric-system stakeholders with actionable information through interactive, visually compelling, and practical visualizations and tools that can help identify vulnerable populations and infrastructure locations potentially at risk from climate-related factors. By building new targeted visualization tools and improving access to an expanding catalogue of climate data generated as part of California's Fourth Climate Change Assessment (a scientific evaluation that provides information to build resilience to climate impacts), this project provides critical data on climate-related risks from a variety of stressors on the state's electricity infrastructure and supports improved planning for future reliability.

Project Purpose

Cal-Adapt's web application provides a path to explore peer-reviewed data showing how climate change could affect California at state and local levels. The web application provides easy access to this data through downloads, visualizations, and the Cal-Adapt Application Programming Interface for research, outreach, and adaptation planning. This project focused on identifying new datasets to incorporate within Cal-Adapt, in addition to new features and targeted tools to better meet the needs of electricity-sector managers and other decision makers. This research built upon the foundational success of Cal-Adapt and leveraged existing infrastructure, data, and features. The resulting Cal-Adapt web application is a collaboration of state agency funding programs and university and private-sector researchers. Free public access is offered to peer-reviewed data that support exploration of California's climate change impacts on state infrastructure, communities, and natural resources. Cal-Adapt's users include energy-sector stakeholders, infrastructure managers, municipal planners, community-based organizations, state agencies, scientists and climate experts, educators, and interested members of the public.

Project Approach

The Cal-Adapt team gathered stakeholder insights through an ongoing online survey, numerous workshops and webinars, and more than 36 hours of focused interviews. Website development included building new climate data visualization tools and addressing feature requests directly from stakeholder input. 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.

The research approach was also collaborative and included partnerships with climate scientists and domain experts who helped develop functional and rigorous tools that provide actionable information to stakeholders on expected climate impacts.

Project Results

The Cal-Adapt web application was redesigned to make it easier for new and existing users to learn about climate data, understand the tools and features on Cal-Adapt, and connect with other state resources available for climate adaptation and resiliency planning.

Existing Cal-Adapt tools were also redesigned to streamline and standardize exploring and accessing climate data including the Landing (https://cal-adapt.org) and About (https://cal-adapt.org/about/) pages. Updating the underlying source code and creating a standard dashboard-style template improved the ease of use for new and existing users and allowed new tools to be developed more quickly. This effort allowed the team to make sure the code base was up-to-date and compliant with security measures.

California's investor-owned utilities desired access to primary climate change data through Cal-Adapt to analyze the data with their respective geographic information system mapping software. To better meet those utility needs, a new data download tool was developed that allowed users to access the advanced features available to customize data extraction without requiring any code. This tool bridges the middle ground between advanced users with some programming skill and standard users with desktop software. Users can walk through a graphical user interface, which allows users to select regions of interest, temporal interval, or level of temporal aggregation (for example monthly, annual, or decadal averages).

New data visualization tools were developed including custom analytical tools that depict climate related risks, using data and new understanding from ongoing energy-sector research projects. In addition to providing improved data services and access through the Data Download tool, the Cal-Adapt team developed tools specifically to showcase California's Fourth Climate Change Assessment climate-change data, focusing on wildfire projections, sea-level rise models, and a new Extreme Weather tool that includes near real-time wind speed.

Technology and Knowledge Transfer

The Cal-Adapt web-application's ongoing mission is to make data portraying climate change in California more accessible and actionable for a broader audience. The stakeholder outreach and engagement efforts provide a rich source of information on the evolving needs of

Cal-Adapt's past, current, and future user bases. The stakeholder outreach and engagement efforts included holding interviews, building a user community, gathering feedback via a user survey, and communicating through a newsletter and a blog. Training material, workshops, and quarterly webinars provided the opportunity to engage with stakeholders during new tool development and were used to enhance outreach and training of potential new and returning users.

The Cal-Adapt web development team outlined steps that seamlessly transfer the web application to either a different organization or to a state agency (if required as part of the expanding Cal-Adapt enterprise). The team developed a technology transfer brief to show, in detail, how the web application can be transferred. Cal-Adapt was built using an open and flexible web architecture that is cloud-based and runs on Amazon Web Services, which allows straightforward transfer of ownership.

The California Energy Commission developed a vision for building an ongoing Cal-Adapt enterprise (CEC, 2021a) that encompasses user-friendly and easy-to-use interactive tools on the Cal-Adapt web application while designing the new Cal-Adapt Analytics Engine (CEC, 2021b). This new analytics engine is optimized for the more technically savvy user who is comfortable writing their own computer code and provides unprecedented computational and technical resources to directly support energy resilience.

Benefits to California

California is a global leader in addressing climate change and developing energy policies that conserve resources, protect the environment, and protect public health and safety. Targets have been set for the state to reduce greenhouse gas emissions 40 percent below 1990 levels by 2030. The Cal-Adapt web application was recognized by California's legislature as a key resource to support local hazard mitigation efforts, and helped California advance its climate policy by providing easy access and exploration of high-resolution, regionally downscaled climate projections that are sanctioned by the state to be used in climate adaptation resiliency and planning efforts.

Understanding potential risks from climate variables including extreme heat, increased wildfire, and sea level rise, as made possible via the tools developed for this research, will enable improved planning such as the siting of power generation facilities and new transmission lines, both critical for meeting California's ambitious renewable energy mandates. The tools support the enhancement of analytical capabilities to provide better information for infrastructure planning as well as the importance of including climate science into planning and decision-making to meet the 2030 greenhouse gas reduction goals – the importance of which is stressed in policy reports such as the *2016 Integrated Energy Policy Report Update* – Executive Summary (16-IEPR-01).

This research supports achieving the state's statutory energy goals by providing necessary information on climate change consequences to California's populations and infrastructure by identifying locations that may be at risk from climate-related impacts such as increased wildfires and extreme heat events. With this information, utilities, state agencies, local planners, resource managers, and communities will be better prepared to safeguard

vulnerable populations and important assets. Enhancements to the Cal-Adapt web application described in this project will help the energy sector meet its important climate, energy, air quality, and other environmental mandates while maintaining safe, reliable, and affordable energy for Californians.

CHAPTER 1: Introduction

Building on Cal-Adapt

Electricity sector operations, management, and planning rely upon best-available and peer-reviewed data on projected climate and weather-related risks to maintain safe, efficient, and reliable energy for Californians. California's energy infrastructure, including power generation facilities and transmission lines, is vulnerable to climate-related impacts and extreme weather events that may differ significantly from historical records. Understanding projected climate-related risks that may cause disruption and energy vulnerability is critical to both energy-sector resilience and planning. Research supported by the state of California has provided high-quality, peer-reviewed data and scientific analyses of many climate-related factors including sea-level rise (SLR), inland flooding, storm events, wildfire, and extreme heat events, which can all be integrated into energy-sector decision support and planning through Cal-Adapt's web application. Cal-Adapt provides electricity system stakeholders with actionable information through interactive, visually compelling, and useful visualizations and decision support tools to identify vulnerable populations and infrastructure locations potentially at risk from climate-related factors that are important to securing California's energy future. Targeted visualization tools developed in the course of this research show climate-related risks from a variety of stressors on electricity infrastructure, enabling improved planning for future reliability.

Project Goal

Cal-Adapt is an interactive, publicly accessible web-based platform that was developed at the University of California, Berkeley's (UC Berkeley) Geospatial Innovation Facility (GIF) with funding and advisory oversight from the California Energy Commission (CEC). Cal-Adapt provides intuitive and easy-to-understand visualizations of locally relevant climate-related risks that enable decision makers to turn research results and climate projections into effective adaptation decisions and policies. The goal of this research was to further develop the Cal-Adapt platform to provide peer-reviewed, easily accessible data on the changing climate and its impacts on California's energy infrastructure, allowing for improved planning that is informed by climate risk.

The research approach was user-oriented and began with needs assessment outreach to key energy-sector stakeholders. The project team facilitated a series of workshops, webinars, focused interviews, and one-on-one conversations with the state's electricity investor-owned utilities (IOU) to identify new datasets to incorporate into Cal-Adapt and new features and targeted tools that could be developed to better meet the needs of electricity sector managers and decision makers.

Stakeholder feedback guided major project tasks, including to:

- Develop advanced easy-to-use and flexible data services.
- Design innovative web-based visualizations.
- Build custom analytical tools.

Project Background

The CEC and the GIF initially released Cal-Adapt 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, as recommended in the 2009 California Climate Adaptation Strategy (CNRA, 2009).

The GIF, with funding support from the CEC, developed and launched the current iteration of Cal-Adapt 2.0 as part of California's Fourth Climate Change Assessment (Fourth Assessment).[1] Cal-Adapt 2.0 included updates and enhancements that increased its ease of use, information value, interactive visualizations, and data accessibility (Thomas et al., 2018). Cal-Adapt's design and functionality was developed in collaboration with beta testers and advisory committee members who provided valuable feedback throughout several updates.

Three key principles guided the design of the Cal-Adapt web application, which was built to: (1) allow easy access to primary scientific peer-reviewed climate change data for a variety of users; (2) provide locally relevant climate information, presented in understandable themes and topics; and (3) present interactive maps and charts that engage users and allow them to explore different aspects of climate change (Thomas et al., 2018). Users were also connected to additional resources, tools, publications, and case studies through links to the ongoing Integrated Climate Adaptation and Resiliency Program Adaptation Clearinghouse project.

The flexible, easy-to-use design has enabled wide use of Cal-Adapt by energy stakeholders as well as state and local agencies to help guide locally relevant climate action plans and adaptation strategies. California IOUs have employed Cal-Adapt tools and data to support energy sector resilience efforts, including San Diego Gas & Electric's (SDG&E) exploration of climate dimensions of system hardening projects and Southern California Edison's (SCE) work on integrating climate projections into existing planning models. Cal-Adapt tools and data have supported many other resilience-related initiatives, including the "Build Resistance against Climate Effects" (CalBRACE) project through the California Department of Public Health, which has generated county-level reports of climate-related risks to public health. Cal-Adapt is being used to support the Climate Adaptation Guide prepared by the Governor's Office of Planning and Research, and many local agencies and their consultants are using maps and graphs from Cal-Adapt directly in their climate planning documents. In addition, Cal-Adapt is named as a resource by landmark legislation (SB 379, Jackson, Chapter 608, Statutes of 2015) that requires the integration of climate-related risks into local hazard mitigation plans.

[1] California's Climate Change Assessments contribute to the scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions, while also directly informing State policies, plans, programs, and guidance, to promote effective and integrated action to safeguard California from climate change (California Climate Change Assessment, 2022).

This research builds on the success of Cal-Adapt 2.0 and leverages existing infrastructure, data, and features to improve usability to energy-sector stakeholders through improved easy-to-use and flexible data services, new innovative web-based visualizations, and custom tool development targeted to energy-sector stakeholders and expanded outreach and training efforts.

Related Efforts

Cal-Adapt development has primarily been funded through the CEC as an energy-sector tool for understanding of and planning for expected climate-change impacts. Because Cal-Adapt is a free resource that offers climate projections sanctioned by the state, the data and tools on Cal-Adapt have also been used widely in areas outside of the energy sector.

Since 2018, Cal-Adapt data hosting and website development have been supported under three separate grants: this award (EPC-17-033), CEC funded award PIR-17-012 (*Developing Next-Generation Cal-Adapt Features to Support Natural Gas 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 that specific grant, there is also considerable overlap among the different awards, which allows the state to leverage climate science advancements across several state agencies. Because the Cal-Adapt site is public, changes and updates to the site were reviewed and approved by both the CEC and the Strategic Growth Council (SGC).

Stakeholder outreach activities such as webinars, blog posts, and newsletters target a diverse range of user groups including energy-sector stakeholders, state agencies, local and regional planners, natural resource and water managers, community-based organizations, and the interested public. While certain topics are specifically related to a specific grant-funding source, attendance and feedback are widely encouraged from a broad audience. Throughout this report, areas of significant overlap with one or more of the other Cal-Adapt research projects are noted. A brief overview of those awards follows.

PIR-17-012: Developing Next-Generation Cal-Adapt Features to Support Natural Gas Sector Resilience

Funded by the Fiscal Year 2017–2018 Natural Gas Research and Development Program, the goal of this award was to develop next-generation enhancements to Cal-Adapt that integrate new research results (including those from the Fourth Assessment) and expand the capabilities of Cal-Adapt to provide actionable information on climate-related vulnerabilities and resilience to natural gas sector stakeholders. Highlights of new tools, data, and features include: the new Extreme Precipitation and the Maps of Projected Change tools; a curated Hourly Observed Historical Dataset and Variable Infiltration Capacity hydrological modeled data; and new features that allow users to input their own thresholds in the tools (for example, extreme heat- and cooling-degree days and heating degree days).

Strategic Growth Council

The CEC originally funded development of Cal-Adapt to serve energy-sector users. Research funding from the SGC (completed in 2021) supported a broader user base that includes local governments and others engaged in climate change analysis, mitigation, and adaptation. The SGC-funded project allowed Cal-Adapt to expand beyond primary energy-sector users (funded through the CEC) to a more diverse user community, especially users working in municipal governments, natural-resource management agencies, and community-based organizations. The interactive visualizations and easily accessible data on Cal-Adapt have also been used by academic scientists and professionals working in sectors like forestry, watershed and water resource management, agriculture, and public health. Additionally, the Cal-Adapt web application can support climate change education in community, school, and university settings.

An additional goal of the SGC-funded research was to share climate change information across state agencies and California's climate-investment programs to advance the state's mandated climate goals. The project team supports interagency coordination that can help leverage resources across multiple projects and state agencies and ensure that new data and tools developed in Cal-Adapt provide multiple benefits. The climate data visualizations and guidance materials developed through this research help businesses, public agencies, nonprofits, and other community institutions understand the risks of climate change and support efforts to plan for and adapt to future conditions. The Final Report for the SGC-funded research appears in Appendix C.

Impacts of COVID-19 Pandemic

During much of the duration of this project, California was in the midst of the COVID-19 pandemic. This initiated a move to fully remote work for much of both 2020 and 2021. While much of the web development transitioned seamlessly to remote work, revising this project's planned stakeholder engagement activities presented challenges. The original stakeholder engagement plan detailed both in-person user-needs assessment workshops and on-site workshops at IOUs. While the research team was able to transition these activities to a virtual format, there were aspects of communication and feedback that were difficult to achieve in a fully remote environment.

CHAPTER 2:
Project Approach

Stakeholders were actively engaged throughout the tool development process. The Cal-Adapt web application development team collaborated with users to ensure that tools and visualizations built were actionable and fit within stakeholders' current and planned climate data needs and workflows. Each major tool was identified through collaboration with the CEC, the technical advisory committee (TAC), and other users. Initial design for new tools and features was discussed with the CEC and used to build a beta version of envisioned web pages. The resulting beta tool or visualization was then shared with the CEC and other stakeholders for review. This iterative development of visualizations and tools allowed the research team to present initial tools to stakeholders, gather feedback, and refine tool design.

Stakeholder Engagement

As a key component of this research, the research team implemented a user-oriented research approach and in close coordination with the CEC, IOUs, TAC, state agency partners, and other energy-sector stakeholders identified new data services, visualizations, and other features that would be helpful for users when planning for a future climate. The Cal-Adapt team gathered stakeholder insights through an ongoing online survey, numerous workshops and webinars, and focused interviews. These efforts helped identify new datasets to incorporate onto Cal-Adapt and new features and targeted tools that could be developed to better meet the needs of a range of California energy stakeholders, climate-adaptation practitioners, planners, resource managers, educators, and utility ratepayers.

Stakeholder Engagement Plan

A comprehensive stakeholder engagement plan was developed that detailed the planned approach and was designed to regularly elicit feedback from stakeholders throughout the project. The document (see Appendix A) outlined the stakeholder engagement process and presented an overview of the outreach tasks, including to:

- Identify key stakeholders.
- Engage stakeholders and gather feedback.
- Build a user community.

Identify Key Stakeholders

The Cal-Adapt team developed a list of energy-sector contacts that was continuously updated throughout the course of this project. The potential user list included staff from IOUs who previously engaged with Cal-Adapt during on-site meetings or conference calls, in addition to the state's three large electric IOUs (Pacific Gas and Electric Company [PG&E], Southern California Edison [SCE], and San Diego Gas and & Electric Company [SDG&E]), and potential users at much smaller regional utilities (including PacificCorp, Liberty Utilities, and Bear Valley Electric Service).

Additional contacts at stakeholder organizations included the California Independent System Operator (California ISO), the California Public Utilities Commission (CPUC), and other state agencies, all of which were added to the contact list. Contacts were also added from attendee lists of Cal-Adapt webinars and workshops, Cal-Adapt Newsletter subscribers, and active users who reached out to the GIF team through support@cal-adapt.org.

Particular focus was given to identifying technical experts within each organization who could recognize their agency needs for directly accessing data and features on Cal-Adapt. These technical experts were invited to beta test particular tools or features and attend ongoing workshops and webinars.

Stakeholder Engagement Activities

The project team incorporated a variety of approaches and activities to elicit engagement and feedback which are further described in the following sections.

User Needs Assessment Workshops

The Cal-Adapt team planned to hold a minimum of two in-person user needs assessment workshops open to the public and focused on the energy and electricity sector. However, the COVID-19 pandemic had effectively shut down this kind of event in early 2020. In response, the project team put together several remote workshops designed to introduce users to new tools and features and elicit their feedback to help guide website development. Workshop attendees represented a range of users including energy-sector stakeholders, state agency representatives, and municipal planners. These public workshops did overlap between the different funding streams, and several remote workshops were led by SGC-funded efforts with considerable application to the CEC-funded project.

The Cal-Adapt team developed a standard workshop format that made it possible to easily prepare for events. A standard registration form was developed that captured information on potential attendees and invited their input on climate topics most relevant to them. Using this information, the research team planned the workshop, which began with a brief background presentation on Cal-Adapt and an introduction to relevant topics specific to that user group. Participants then attended breakout sessions where it was possible to hear directly from Cal-Adapt users in a smaller group setting. For each breakout group, facilitators had prepared questions in advance and reserved time for general questions and feedback. This format was extremely effective at eliciting actionable feedback from users, which in turn was invaluable in shaping ongoing and future developments in Cal-Adapt.

The invitation lists for these events were developed from the key stakeholder list and other sources identified in consultation with the CEC, TAC, and other energy-sector partners.

Targeted Workshops with Investment-Owned Utilities

A critical goal of this project was to engage key IOU stakeholders by offering on-site workshops designed to introduce new features and elicit feedback on energy-sector needs for custom tool development. This approach was adapted to a remote format in response to the COVID-19 pandemic. The most effective method of generating discussion and feedback from IOUs was informal web-based conference calls. IOU-focused discussions helped the research

team identify and connect with a list of key people within each organization who are using Cal-Adapt or may use the site in the future. Key insights from these meetings are summarized in Chapter 4.

Public Webinars

Quarterly webinars were designed to engage stakeholders early in the design stage as new tools were built and also to enhance outreach and training of potential new and returning users. A full list of the webinars held as part of this research and the SGC award is included in Chapter 4.

Webinar participation rates varied significantly (28–80 attendees), depending on the topic. While time was provided for questions and audiences were encouraged to use online chats, the webinar format proved most effective at showcasing new tools and communicating new developments on Cal-Adapt, rather than generating substantial feedback from participants.

Cal-Adapt User Survey

The Cal-Adapt team developed an online user survey designed to gather feedback on who is using Cal-Adapt, what they are using it for, and what improvements or additions they would like to see. The survey was advertised on the Cal-Adapt website, sent to the newsletter list, and shared with all Cal-Adapt TAC members for dissemination to their respective networks. By mid-2022 this survey had more than 80 respondents.

Information about Cal-Adapt users helped the development team build new features and tools with the user audience in mind. For example, the majority of Cal-Adapt users have some familiarity with climate science and data, and the majority of users apply information from Cal-Adapt within standard reporting formats including spreadsheets, presentations, and documents (Figure 1). This information helped guide the development of several ways to access simple graphics and .csv files throughout the web application and provided access to raster data files.

Figure 1: Cal-Adapt User Survey Results

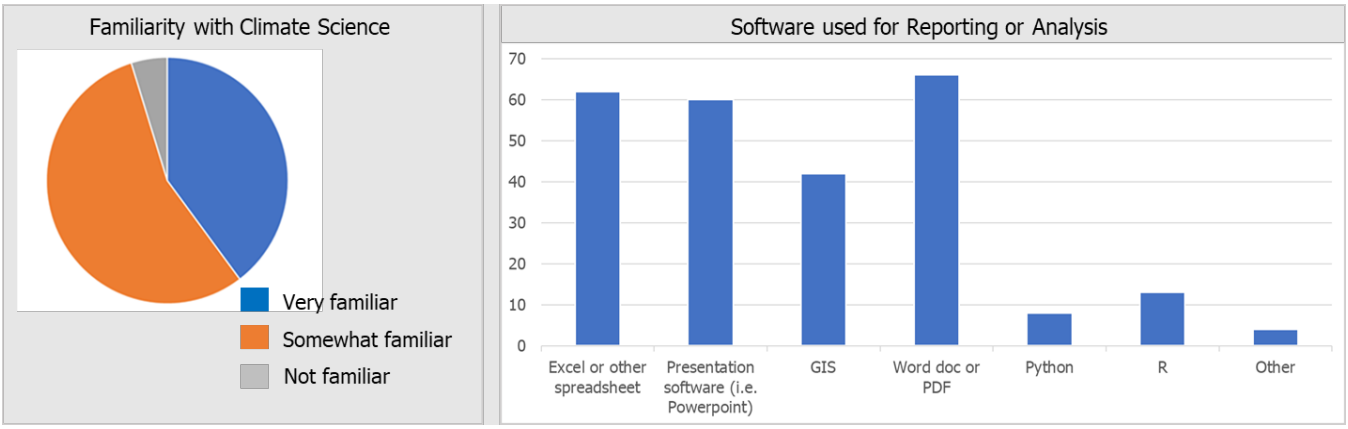

Figure 1 shows the results from two of the questions asked of respondents in the Cal-Adapt online user survey. Respondents were asked to categorize their familiarity with climate science and to select the software packages they commonly use for reporting and analysis.

Source: Thomas, et al., 2024

Focused Interviews

As part of the scope of work for the Cal-Adapt SGC award, more than 36 hours of focused interviews were conducted to guide Cal-Adapt development. While much of the focus of this effort was to expand the user base and learn more about the climate data needs of local planners, state agency representatives, natural resource managers, and local communities, a group of energy-sector stakeholders was also included in the interview process.

These interviews were semi-structured, which allowed open-ended conversation. Key questions discussed within each interview included:

- How does your organization currently use climate data?
- What information do you need to make climate data useful and actionable? In what format is climate data most useful (for example, exportable graphics, reports, csv files, or raster data)?
- What support might your organization need to use Cal-Adapt tools (training, API, others)?
- What additional data layers or features would be most useful?
- What suggestions do you have for improvements to Cal-Adapt to better meet your needs?

Building a User Community

To ensure that Cal-Adapt tools and data were used effectively by a broad spectrum of users, the research team built a community of users. Feedback from those users assisted in development and refinement of the tools; direct communication with users helped the team to offer direct assistance when needed.

The Cal-Adapt Newsletter and Blog

One method of direct communication with Cal-Adapt users was through the Cal-Adapt newsletter, which had more than 400 subscribers by mid-2022. With Cal-Adapt 2.0, the Cal-Adapt newsletter migrated to MailerLite, a hosted newsletter service.

MailerLite provided several powerful and easy-to-use features including user subscription management, tools, and examples for designing newsletters and subscription forms, and tools for tracking statistics on how users interact with newsletter content. The newsletter was used to highlight new blog entries, new tutorials on using Cal-Adapt API, new tools and data added to Cal-Adapt, and upcoming events such as workshops and webinars.

Support@cal-adapt.org

Another valuable method of direct communication with users was the support email address. Users could reach out directly to the GIF web development team with questions or comments about Cal-Adapt data and tools. Developers provided technical assistance to inquiries when possible or referred users to documents or other guidance. Many of these requests and

suggestions were implemented within this award and the SGC award, such as the development of new Frequently Asked Questions and Glossary sections.

Training Materials

Cal-Adapt's web service architecture was designed so that users have considerable control over aggregating, exporting, and displaying climate variables for advanced analysis beyond what is available in Cal-Adapt web-based tools. Detailed instructions on using the Cal-Adapt Application Programming Interface (API) can be found at https://berkeley-gif.github.io/caladapt-docs/.

The API documents also included training materials focused on the Cal-Adapt API. The GIF wrote several cookbook examples for developers on using the Cal-Adapt API with Python and Project Jupyter (Jupyter) notebooks. The Jupyter Notebook is an open-source web application that allows users to create and share documents that contain live code, equations, visualizations, and narrative text for rapid prototyping and data-analysis sharing.

Tool Design, Development, and Testing Process

User outreach during the early tool design stages was expanded to include user input beyond the CEC and TAC. For major new tools such as the expanded *Sea Level Rise and Wildfire* tools the research team reached out to experts and key stakeholders involved in that specific climate impact topic to define which questions each tool should address and what features were required to answer those questions.

For workshop break-out sessions and key stakeholder meetings convened to plan and design specific tools, a set of questions tailored to that tool included:

- What questions do you need to answer about this climate topic?
- How do you plan on using this tool (for example, putting charts into reports or presentations, downloading raster or csv data)? Can you give examples of use cases?
- What is the most important information to include in this tool?
- Are there additional datasets that should be included with this tool?
- What is the key functionality needed in this tool?

This information was used to build a working beta version of the new tool, which was then reviewed in a design meeting with the CEC and the project's science advisor at Eagle Rock Analytics (ERA) to ensure that the tool and data visualizations met state recommendations and followed state guidance. Interested participants were then invited to beta test the tool. Final revisions were made, taking into account the range of feedback acquired.

Beta Testing

A more formal beta testing process for Cal-Adapt tools was implemented. Beta testers were invited to participate through a variety of formats including the TAC groups, webinars, newsletters, and the support email correspondence. This project followed best practices to

improve usability of web interfaces for atmospheric and climate data, as outlined in Oakley and Daudert (2016).

The testing protocol had two phases: a live observed tool interaction with prompts to answer questions requiring user exploration of the tool and a follow-up survey form.

Live Observed Tool Interactions

Cal-Adapt beta testing typically involved both open-ended and multiple-choice questions. First, the Cal-Adapt team identified a set of questions to elicit specific feedback. The questions were neutral and designed to allow open-ended answers (Oakley and Daudert, 2016). Open-ended questions (for example, "How do you feel about this Landing page," or "What stands out to you on this page?") were interspersed with observed tasks such as, "Navigate to a specific address."

These sessions were facilitated in a semi-structured format that incorporated beta tester comments. Goals of the live observation phase were to:

- See how people navigated the tool, particularly where they got "stuck," missed important cues, or took a long time to find what they were looking for.
- Explore any gaps between the information users thought they were getting and what they actually got.
- Capture broad and specific feedback.

Participants gave their permission when recordings were made. If the session was not being recorded two Cal-Adapt team members attended the sessions: one to direct the session, the other to take detailed notes.

Survey Form

In addition to hands-on tool walk-throughs with beta testers, a Google survey form was created. This was most useful for complex activities that required the tester to carefully read instructions or provide feedback in written form rather than by screen-sharing. The survey also included a standardized "system usability" test. The System Usability Scale is a 10-item questionnaire that uses a Likert-type scale ranging from "strongly disagree" to "strongly agree." This standardized score measures the usability of a product and can be compared across different applications (Oakley and Daudert, 2016).

Iterative Design

The Cal-Adapt development team compiled the information learned in beta testing and created a prioritized list of suggested refinements, bugs, and feature requests. These changes were then implemented in the tool code and a second round of beta testing was performed. The next iteration of tool design was reviewed with the CEC and the science advisor at ERA before the public launch on Cal-Adapt.org. New tools went through three or more iterations before they were ready to launch.

Website Application Architecture

The core of the Cal-Adapt website is the web architecture and code that enables seamless user experiences when exploring and visualizing projected climate impacts. Cal-Adapt is Cloud-based and runs on Amazon Web Services (AWS). The web application was built on top of a Python-based Django web framework, along with supporting libraries including the Geospatial Data Abstraction Library, 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. Key capabilities for spatial querying and manipulating geo-formats were 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.

This powerful combination of tools enabled creation of a flexible, spatially enabled Cal-Adapt Web API, through which developers and researchers can access the rich environmental and climate variables available through Cal-Adapt. The Cal-Adapt API uses an extra-large Elastic Compute Cloud (EC2) instance type on AWS that allows fast, interactive, and dynamic visualizations on the web. Details on the Cal-Adapt API are included in the API documentation on the publicly accessible Cal-Adapt GitHub site: https://berkeley-gif.github.io/caladapt-docs/index.html.

The Cal-Adapt user interface was 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. The front-end code was built and packaged using Babel and Webpack.

A Collaborative Approach

The Cal-Adapt project team's research methods evolved throughout the span of this project. Complex climate-data-science topics as showcased on the website required support from climate scientists and domain experts to develop functional and rigorous tools that can provide actionable information to stakeholders on expected climate impacts. The partnership with Dr. Owen Doherty of ERA as the science advisor to Cal-Adapt greatly improved the statistical rigor of the data visualizations, particularly as seen in the "Extreme Weather" and "Extreme Precipitation" tools.

The research team worked closely with domain expert Larry Dale Natural Resource Associates and Dr. LeRoy Westerling to develop an expanded "Wildfire" risk tool. To address the needs identified from stakeholder engagement, Dr. Westerling's team at the University of California, Merced (UC Merced), produced monthly wildfire scenario projections for "area burned" (land area burned by wildfire). Domain expert Larry Dale helped the research team develop computer code that processes UC Merced's wildfire data into a decadal wildfire probability dataset, which in turn shows the probability of occurrence of one or more fires in a grid cell, within a decade.

CHAPTER 3:
Project Results

An Enhanced Cal-Adapt

Historically, using Cal-Adapt data and tools required a minimum level of climate science literacy including an understanding of climate models, emissions scenarios, environmental variabilities, and scientific uncertainties. Development on Cal-Adapt's web application makes data portraying climate change in California more accessible and actionable for a broad audience and was importantly driven by insights and feedback from the online survey, numerous workshops and webinars, and more than 36 hours of focused interviews (described in Chapter 2). One of the main takeaways from the interactions was that users were looking for more guidance and an easier entry point to climate data.

In recognition of these needs, the development team redesigned Cal-Adapt to make it easier for new and existing users to learn about climate data, understand the tools and features on Cal-Adapt, and connect with other available state resources. Improvements most relevant to energy-sector stakeholders follow.

Improved Landing and About Pages

Feedback from stakeholders identified a lack of clarity around what exactly Cal-Adapt is and who it is designed for. Newer users noted difficulty navigating Cal-Adapt and finding the information they required. To improve Cal-Adapt's usability, the development team redesigned and updated content throughout the website, including the main Landing page and the About page.

The development team developed several mock-ups for each of these pages and beta-tested options with a core group of users. Beta testers overwhelmingly preferred the new Landing page design shown in Figure 2, which was organized with less text and quicker access to key information on the website.

The About page text was collaboratively revised with the CEC to better describe Cal-Adapt's mission, audience, partners, and background. The clarified tagline and mission statement follow here:

> "Our mission is to make data portraying climate change in California more accessible and actionable for a broad audience, with an emphasis on energy-sector stakeholders and local governments. We do this by:
>
> - Building tools for exploring and downloading high-quality, peer-reviewed climate data from California's scientific and research community. Cal-Adapt presents research developed under California's climate change assessments, with Cal-Adapt 2.0 focusing on California's Fourth Climate Change Assessment, including datasets portraying sea level rise, wildfires, droughts, storms, and extreme heat events.

- Designing tools and content to help users better understand climate data (via tooltips, Glossary and Cal-Adapt Blog) and learn best practices for working with climate projections (see our Get Started guide). We make it easy to share charts and tables of climate data with stakeholders and provide options for customizing data visualizations to meet sector specific requirements in some of our more technical tools.
- Building a public Cal-Adapt API to empower researchers and developers to integrate climate data on Cal-Adapt into existing workflows and develop domain specific applications.
- Engaging with and learning from our users through workshops, webinars and stakeholder outreach."

Figure 2: Cal-Adapt Landing Page

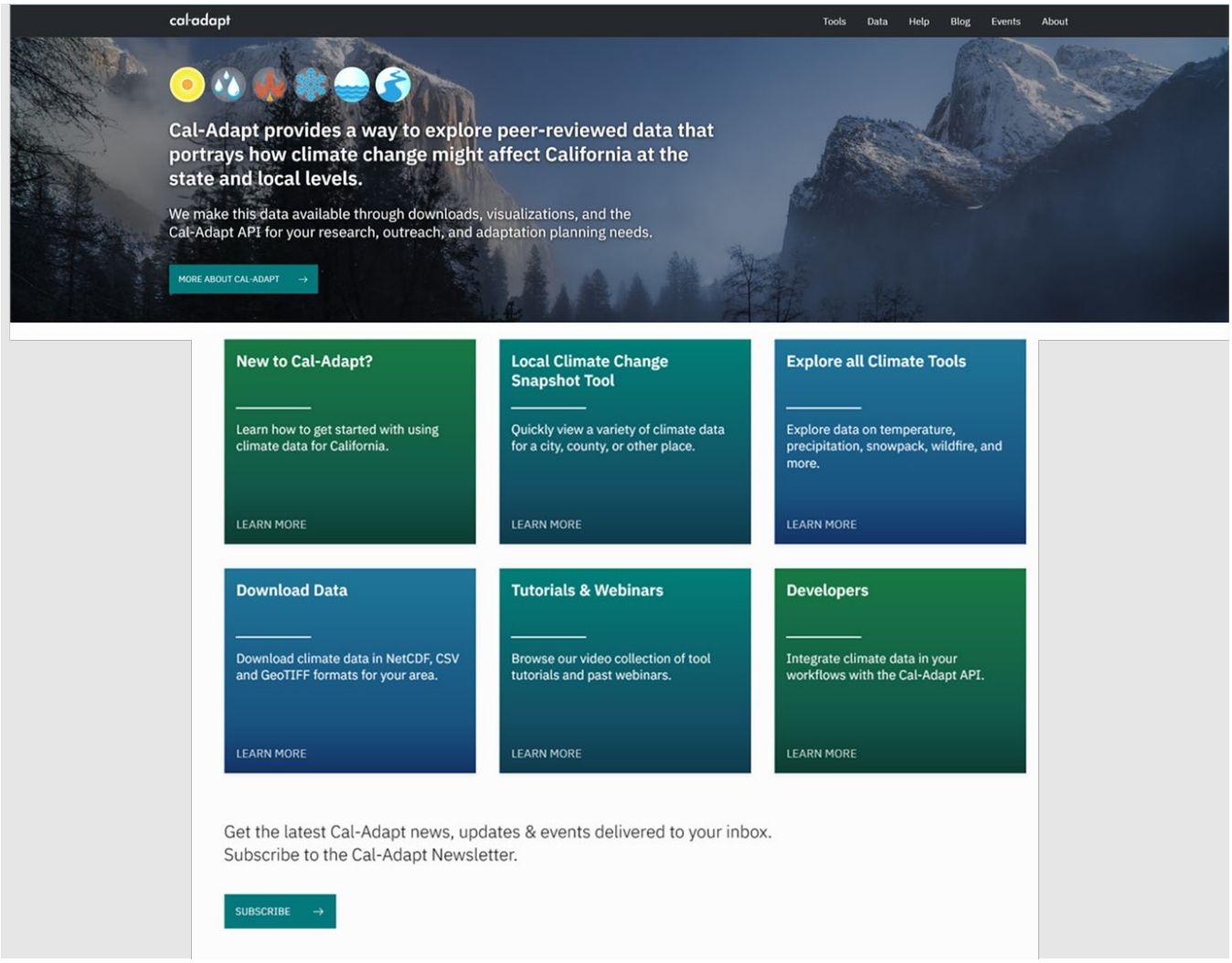

Figure 2 is a screenshot of the redesigned and updated landing page for the Cal-Adapt web application.

Source: https://cal-adapt.org

Standardized Tool Design

The Cal-Adapt team redesigned existing Cal-Adapt tools to streamline and standardize the user experience of exploring and accessing climate data. Those climate tools evolved over a series of funding cycles and had therefore been developed in an ad-hoc fashion. Updating the source code and creating a standard dashboard-style template improved ease of use for new and existing users, and also allowed new tools to be developed more quickly. Additionally, this made it possible to ensure that the code base was up-to-date and compliant with security measures. Key elements of this updated modular dashboard approach include:

- An improved "Quick Stats" table showing three default time periods and both *model average* and *model range* values
- Standardized locations of variables and user-input thresholds
- Consistent map "Change Location" components across tools and integrated direct links to Glossary terms in "Learn More" tooltips to improve usability
- Additional links to other state resources such as the Integrated Climate Adaptation and Resiliency Program Adaptation Clearinghouse
- Improved links to source data easily located within each tool
- Updated links to peer-reviewed publications for each dataset, including Fourth Assessment reports
- New text descriptions of data visualization graphics

Strategic Growth Council (SGC) Focus

The target audience for the SGC-focused enhancements was a broad audience of local climate planners, community organizations, technical users, educators, and anyone with an interest in exploring climate change projections in California. Additional improvements made to Cal-Adapt as part of that research project include new Help content (Get Started, FAQ's, and Glossary) which are described in detail in Appendix C.

Web Site Hosting and Data Services

The core of the Cal-Adapt website is the web architecture and code that enables a seamless user experience for exploring and visualizing projected climate impacts. As mentioned in Chapter 2, Cal-Adapt is Cloud- based and runs on Amazon Web Services (AWS). The web application was built on top of a Python-based Django web framework, along with supporting libraries including the Geospatial Data Abstraction Library, NumPy, and SciPy.

The Cal-Adapt team performed ongoing maintenance and code updates to ensure that the web application continued to perform to specifications. This included updates to new code versions (for example, Python 2 to Python 3) and refactoring of source code to improve performance. This new code base was used to create the newly standardized tools.

Data Hosting

Cal-Adapt employed a hybrid data storage structure to efficiently host large stores of climate data available through the website. Cal-Adapt processes data that is received from research institutions and creates derived products for selected climate indicators. Depending on the climate indicator, users can download data for four priority Global Climate Models (GCMs) — HadGEM2-ES, CNRM-CM5, CanESM2, MIROC5 — or 10 GCMs through climate tools and the Cal-Adapt API (Pierce et al., 2018). These GCMs are used in the generation of interactive visualizations and tools on Cal-Adapt. They are only a subset of the full suite of 32 GCMs downscaled for California. Primary datasets including the full suite of 32 GCMs downscaled for California are also available on Cal-Adapt in Network Common Data Form (NetCDF) format and hosted on the Cal-Adapt Climate Data server, which is a 25 Terabyte Dell PowerEdge server managed by the GIF to support additional scientific inquiry and analysis.

Performance Testing

While Cal-Adapt's web architecture works effectively with the Coupled Model Intercomparison Project, Phase 5 (CMIP5) data structure, future Coupled Model Intercomparison Project, Phase 6 (CMIP6) datasets will have higher spatial and temporal resolution so will necessarily require much larger storage and computing options. As part of this project, the Cal-Adapt development team researched and tested different data-storage formats to determine optimal performance. This included testing NetCDF as a multidimensional storage format within the API against current high-performance Geotiff format. The benchmarked comparison indicated that NetCDF is sub-optimal in delivering the high-speed interactivity featured on Cal-Adapt.

Development of an advanced AWS architecture that uses a Cloud-optimized data format (Zarr) and distributed Cloud processing capable of handling vastly improved spatial and temporal resolution datasets (that will be generated as part of California's Fifth Climate Change Assessment) is ongoing under grant EPC-20-007.

Additional Datasets

Many new climate-related datasets were added to the Cal-Adapt data catalog during this project. Decisions as to what data are available through Cal-Adapt were made by the CEC. In addition to the many datasets already hosted through Cal-Adapt and described in Thomas et al. (2018), the following additional datasets are now available through the web application:

- **CalFloD3D-TFS:** Inundation layers representing coastal flooding scenarios caused by sea-level rise, storm surge, and inland flooding due to rainfall under various climate-change scenarios. This statewide model assesses coastal flooding exposure over five 20-year periods between 2000 and 2100 using the 3Di hydrodynamic model (Stelling, 2012) to model inundated areas at 50-meter (m) x 50-m spatial resolution during extremely high sea-level events (72-hour storm events). Certain areas of the state, relevant to the state's transportation fuel sector (TFS), are also available at high resolution (5m x 5m). Details are described in Radke et al., 2018.
- **GridMET Observed Meteorological Data:** This is a modified version (temporally capped at 2020, and spatially clipped to Cal-Adapt area) of gridMET, which is a dataset

of daily high-spatial resolution (approximately 4km x approximately 4km, 1/24th degree) surface meteorological data covering the contiguous United States from 1979 to yesterday. GridMET is produced by the Climatology Lab at UC Merced (Abatzoglou, 2021).

- **Hourly Observed Historical Data:** This product consists of 39 stations across the state, each with an observation period of greater than 47 years (1973 to present) from the Met Office Hadley Centre's Integrated Surface Database (HadISD) global record (Doherty and Evan, 2020). Stations identified for use in this data product were chosen based on systematic assessment of completeness, error flags, and other criteria that indicated them to be high quality sources of hourly temperature data. The dataset is available for download from the data server in tabular format.
- **Hourly Sea-Level Projections:** Two distinct hourly sea-level projections are included in tabular format, one developed for the Fourth Assessment (Pierce et al., 2018), and the other developed for the Ocean Protection Council (Griggs et al., 2017)
- **Localized Constructed Analogs Derived Products:** Datasets created from localized constructed analogs (LOCA) downscaled CMIP5 climate projections for Cal-Adapt tools (Pierce et al., 2018) at 6km x 6km resolution are presented. These include the modeled annual variability envelope (maximum and minimum from a range of annual average values from all 32 GCMs) and precalculated data tables of extreme heat counts for California counties and census tracts for four priority models and two emission scenarios. Climate indicators are available for:
    - Keetch-Byram Drought Index
    - Cooling Degree Days
    - Dry Spells
    - Extreme Heat
    - Heating Degree Days
    - Maximum Temperature
    - Minimum Temperature
    - Precipitation
    - Warm Nights
- **LOCA Downscaled CMIP5 Climate Projections:** Additional variables were made available through the Cal-Adapt Data Server, API and Data Download tool (Pierce et al., 2018). They were:
    - Relative Humidity
    - Solar Radiation
    - Wind Speed
- **LOCA Variable Infiltration Capacity Model Runs Derived Products:**

  "The LOCA meteorological data (daily minimum temperature, daily maximum temperature and precipitation) are used to force the Variable Infiltration Capacity land surface model to provide high-resolution projections for a suite of hydrological

parameters on the 16th degree LOCA grid" (Pierce, 2023). From these runs, datasets were created for Cal-Adapt tools. These currently include the modeled annual variability envelope (maximum and minimum from range of annual average values from all 32 GCMs) for select climate variables, including:

  - Standardized Precipitation-Evaporation Index
  - Air Temperature
  - Baseflow
  - Evapotranspiration
  - Runoff
  - Snow-Water Equivalent

- **Monthly Wildfire Simulations for the Fourth Assessment:** Projected monthly wildfire scenarios, using a statistical model based on historical data of climate, vegetation, population density, and fire history coupled with regionally downscaled LOCA climate projections. Details are described in Westerling, 2018.
- **Wildfire Simulations Derived Products:** Monthly/annual decadal wildfire probability derived from monthly/annual wildfire scenario projections, following methods as described in Dale et al., 2018. The monthly/annual hectare data was converted to probability by detecting the presence of a wildfire in a cell in each simulation and integrating those simulations to create a year monthly/yearly probability for each cell. The data were then aggregated by decade.

Data Download Tool

A new data download tool was developed that allows users to access some of the advanced features available to customize data extraction through the Cal-Adapt API without requiring a code. This tool bridges middle ground between an API user with some programming skills and a standard user with desktop software. Users are guided through four steps to download data via a graphical user interface, which allows users to select their regions of interest, temporal interval, and level of temporal aggregation (for example monthly, annual, or decadal averages).

Cal-Adapt's new four-step data download process grew from user input on the structures of data access and manipulation that support climate analysis and adaptation. A key requested feature was that the tool enables easy bulk downloads of multiple-point or polygon locations. Users can now upload a spreadsheet listing multiple point locations and easily extract climate variables of interest at those locations.

The tool offers a suite of new features to make data easier to discover and format. Users can:

- Download data for multiple locations in a single process.
- Temporally aggregate data with common operations (seasonal, decadal).
- Convert units.
- Access additional datasets and variables (such as wind speed and solar radiation).
- Download multiple models and representative concentration pathway (RCP) scenarios.
- Search key terms to access relevant data more quickly.

The data download process has four steps:

1. **Search Data Catalog:** Users are prompted to search the data catalog using search terms or filters for climate variables and publishers (Figure 3). Alternatively, the user can select one of many datasets hosted by Cal-Adapt.
2. **Select Download Format:** Once users have selected the dataset of interest, they are presented with a more detailed description of the dataset and the various ways it can be downloaded. Users can download the original source files (often in NetCDF format) from the Cal-Adapt Data Server (the physical server where the original NetCDF data is stored) and can also download spatial subsets in raster or tabular formats for selected models from the Cal-Adapt API. Download formats vary by dataset.
3. **Select Spatial Extent:** Spatial subsetting for gridded datasets can be done in various ways.
    a. Draw a feature (point, line, or polygon) on the map, using the Draw toolbar.
    b. Select a polygon from different boundary datasets (like counties or census tracts).
    c. Upload a file with spatial features (point, line, polygon).

For station-based datasets, the user does not need to select a spatial extent but can instead select the stations directly in the next step.

Figure 3: The Data Download Search Page

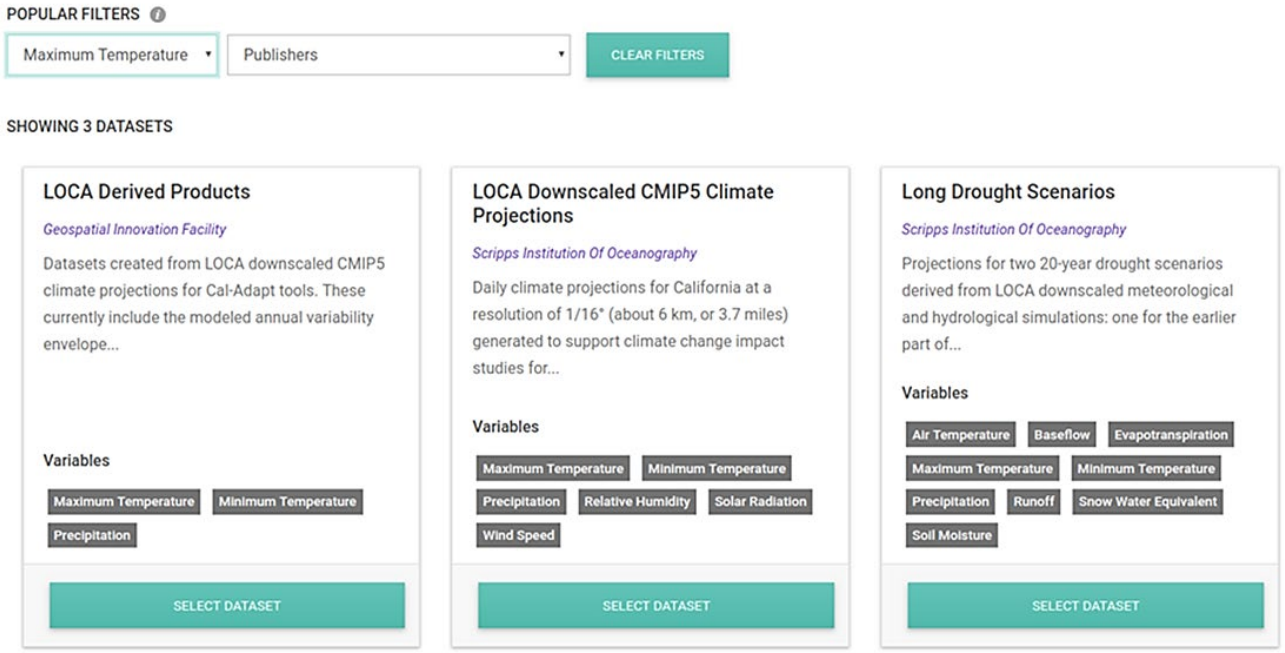

Figure 3: A screenshot showing the Search Data Catalog page. This is the first step that a user would take to access and acquire climate data through the new, interactive data download tool. Users can walk- through a graphical user interface, which allows them to select their regions of interest, temporal interval, and level of temporal aggregation (for example monthly, annual, or decadal averages).

Source: https://cal-adapt.org

4. **Select Series and Download:** In the final step, users are presented with a list of all the timeseries available for a selected dataset through the Cal-Adapt API. Users can select up to 10 series at a time to download. If additional data is required, users will need to clear the previous series selection after downloading and select again. Some of the datasets have hundreds of individual time series with various combinations of climate variables, scenarios or GCMs. To make it easier to find data, use the drop-down filters to narrow down the list in the table.

Since many users prefer downloading data in a tabular format, additional temporal aggregations are available if the user has selected the Tabular Format option. After selecting the series and any aggregation options the user can click the download button to send a request to the Cal-Adapt API. The server will return a zip file with data when it is ready.

Enhanced Data Visualization

As part of the research, new data visualization tools were developed that depict climate-related risks from a range of stressors on California's electricity infrastructure, using data and new understanding produced by ongoing energy-sector research projects (including from the Fourth Assessment). In addition to providing improved data services and access to Fourth Assessment datasets, the Cal-Adapt team developed tools specifically to showcase Fourth Assessment data, with a focus on wildfire projections, sea-level rise models, and a new Extreme Weather tool that includes near real-time wind speeds.

Enhanced Wildfire Tool

Climate models estimate increased risk to wildfires. However, the frequency, severity, and impacts of wildfire are sensitive to climate change as well as to many other factors including development patterns, temperature increases, wind patterns, precipitation change, and pest infestations. Therefore, it is difficult to project exactly where and how fires will burn.

Electricity-sector stakeholders identified the need for additional information on wildfire projections, which go beyond information supplied by the wildfire tool that was already developed and published to Cal-Adapt under a prior grant (Thomas et al., 2018). For this agreement the Cal-Adapt team therefore developed an enhanced wildfire-projections tool that includes monthly time steps and new projected wildfire probability as described in Dale, 2018. The structure of the Cal-Adapt web application makes it possible to add more data visualizations in the future, if and when wildfire-severity data is generated and made available and funding for development of those additions is also available.

Tool Development

Development of the enhanced wildfire tool was a collaboration between Dr. LeRoy Westerling's research team at UC Merced, which was producing the data, consultant Larry Dale from Larry Dale Natural Resource Associates, and the Cal-Adapt development team. At the request of stakeholders, UC Merced reran their modeling effort to produce results at a monthly time step for inclusion in the tool and available as downloadable data from the website (previously it was at an annual timestep). The Cal-Adapt team developed a beta version of the enhanced tool

and tested it with a group of interested participants from IOUs and other stakeholders. Input from beta testers contributed to the final design of the tool.

The enhanced wildfire tool on Cal-Adapt allows users to explore Fourth Assessment wildfire-scenario projections from UC Merced for area burned and estimated decadal wildfire probabilities for California. The wildfire-scenario projections used a statistical model based on historical data of climate, vegetation, population density, and fire history, coupled with regionally downscaled LOCA climate projections (Westerling, 2018). Projected data is available for California's four priority GCMs and for two possible emissions scenarios (representative concentration pathways 4.5 and 8.5). Data were initially presented in 6km x 6km grid cells and users can aggregate data by other boundary layers like counties or watersheds.

The Annual or Monthly Average Area Burned data show users if wildfire is likely to increase. These projections are most robust for the Sierra Nevada, given the model inputs. As seen in recent years, however, much of California can expect an increased risk of wildfire with a wildfire season that starts earlier, runs longer, and has more extreme fire events. A map animation (Figure 4) allows users to visualize changing wildfire projections through 2100.

The Decadal Wildfire Probability dataset was developed from the UC Merced wildfire simulations by the Cal-Adapt team following the methodology described in Dale et al., 2018. The wildfire data were converted to probability by detecting the presence of a wildfire with a grid cell in each simulation, then integrating those simulations to create monthly and yearly wildfire probabilities for each cell. These data were then aggregated to highlight the probability of occurrence of one or more fires in a grid cell during a decade.

It is important to note that locations outside the combined fire state and federal protection responsibility areas were excluded from wildfire simulations produced for California's Fourth Climate Change Assessment. These "No Data" areas are generally in areas that have been converted to intensive human use, such as urban and agricultural areas.

Figure 4: Wildfire Data Visualization

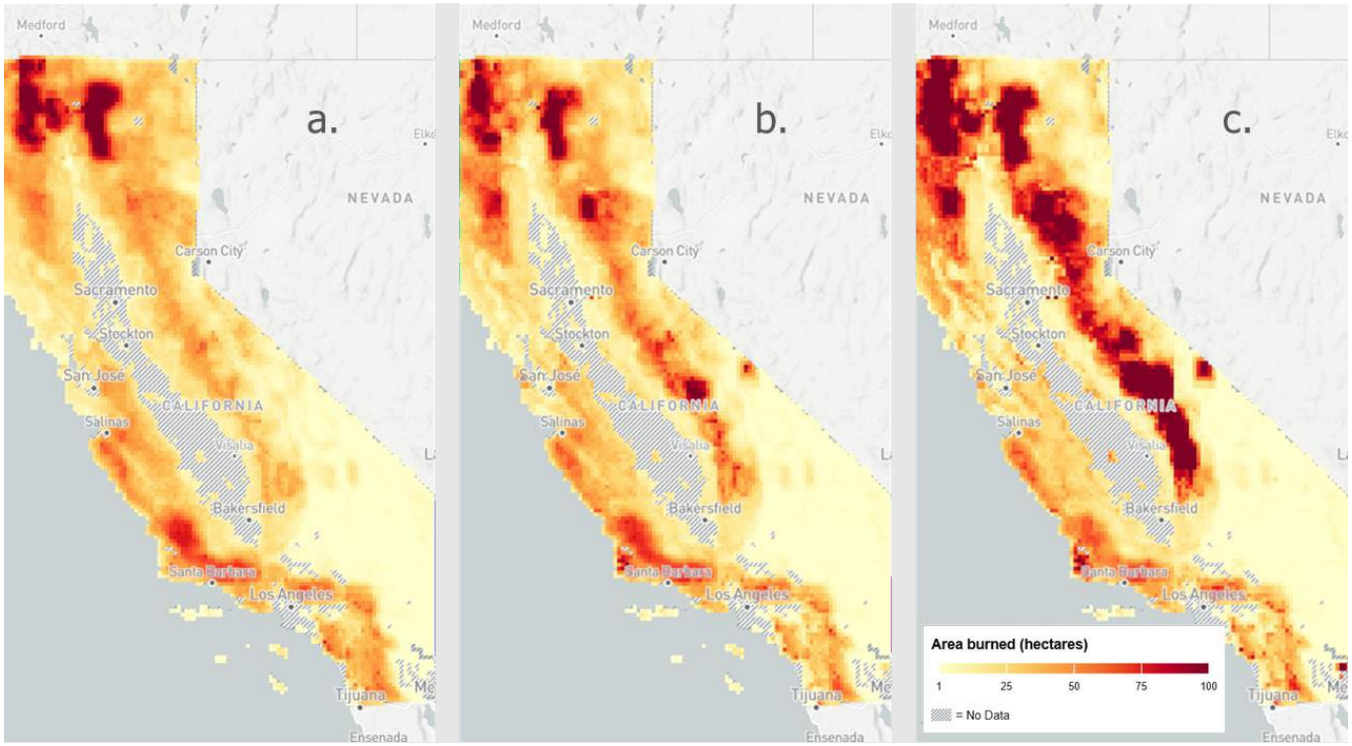

Figure 4: An example of the map animation viewer in the wildfire tool is shown. These maps represent a time series view of Modeled Annual Area Burned for the HadGEM2-ES Global Climate Model under a high-emissions scenario, RCP 8.5. a) is a map view of the 2000-2009 decadal average time step, and b) shows the 2050-2059 decadal average time step, and c) shows the 2090-2099 decadal average time step.

Source: https://cal-adapt.org

Outreach and Education

The Cal-Adapt team organized a webinar entitled "Wildfire Projections under a Changing Climate," which was designed to help participants learn more about Fourth Assessment wildfire projections and work in progress under the Pyregence Consortium to support California's Fifth Climate Change Assessment (EPC-18-026). Webinar speakers included LeRoy Westerling from UC Merced, Nancy Thomas from Cal-Adapt, Owen Doherty from Eagle Rock Analytics, and David Saah, who represented the Pyregence Consortium. The webinar explored how wildfire projections are created, how they should and should not be interpreted, and how projection and modeling methods are being updated for California's Fifth Climate Change Assessment (Fifth Assessment).

To start the webinar, Dr. Leroy Westerling offered an overview of wildfire modeling techniques, particularly those that contributed to California's Fourth Climate Change Assessment. Following are some of the presentation's highlights:

- Wildfire modeling and projection must take into account a suite of environmental and social variables like land use scenarios, forest-management practices, climate change projections, topography, vegetation patterns, ignition causes, and historic fire occurrences.

- Annual area burned and extreme wildfire event frequency are both projected to increase in California.
- Much of this increase is projected to occur in the Sierra Nevada, particularly in the northern parts of the state.
- Wildfire in California will worsen if tree mortality, dead heavy fuels, and biomass continue to accumulate.
- Fuels treatment can potentially mitigate wildfire frequency, extent, and severity.
- Wildfire modeling is more complicated by the potential for simultaneous stressors such as prolonged drought and an extended, intense wildfire season.

The Cal-Adapt team presented the features and functionality of the enhanced Wildfire tool on the website, including both projected area burned and decadal wildfire probability. A representative from ERA introduced best practices for working with wildfire projections and other climate change data, including uncertainty. Key recommendations included:

- Considering more than one data point (both spatially and temporally).
- Looking at climate change data aggregated over longer periods of time, like 30-year time windows rather than single years.
- Including as many climate model runs as feasible to capture the full range of projected outcomes and to assess overall trends.
- Comparing model projections to modeled historical data.

The final webinar speaker was David Saah, who introduced the Pyregence Consortium and the wildfire modeling and process that will support the Fifth Assessment. Wildfire modeling for the Fifth Assessment will incorporate the newest science in modeling and management. Outputs will include projections for area burned as well as smoke emissions (particulate matter 2.5).

Sea-Level Rise Tools

As part of this research two tools enabling users to explore potential sea-level rise and coastal flooding, showcasing multiple datasets developed under California's Fourth Climate Change Assessments, were developed. A data-visualization tool using two hourly SLR datasets calculating probabilistic SLR projections as a function of time and emissions scenario (Pierce et al., 2018; Griggs et al., 2017) was developed. In addition, the "Sea Level Rise – Coastal Inundation Scenarios" tool allows users to explore two different Fourth Assessment models within the same viewer: the Hourly Projections of Sea-Level tool and the Sea-Level Rise — Coastal Inundation Scenarios tool.

Hourly Projections of Sea-Level Tool

The Hourly Projections of Sea-Level tool allows users to explore hourly sea-level projections at one of nine selected tide-gauge locations along the California coast (Crescent City, La Jolla, Los Angeles, Monterey, Point Arena, Point Reyes, Port San Luis, San Francisco, Santa Barbara). Hourly sea-level data include contributions from astronomical tides, regional and

local weather influences, shorter-period climate fluctuations (for example, El Niño and other climate patterns), and long-term (decade to century timescale) changes in regional sea levels (Pierce et al., 2018).

These regional sea-level-rise projections leverage a probabilistic framework originally developed by Kopp et al., 2014. The probabilistic framework is helpful because despite substantial advances in the science of sea-level rise, substantial uncertainty remains in mid- and late-century projections of sea levels. Probabilistic sea-level-rise projections provide a range of possible outcomes in a framework that enables decision makers to choose appropriate numbers for their levels of risk tolerance.

The data visualization as shown in Figure 5 was developed in close collaboration with the CEC and shows the projected fraction of a year when sea level is above a threshold (either user defined or the Historical Maximum value): in the 50th percentile, 95th percentile, and 99.9th percentile sea-level-rise scenarios (Pierce et al., 2018).

Figure 5: Hourly Projections of Sea Level

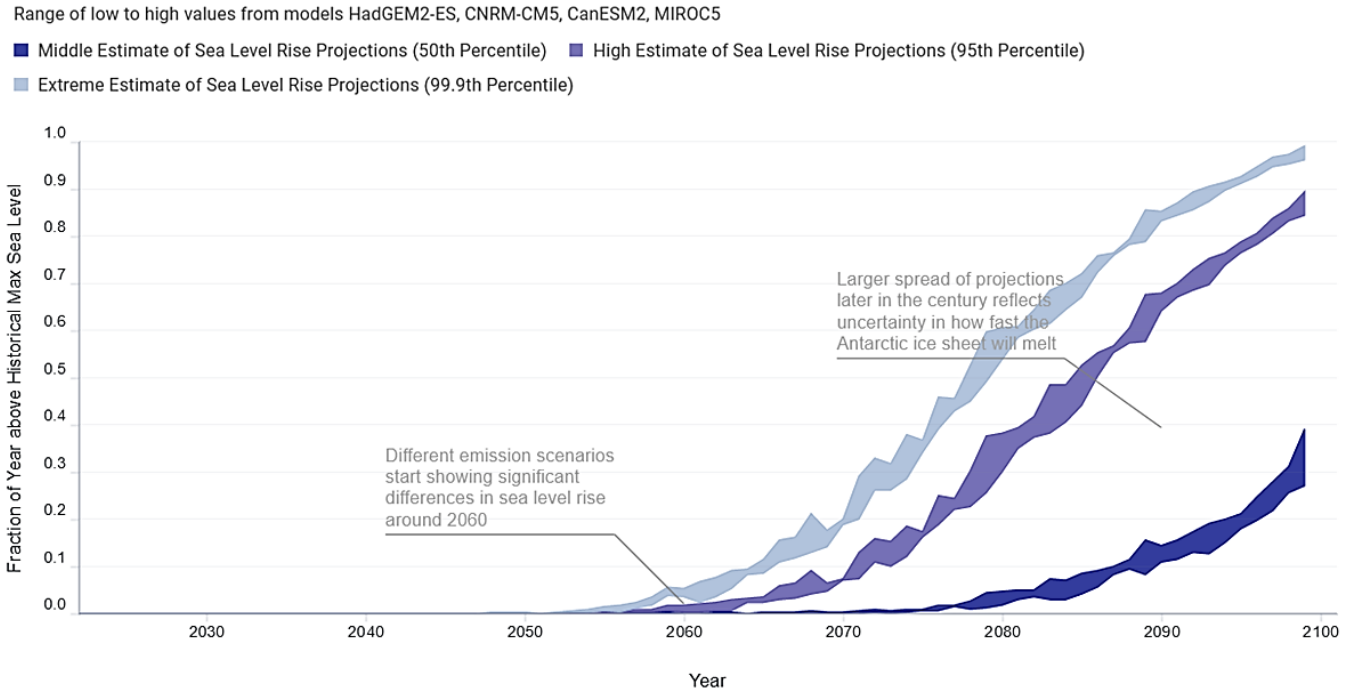

Figure 5 shows the projected fraction of year with sea levels above 170cm (5.6 ft) at the San Francisco tide gauge station under the RCP 8.5 greenhouse-gas emission scenario where emissions continue to rise strongly through 2050 and plateau around 2100. The source data is from California's Fourth Climate Change Assessment.

Source: https://cal-adapt.org

Two sets of probabilistic sea-level rise projections for California were generated for RCP 4.5 and RCP 8.5 greenhouse-gas emission scenarios, including hourly sea-level projections generated for the Fourth Assessment and hourly sea-level projections generated for the California Ocean Protection Council. The results of both datasets can be explored within the tool. Both sets of projections incorporate estimates of components that contribute to global and regional sea-level rise such as thermal expansion of seawater, glacier ice melt, and glacial

isostatic adjustments. However, the Fourth Assessment projections also incorporate relatively recent (DeConto and Pollard, 2016) scientific findings on the potential for rapid demise of the West Antarctic Ice Sheet, which could dramatically accelerate sea-level rise in the latter decades of this century. Sea-level rise scenarios presented include the 50th percentile (middle estimate), 95th percentile (high estimate), and 99.9th percentile (extreme estimate).

Sea-Level Rise – Coastal Inundation Scenarios Tool

The Sea Level Rise - Coastal Inundation Scenarios tool explores projected water levels associated with SLR and a near 100-year storm scenario along the California coast and in San Francisco Bay, from two different models: CalFloD3D-TFS and Coastal Storm Modeling System (CoSMoS) (Radke et al., 2018; Barnard et al., 2019). This tool allows users to better identify SLR datasets available in their regions and improve understanding of various model results based on factors such as spatial resolution and individual model dynamics. An additional focus of the tool was to improve access to the different models that go into the data visualization so that users can access and download the highest-resolution data available for their respective needs.

Global models indicate that California will experience substantial sea-level rise during this century. The exact magnitude of the SLR depends on factors including global emissions, the rate at which oceans absorb heat, melting rates and movement of land-based ice sheets, and local coastal land subsidence or uplift. This tool presents a subset of data from two of several SLR models available for California, which were (partially) funded by the Fourth Assessment. These models (CalFloD3D-TFS and CoSMoS) include SLR and storm inundation modeling. With the inclusion of time and physical processes, these dynamic models give more realistic inundation simulations than static models (for example, the bathtub and pathway models).

Users can explore coastal inundation scenarios associated with SLR and a near 100-year storm scenario along the California coast and San Francisco Bay from CoSMoS and CalFloD3D-TFS for two time periods: near term (2020–2040) and end of century (2080–2100). The CoSMoS model provides flooding products at 2-meter spatial resolution under different return-interval storms, combined with incremental SLR scenarios from 0–3 meters (0–9.8 feet). The CalFloD3D-TFS model provides flooding datasets for combinations of two primary RCP scenarios, four priority climate models, and three probabilistic SLR (50th, 95th, 99.9th percentiles) values for five planning horizons. In addition, the CalFloD3D-TFS includes outputs with two spatial resolutions for different regions of the state. The inundation scenarios from the 50-meter resolution CalFloD3D-TFS model are available for the entire California coastline and San Francisco Bay. The 5-meter resolution CalFloD3D-TFS model uses more detailed topography, bathymetry, and building footprints and is available for some areas along the coast. Details are described in Radke et al., 2018.

For this tool, the CoSMoS flooding datasets for the 100-year-return interval and incremental SLR scenarios were cross-walked with the CalFloD3D-TFS datasets for two planning horizons (2020–2040 and 2080–2100) based on maximum water level at the corresponding tide gauge locations during flood events. This crosswalk allowed model results to represent similar scenarios that could be displayed within a single map viewer (Figure 6). The map viewer shows data coverage extents for the two models at the state and county levels and presents

the available coastal inundation datasets as a user zooms in on the map. The map viewer was also designed to emphasize overlap areas between the different models to showcase where there is agreement despite the different modeling approaches.

Figure 6: Sea-Level Rise – Coastal Inundation Scenarios

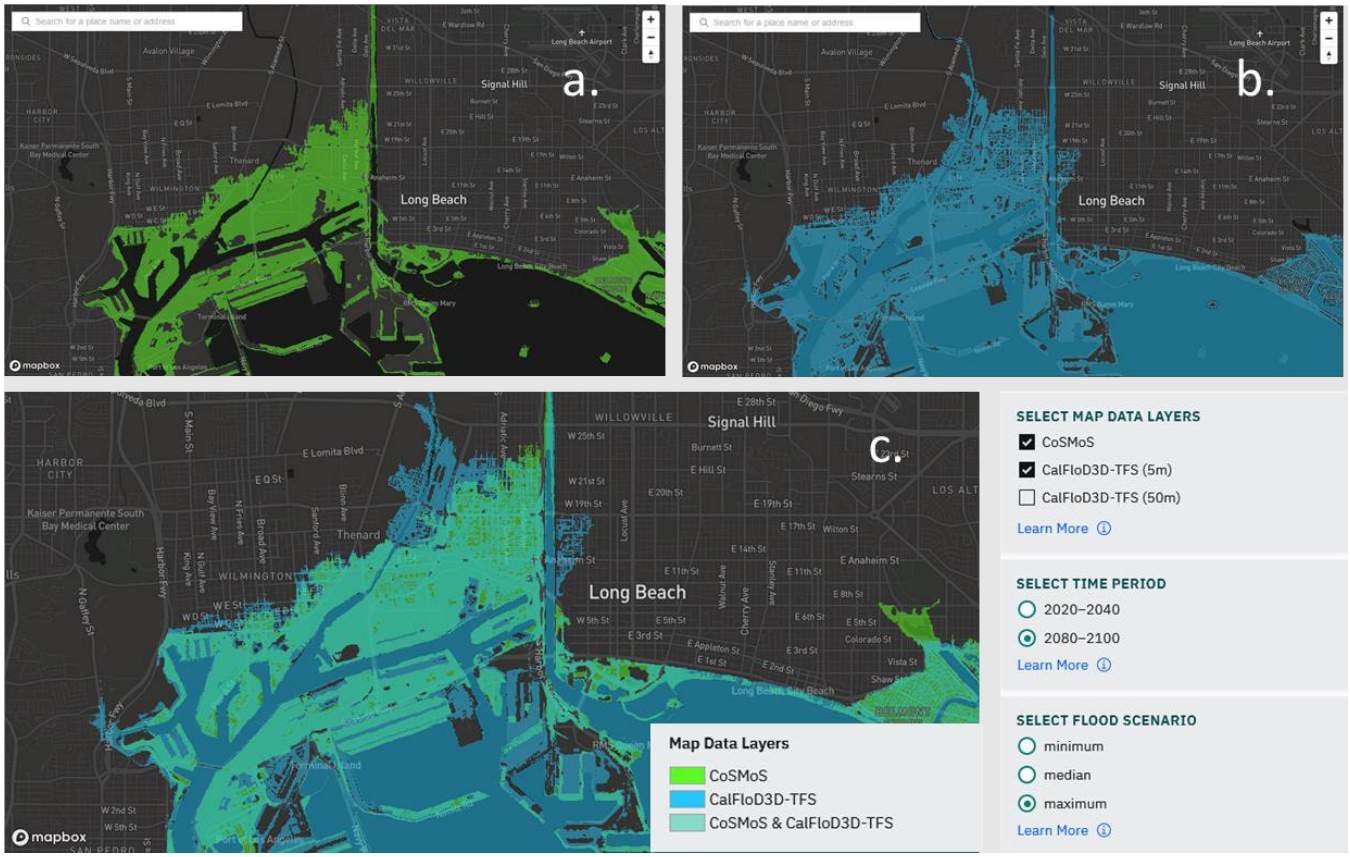

Figure 6 shows the projected water levels associated with SLR and a near 100-year storm scenario for the Long Beach area for both CalFloD3D-TFS and CoSMoS models projected to the end-of-century time period (2080–2100) for a maximum SLR scenario. This graphic illustrates how users can visualize the different models: a) shows the inundation levels for the CoSMoS model, b) shows the results of the CalFloD3D-TFS 5 m model, and c) shows both models and the areas of agreement (overlay).

Source: https://cal-adapt.org

SLR Data Sources

The Coastal Storm Modeling System (CoSMoS) is a modeling approach developed by the U.S. Geological Survey that projects coastal flooding and shoreline change (sandy beach change and cliff retreat) due to SLR and coastal storms driven by climate change. CoSMoS was designed to understand the present-day and future vulnerability of the coast in support of federal and state climate change guidance, local planning, and emergency response. Cal-Adapt presents a subset of the CoSMoS data products within this tool. More details on CoSMoS, its use of multiple component models, and additional model outputs from flooding and erosion are available at *Our Coast Our Future* (https://ourcoastourfuture.org/).

The CalFloD3D-TFS model assesses potential coastal flooding exposure to areas of interest to the state's transportation fuel sector over five 20-year planning horizons and Fourth

Assessment scenarios using a 3Di hydrodynamic model during extremely high sea-level events (72-hour storm event). Due to the inclusion of aboveground objects such as buildings and levees, CalFloD-3D shows detailed land surface details. Details are described in Radke et al., 2018. A statewide dataset at 50-meters spatial resolution is the output of regional-scale modeling. A local scale model using a 5-meter surface model containing more detailed topography, bathymetry, and building footprints is available for some areas along the coast.

Extreme Weather Tool Base on Historical Weather Station Data

A new tool was developed that allows users to explore extreme weather — specifically, temperature and wind speed — for past weather and present-day conditions, using a quality-controlled dataset for historical hourly weather observations, curated for use by the energy sector for 38 weather stations across California. Unlike other Cal-Adapt tools, the Extreme Weather tool presents near real-time weather information rather than projected climate data (Figure 7). This project funded the addition of the wind-speed variable to the Extreme Weather tool. The possibility of exploring extreme minimum and maximum temperatures in the tool was funded under a related CEC-funded project PIR-17-012.

The Extreme Weather tool was developed in close collaboration with the CEC and climate scientist Owen Doherty (ERA). ERA curated the historical hourly weather observations and included the dataset for download on Cal-Adapt, along with an explanatory guide to aid potential users of the hourly dataset (Doherty and Evan, 2020).

Input Data Sources

The Hourly Observed Historical Data product consists of 39 stations across the state, each with an observation period extending from 1973 to 2022 from the HadISD global record. Stations identified for use in this data product were chosen based on their high-quality temperature data. Due to observing techniques, instrumentation used, and similarities in quality assessment/quality control protocols, it is likely that data for dew point and mean sea level pressure will be of similar quality, though this has not been assessed fully. 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) National Weather Service. The National Weather Service (NWS) is an agency of the federal government that provides weather, water, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas. The Near-Term forecast provided by the NWS focuses on large-scale temperature and precipitation patterns for the next seven days, as shown in Figure 7.

Figure 7: Extreme Weather, Wind Speed

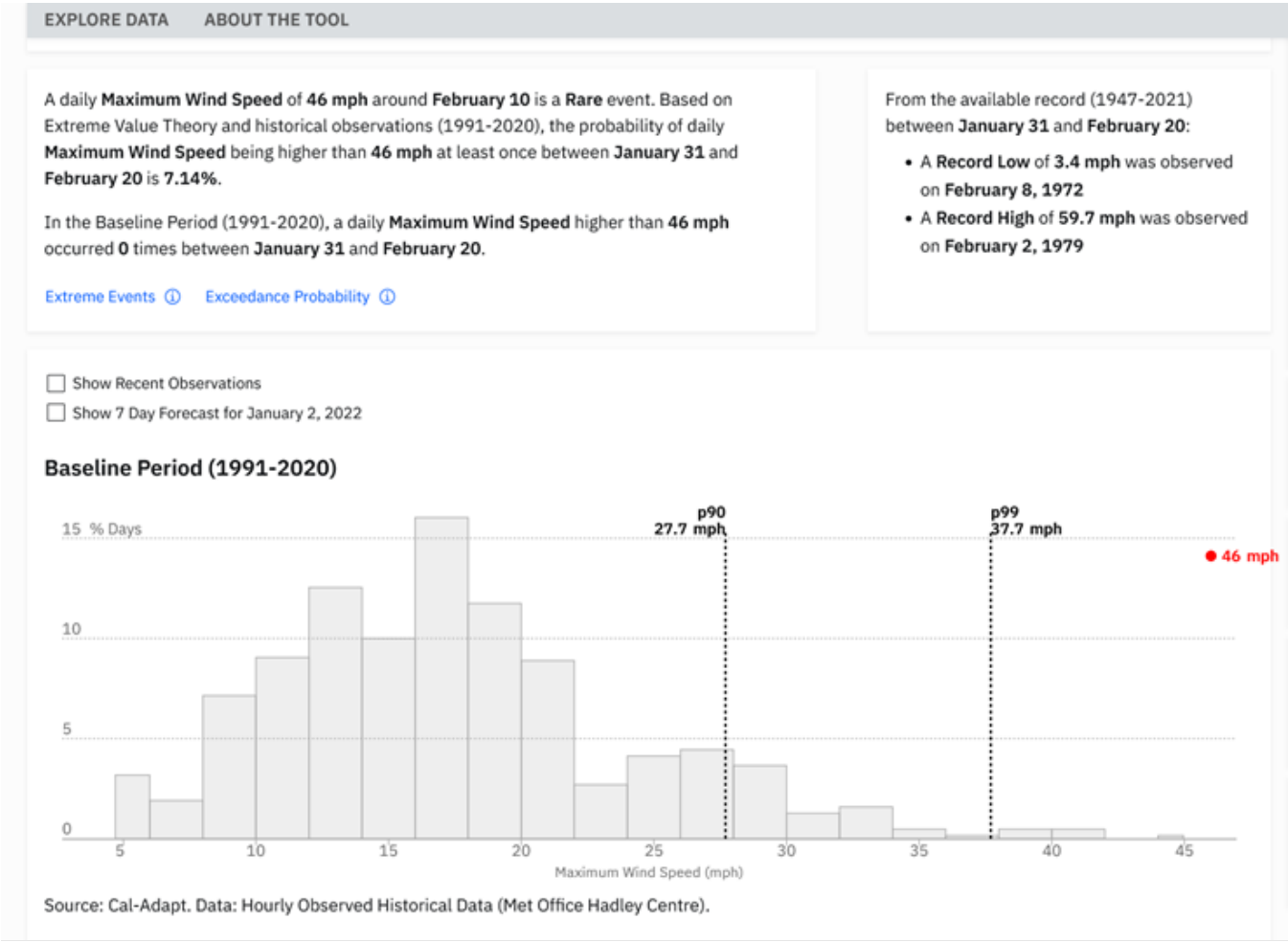

Figure 7 is a screenshot from the new Extreme Weather tool on Cal-Adapt, shown for the maximum wind speed variable at the San Francisco International Airport weather station. Selected data is for February 10. The threshold value of 46 mph is shown here, which matches recorded maximum wind speed on February 10, 2020.

Source: Cal-Adapt

Recent weather observations presented within the Extreme Weather tool are from the NOAA's National Centers for Environmental Information, which is the federal government agency that manages one of the world's largest archives of atmospheric data.[2] 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 Methodology

The extreme value theory tool is a statistical methodology used for describing rare events (Coles, 2001). There are several ways to apply the extreme value theory to weather variables, including fitting a generalized extreme value distribution (GEV) over block maxima (annual

[2] Note: there is usually a time lag of 2 to 3 days in the data provided by National Centers for Environmental Information, so there may not be data for the last 2 to 3 days.

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 block maxima approach.

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

It is important to note that the Extreme Weather tool is designed to inform estimated probabilities of extreme weather events across a broad range of environments and climate zones in California. 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 planning purposes.

CHAPTER 4:
Technology and Knowledge Transfer Activities

Technology Transfer Plan

The Cal-Adapt team developed a technology transfer brief to detail how the web application could best be transferred to the state (or to another entity). Cal-Adapt was built with an open and flexible web architecture that is Cloud-based and runs on AWS. This application environment would allow seamless transfer of ownership if required under future Cal-Adapt funding.

The hosting, management, and ongoing development of the web application would require experience in Python, JavaScript, and some familiarity with AWS. Cal-Adapt is built on top of the Python-based Django web framework, along with supporting libraries such as the Geospatial Data Abstraction Library, 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 website components and transfer plan are briefly listed here and are also included in Appendix B:

- **Amazon Account:** The database, web server, services, and data are hosted on a GIF account. Cal-Adapt runs on a single AWS m4.large EC2 virtual server instance type and uses an 857GB EBS volume for data storage. Monthly costs are flexible and subject to change with data volume and use. To transfer ownership of the Cal-Adapt web application, an image of the production server showing 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 required to run the entire site. This AMI would be shared with the Amazon account tasked with the hosting and management of Cal-Adapt. This AMI could be copied and launched as a new EC2 instance. At that point, the GIF-hosted instance would be deregistered.
- **Source Code:** The GIF team developed the code base that supports the front-end tools and visualizations available on a Cal-Adapt GitHub repository. The front-end data visualization tools featured on Cal-Adapt were designed to allow users to easily interact with and explore key scientific research on climate change, using JavaScript-based libraries. The latest version of the source code could be packaged or cloned from GitHub and provided for future development.
- **Physical Data Server:** The GIF manages and maintains the Cal-Adapt data server, which is the 25-terabyte Ubuntu Linux Dell PowerEdge R730 server that hosts the primary climate research data, including the full suite of 32 global climate models

downscaled for the Fourth Assessment (commonly stored in NetCDF format). This device could be shipped to a new location for ongoing accessibility to California's climate-change research.

- **Domain Name:** The cal-adapt.org domain name ownership can be transferred to a new payment source when required.

Electricity Sector Stakeholder Insights

The stakeholder outreach and engagement efforts described in Chapter 2 provided rich sources of information on the evolving needs of the Cal-Adapt web application's past, current, and potential user bases.

IOU stakeholders emphasized the value they place on the climate projections available through Cal-Adapt being peer reviewed and state sanctioned for use by utilities. Data transparency is critical, particularly when sharing information with local communities. IOUs have shown increased interest and usage of Cal-Adapt data and tools as they relate to CPUC Decision 20-08-046 on climate change adaptation. Additional information gained via the collaborations with IOUs and other electricity-sector stakeholders follows.

Common Use Cases of Cal-Adapt

- IOUs use Cal-Adapt and its underlying data to inform vulnerability assessments (for example, SCE's recent vulnerability assessment).
- Cal-Adapt tools support climate-resilient design and exploration of the climate dimensions of system-hardening projects.
- Cal-Adapt visualization tools are useful for IOU internal education and discussions.
- Climate data on Cal-Adapt is used for comparison with internally created data (for example, wildfire projections).
- Cal-Adapt is used to generate maps and other visuals for presentations and reports to build narratives that describe climate challenges (particularly when presenting to city councils and the general public).
- Data and visualizations from Cal-Adapt are used to support grant funding applications for climate-change adaptation and resilience projects.
- Energy sector consultants, such as ICF, frequently access climate projections and data through Cal-Adapt for specific studies. For example, ICF worked with California utilities to anticipate grid load challenges caused by extreme heat and warm nights accessed through Cal-Adapt and then plan adaptations that accommodate these projected peak energy conditions.

Best Features of Cal-Adapt

Through the stakeholder engagement efforts, many helpful recommendations for improvements to the website were identified that are detailed below. In addition to suggested

improvements, stakeholder feedback helped identify the best features of Cal-Adapt that already make it a useful and actionable tool for adaptation planning:

- An authoritative and trustworthy source of data, sanctioned by the state
- Development team's responsiveness and active support in helping users access data, tools, and visualizations
- Site's general ease of use and aesthetically appealing user interface
- Depth and quality of linked citations and reference materials
- Data access that supports a range of user technical capacity, including scenario and threshold flexibility for advanced users
- Co-location of historical and projected climate data
- Open-source status
- Easy switch and toggle options to quickly explore climate data
- Frequent updates and new tools
- Wealth of data-download options
- Data visualizations that inform and educate users
- Incorporation of statistically robust tool approaches

Key Recommendations for Improvements

Electricity sector stakeholders reported the following gaps and challenges in using Cal-Adapt to support their data needs. Some of the gaps were directly addressed within the Cal-Adapt enhancements under this award while others are still outstanding or cannot yet be reconciled, given the state of the science. These recommendations are synthesized and presented here either as being in this project's scope and addressed as part of this research, or as recommendations for future research or funding, which are detailed in Chapter 5, Conclusions & Recommendations in the Energy-related Recommendations for Future Research section. Additional feedback gained through stakeholder outreach as part of the SGC project that is relevant to local planning agencies, municipalities, and community-based organizations is shown in Appendix C.

In Scope and Addressed Within This Project

- Improved ability to access data through Cal-Adapt, including a greater number of features, user-entered locations, and metadata for downloads.
    - The Data Download tool was built in response to energy stakeholder requests to provide easy access to climate data in both raster and tabular format, without having to write any computer code.
- Information presented to reflect time horizons of interest to energy-sector users in an easy-access format. The 30-year time horizon (approximately mid-century) is most used.
    - This feedback has been addressed with the redesigned "Quick Stats" table that now presents both mid-century and end-of-century time periods as defaults.

- Interest in adding near-term climate forecasts to Cal-Adapt.
    - The new Extreme Weather tool includes near-term temperature and wind speed forecasts from NOAA.
- Update observed data to bring it up to the current day, especially since many energy utilities work with the assumption that seasonal forecasts in the near-term (for example, the next 5 or 10 years) are better informed by recent climate than projected climate.
    - Cal-Adapt now includes access to gridMet data available through the API, recommended as the best-available source data by ERA (see SGC Final Report for additional research details).
- More text-rich explanations of datasets in data tools and in the download process, instead of only a link to a paper.
    - Revised tools include a more thorough description of datasets, along with links to peer-reviewed research.
- Greater attention to extreme events, especially the duration of extreme events (drought, heat waves, fire season).
    - Some requested improvements to extreme events have been addressed within this research while others remain as topics of scientific research and improved climate modeling. New tools allow users to explore how extreme current weather events may be in relation to historical observations. The Extreme Heat tool allows users to enter their own threshold values to explore the frequency and duration of heat waves. The Wildfire tool presents average area projected to burn at both annual and monthly scales. Users can also apply the temporal aggregation of their choosing in the Data Download tool to pre-process seasonal datasets.
- Compounding effects — for example, drought plus extreme heat together, or wildfire season plus extreme precipitation.
    - Partners at ERA led research to determine methods to include compound events on Cal-Adapt, shown in Appendix C. New datasets have been processed and are available through the Data Download tool and API on Cal-Adapt. These datasets are derived from multivariate climate impacts, including Standardized Precipitation-Evaporation Index, which characterizes drought and Keetch-Byram Drought Index as a method of exploring wildfire weather.

Outreach and Training

The Cal-Adapt team has developed more guidance and training materials so that users can better understand and apply the wealth of available data and tools. The outreach and training webinars and workshops were open to the public and are listed. The webinars were carried out to the benefit of the concurrent agreements.

Webinars

Webinars were recorded and available on Cal-Adapt. Attendee numbers ranged from 28–80 participants, depending on the topic:

- Cal-Adapt–Linking Climate Science with Practitioner Need, December 6, 2018
- Introducing the New Extreme Precipitation Tool on Cal-Adapt, March 28, 2019
- Accessing Climate Data Through Cal-Adapt, May 27, 2019
- Introduction to Climate Data, January 23, 2020
- Wildfire Projections Under a Changing Climate, October 20, 2020
- Working With Cal-Adapt Data in ArcGIS Pro and R, November 12, 2020
- Local Climate Change Snapshot Tool, March 11, 2021
- Hands-On Workshop for Working with Cal-Adapt Data in R, October 1, 2021
- Introducing Cal-Adapt's New Look and Features, December 9, 2021

Workshops and Presentations

The Cal-Adapt team's outreach efforts included hosting Cal-Adapt focused-user needs assessment workshops and participation in events hosted by other state and regional entities.

- California Public Utility Commission (CPUC) Workshop, August 6, 2018: the team presented on Cal-Adapt at a workshop on adaptation to climate change OIR (EPIC)
- National Academy of Sciences, August 14–15, 2018: Nancy Thomas (Cal-Adapt) was an invited speaker as part of a workshop on "Making Climate Assessments Work: Learning from California and other Subnational Assessment Efforts" (EPIC)
- California Adaptation Forum, August 27–29, 2018: Thomas was an invited speaker on a panel on "Sea-Level Rise Adaptation: Understanding the Science, Regulatory Frameworks and Resources" (EPIC)
- Fourth Assessment LA Regional workshop, November 2, 2018: presented on Cal-Adapt and held user-needs assessment break-out group to identify user needs around local adaptation planning (EPIC)
- Fourth Assessment Climate Science Symposium for the North Coast Region, December 13–14, 2018: presented on Cal-Adapt and held interactive user needs assessment (EPIC & SGC)
- California Climate Action Team Public Health Workgroup workshop, February 4, 2019: invited to demo Cal-Adapt's Extended Drought tool as part of a session on "Drought/ Climate and Health Data and Tools" (SGC)
- Fourth Assessment Sacramento Valley Regional Climate Symposium, February 6, 2019: presented on Cal-Adapt during the "Adaptation Tools and Resources" session (EPIC & SGC)
- Integrated Climate Adaptation and Resiliency Program Technical Advisory Council meeting, February 22, 2019: took part in a workshop entitled "Linking Vulnerability Assessment Frameworks and Climate tools with Practitioner Needs" (SGC)

- Strategic Growth Council Climate Change Research Symposium, November 5–6, 2019: presented a poster on Cal-Adapt and took part in a panel discussion on climate tools and models (SGC)
- American Geophysical Union Fall Meeting, December 2019: presented on "Cal- Adapt: A Cloud Optimized Web Application for Linking Climate Science to Practitioner Needs" (EPIC & Public Interest Energy Research [PIER])
- Sacramento Cal-Adapt User Needs Assessment workshop, December 5, 2019 (SGC): Cal-Adapt user needs workshop held on-site in Sacramento.
- Hourly Temperature Data on Cal-Adapt workshop, December 18, 2019, hosted by the Energy Commission and attended by GIF team (PIER).
- Southern Central Valley Climate Change Adaptation Workshop, May 27, 2020: Cal-Adapt hosted and facilitated this online workshop to discuss data, tools, and support needed for climate change adaptation and resilience in the southern Central Valley (SGC)
- Sierra Region Climate Change Adaptation Workshop, September 29, 2020: Cal-Adapt, the Office of Planning and Research (OPR), and the Sierra Business Council co-hosted this workshop to introduce participants to Cal-Adapt data and tools and the California Adaptation Planning Guide 2.0 through virtual tours and breakout group discussion (SGC)
- APG 2.0 Phase 2, March 17, 2021: Workshop hosted by OPR which included a presentation on how Cal-Adapt can be used for Adaptation Planning (SGC)
- Southern California Association of Governments (SCAG) Climate Change Projections for Adaptation Planning, March 18, 2021: SCAG hosted workshop, which included an introduction to Cal-Adapt data and tools with a demo of the Local Climate Change Snapshot tool (SGC)
- Partners Advancing Climate Equity (PACE) Tools Demonstration, May 14, 2021: PACE workshop, which included an introduction to Cal-Adapt data and tools with a demo of the Local Climate Change Snapshot tool (SGC)
- San Francisco Bay Area Planning and Urban Research Association (SPUR) Climate Vulnerability Assessment Workshop, June 23, 2021: included hands-on exercises using Cal-Adapt tools to help teach key climate science concepts to participants (SGC)
- SCAG Local Climate Change Snapshot tool, July 27, 2021: SCAG hosted workshop with walk-through of the Local Climate Change Snapshot tool (SGC)

CHAPTER 5:
Conclusions and Recommendations

Advancing the State's Mandated Climate Goals

This research helps achieve the state's statutory energy goals by providing actionable information on climate change consequences to California's populations and infrastructure by enabling users to identify local climate-related impacts such as increased wildfire risk and extreme heat events. A goal of this research was to share climate-change information across state agencies and climate-investment programs that advance California's climate goals. The project team supported interagency coordination to help leverage resources across multiple projects and state agencies, and to ensure that new data and tools developed in Cal-Adapt provide multiple benefits to stakeholders. The climate-data visualizations and guidance materials developed through this research are helping utilities, public agencies, nonprofits, and other community institutions more fully understand the local risks of climate change and more effectively plan for and adapt to future conditions. The following sections present the successes of and challenges ahead for this work.

Successful Use Cases

Cal-Adapt is being used to help organizations plan for climate adaptation and resilience. A few examples of the many ways that Cal-Adapt is being used are outlined here.

Energy Sector Examples

- **California's Investor-Owned Utilities (IOUs):** IOUs have employed Cal-Adapt tools and data to support energy sector resilience efforts, including SDG&E's exploration of climate dimensions of system hardening projects and SCE's work on integrating climate projections into existing planning models. IOUs have shared a number of different ways that they use Cal-Adapt for energy adaptation and resiliency efforts, including:
    - Cal-Adapt and its underlying data help to inform vulnerability assessments (for example SCE's recent vulnerability assessment).
    - Cal-Adapt's tools support climate-resilient design and exploration of climate dimensions of system hardening projects.
    - Cal-Adapt visualization tools facilitate internal education and discussion.
    - Climate data on Cal-Adapt is used to compare to internally created data (for example, wildfire projections).
    - Cal-Adapt is used to generate maps and other visuals in presentations and reports that can help build narratives to describe climate challenges (particularly when presenting to city councils and the general public).

    - Data and visualizations from Cal-Adapt are used to support grant funding applications for climate change adaptation and resilience projects.

- **Demand Analysis Working Group:** The CEC's Demand Analysis group has used Cal-Adapt's Cooling Degree Days/Heating Degree Days tool to identify long-term trends implied by climate change scenarios.
- **Consultants:** ICF has worked with California energy utilities to anticipate grid load challenges caused by extreme heat and warm nights and then plan adaptations that accommodate these projected peak energy conditions. ICF staff also used Cal-Adapt to access spatial wildfire projections, which can be overlaid with critical infrastructure to identify potential points of failure.
- **Grid Infrastructure Planning:** UC Berkeley researchers have used Cal-Adapt to provide climate-relevant input variables to examine how climate trends will impact grid infrastructure (Brockway and Dunn, 2020).
- **Hydropower Generation:** A PhD candidate at UC Davis used Cal-Adapt data in a dissertation that optimized hydropower generation in California under climate change conditions and a transition to renewable energy. Of particular use in this analysis were hydrologic variables (Dogan, 2019).

State Agencies

- **California Department of Public Health:** Used climate risks portrayed by Cal-Adapt as the foundation of Build Resistance Against Climate Effects by preparing local public health departments for projected risks.
- **California Government Operations Agency:** Leveraged Cal-Adapt's publicly available Applications Programming Interface (API) to extract climate variables at multiple locations supporting incorporation of adaptation into sustainability roadmaps (Fox et al., 2018).
- **California Natural Resource Agency:** Incorporated data and content from Cal-Adapt within the California Nature online Geographic Information portal as part of California's 30x30 Initiative, as seen in the Climate Explorer story map.
- **State Water Resources Control Board:** Used Cal-Adapt's Stream Flow tool to examine the timing and nature of runoff projected at end-of-century in a report *Recommendations for an Effective Water Rights Response to Climate Change.*

Local Agencies, Municipalities, and Communities

Municipal staff, consultants, and regional climate collaboratives that provide technical assistance often use Cal-Adapt to generate maps and other visuals for presentations, reports, and grant applications (particularly when presenting to city councils and the general public in

meetings). Users report that figures effectively demonstrate/quantify trends and create a sense of urgency.

- **City of Fresno:** Staff at the city of Fresno used data and visualizations from Cal-Adapt to support grant funding applications for climate change adaptation and resilience projects. Recent applications have focused on urban greening and transportation infrastructure improvements. Cal-Adapt data on projected temperature, extreme heat, and precipitation changes have been used to build narratives that describe the challenges Fresno faces and how the city is planning for these conditions.

  An example of how Fresno has used Cal-Adapt in vulnerability assessments can be found in a workshop presentation entitled *Fresno COG Transportation Network Vulnerability Assessment Public Workshop*, June 2019.

- **Climate Resolve:** Non-profit Climate Resolve and its partners have been working with Los Angeles metro-area governments to study urban-heat-island projections and heat-mitigation strategies. Temperature data from Cal-Adapt has been useful in this work, though it can be difficult to translate standard temperature data to urban heat estimates, which can be magnified by pavement and lack of natural cooling.

- **Sierra Business Council:** The Sierra Climate Adaptation and Mitigation Partnership is using data from Cal-Adapt to inform the Sierra Nevada Climate Vulnerability Assessment, which is designed to help Sierra Nevada communities prepare for climate change. This project is a partnership with stakeholders throughout the 22 counties encompassing the Sierra Nevada.

Research and Education

- **California State University Chico (CSUC):** Mark Stemen, Professor of Geography at Chico State University, uses Cal-Adapt in the classroom to teach climate planning and adaptation (Stemen, 2021).

- **California Naturalist Program:** Cal-Adapt has been used as an educational tool for the UC California Naturalist Program and Climate Stewards to learn about climate change and impacts facing California.

- **Agriculture:** Cal-Adapt has been used to create graphics detailing climate change trends in a review paper on impacts to California's agricultural sector published in the Agronomy (Pathak et al., 2018).

- **Groundwater Storage:** A California-based research team has used Cal-Adapt precipitation data to inform projections for groundwater storage in the Central Valley from 2015 to 2050 (Massoud et al., 2018).

- **Hydrologic Cycles:** Researchers from San Diego State University have used down-scaled hydrologic data provided by Cal-Adapt to model changes to the hydrologic cycles for urban Southern California areas driven by climate change, urbanization, and wildfire (Mikesell and Kinoshita, 2019).

Ongoing Challenges

The main takeaway from the extensive stakeholder outreach is that many users and potential users want more guidance and instruction about how to use and understand climate data. Users, including IOUs and other electricity sector stakeholders, look to the state for direct guidance on how to best use climate data for their own vulnerability assessments and adaptation plans. This may occasionally result in a mismatch between what utilities want and what Cal-Adapt actually provides.

Users consistently reported that Cal-Adapt hosts most of the information that users think they need for climate change adaptation planning, but users don't know how to format or apply the information presented on Cal-Adapt for their own planning processes.

Determining appropriate climate change analysis parameters (for example, time horizons, emissions scenarios, GCMs, climate-change indicators, and model ensembles) to use in vulnerability assessments or resilience planning is challenging. Many Cal-Adapt users reported understanding that such choices are specific to location and context, but at the same time, additional (and even prescriptive) guidance would be helpful. Stakeholders consistently reported that additional guidance materials on how to use Cal-Adapt's data and tools, and how to fit that data into their own workflows should be a focus of future state climate adaptation capacity building efforts.

An additional challenge identified was that differences in agency focus and data policies limited the Cal-Adapt team's ability to address user concerns. For example, many agencies want to be able to summarize climate variables at the county level for all tools, while CEC-funded climate scientists have, in some cases, recommended aggregation to finer scales for certain climate variables such as extreme heat and precipitation. This recommendation was done to avoid producing summary characterizations of climate change variables that may be misleading (for example, to avoid obscuring substantial variability within a larger region, such as a county).

Cal-Adapt has a very broad user base, as the online user survey indicates. Developing visualizations and tools that can meet all of these users' needs is a daunting task and beyond the scope of any single project or state agency.

Leveraging State Climate Resources

Because Cal-Adapt has been successful in meeting user needs and expanding the use of climate data within adaptation planning, the research team was encouraged to learn that the CEC staff, in collaboration with OPR, developed plans to expand Cal-Adapt.

The CEC has articulated a vision for a larger Cal-Adapt Enterprise (CEC, 2021a) that encompasses user-friendly and easy-to-use interactive tools as seen on the Cal-Adapt web-application, as well as a new resource called the Cal-Adapt Analytics Engine. The Analytics Engine, under development through EPIC funds (CEC, 2021b), will be optimized for more technically savvy users who are comfortable writing their own computer code, and it will provide unprecedented computational and technical resources to directly support energy resilience. The Analytics Engine is being built to harness the power of the Cloud to support and

serve higher spatial and temporal resolution CMIP6 data and also to be able to support California's Fifth Climate Change Assessment.

Key Recommendations

Decision makers, policy makers, and members of the public all benefit from distillation of complex scientific information into easy-to-use information that enhances understanding and enables smart investment and planning. The research team identified several areas for continued development of the Cal-Adapt web application and the larger Cal-Adapt Enterprise to further support the growing user base.

Energy-related Recommendations for Future Research

Energy sector users expressed interest in additional features of Cal-Adapt that would require research products and/or enhanced computational power beyond what is available within the current web architecture. Several of these recommendations will be addressed under research that forms the basis of the Fifth Assessment, including the new Cal-Adapt Analytics Engine project (CEC, 2021b), which will expand the Cal-Adapt Enterprise to provide unprecedented computational and technical resources to directly support energy resilience.

- Additional variables of interest include:
    - Wind (including wind direction and wind gusts)
    - Inland flooding
    - Urban heat islands
- Finer spatial resolution/smaller grid cell.
- Improved historical data, especially along elevation gradients and coastal terrain.
- Connecting climate change on Cal-Adapt with demographic and socioeconomic data to support outreach to vulnerable, low-income communities.
- A build-your-own dashboard option (which would require Cal-Adapt user accounts to save data and charts). For example, a particular user might want to show drought and temperature information side-by-side.
- An "extreme events" tool to see drought plus heat wave together and to see various probabilities. For example, a user might want to explore the projected spread in extreme events at different thresholds and across different model assemblages.
- More guidance on how to work with NetCDF files.
- More explicit connections and guidance between climate data and legislative or legal mandates (for example, decisions that are part of CPUC's Rulemaking 18-04-019).
- A series of IOU-specific workshops or working groups to discuss:
    - What data are hosted on Cal-Adapt, how to access them through the API.

- Co-production conversations on risk assessment frameworks and defining infrastructure vulnerability (would require a regular Cal-Adapt and IOU applied research working group structure than one-off webinars).

General Recommendations That Extend Beyond the Energy Sector

Research results indicated an ongoing need to provide training and guidance to energy and non-energy users alike. Expanding on the mapping features of tools such as the Maps of Projected Change would additionally allow users more flexibility in exploring climate change data in conjunction with their own spatial data layers of interest. For example, it is recommended that Cal-Adapt expand on:

- Education and Outreach to Educate Users on Climate Science
    - Teach users basics of climate science.
    - Train users to incorporate data, tools, and visualizations in their work.
- Capacity to Assess Vulnerability
    - Disadvantaged communities
    - Asset and property-level risk

Several of these unmet challenges are ideally suited to the larger compute power afforded by the Analytics Engine (CEC, 2021b) project. Climate services should be developed that can:

- Guide users to the right data for their needs.
- Produce actionable data and metrics.
- Provide decision making support for users.
- Translate data into impacts.

An important outcome of this research has been a better understanding of how Cal-Adapt can be used to further the state's climate goals and objectives. This report's synthesis of findings can support California's mandated climate resilience and adaptation efforts.

CHAPTER 6:
Benefits to Ratepayers

Helping California Adapt to a Changing Climate

California is a global leader in addressing climate change and developing energy policies that conserve resources, protect the environment, and protect public health and safety. Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016) sets targets to reduce greenhouse gas emissions to 40 percent below 1990 levels by 2030. To meet California's ambitious renewable-energy mandates, energy utilities require information on the potential risks from climate impacts including extreme heat, increased wildfire, and sea-level rise to improve facility planning for siting for new power generation facilities and transmission lines.

Cal-Adapt has been recognized by California's state agencies and is identified in legislative and regulatory policy as a key resource providing easy access and exploration of high-resolution, regionally downscaled climate projections sanctioned by the state to be used in climate adaptation resiliency and planning. For example, Cal-Adapt is named in Senate Bill 379 (Jackson, Chapter 608, Statutes of 2015) as a state resource to support local hazard mitigation efforts. Cal-Adapt can help energy utilities to prepare for and adapt to climate change by providing critical climate data for IOU energy sector planning, as recognized by the CPUC (CPUC Decision 20-08-046). In addition, the *2019 Integrated Energy Policy Report* (19-IEPR-01) points to the importance of Cal-Adapt as a tool for improved stakeholder engagement to provide better information for infrastructure planning and decision-making to meet the state's 2030 greenhouse gas reduction goals. Other state agency uses of Cal-Adapt can be found in Chapter 5's, State Agencies section.

Through the easy-to-use visualizations and data accessibility on Cal-Adapt, these complex climate datasets are now available to energy-sector stakeholders in a format that is easily understood for current and future electricity and energy infrastructure development. With this information IOUs, state agencies, local planners, resource managers, and communities will be better prepared to safeguard vulnerable populations and important assets.

Greater Reliability and Energy Security

California's energy infrastructure is vulnerable to a variety of weather and climate-related events. However, in the context of a changing climate, historical records do not suffice to support effective planning and risk management. The energy sector must be prepared to contend with a future climate that is different from what is experienced today or has been experienced in the past. Stakeholders involved in electricity system management and planning must therefore have timely access to suitable and peer-reviewed data on projected climate and weather-related risks in a form that is easy to understand and amenable to decision-support.

Increased Safety and Public Health

California's populations, now and in the future, benefit from safe and reliable electricity. A critical facet of the energy sector is its ability to protect ratepayers from service interruptions and from larger service failures that may occur from climate-related events such as heat waves or sea-level rise. By providing a resource for high-quality, peer-reviewed climate data that can serve as a basis for energy sector planning, the enhancements to the Cal-Adapt web application achieved via this research support energy sector preparedness to safeguard locations at risk from extreme climate-related events.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AGU	American Geophysical Union
AMI	Amazon Machine Image
API	application programming interface
AWS	Amazon Web Services
CEC	California Energy Commission
CHAT	California Heat Assessment Tool
CMIP5	Coupled Model Intercomparison Project Phase 5: using a suite of General Circulation Models, CMIP5 provides a standard set of climate change projections and model experiments that are aligned with the IPCC's Fifth Assessment Report.
CMIP6	Coupled Model Intercomparison Project Phase 6
CNRA	California Natural Resources Agency
CoSMoS	Coastal Storm Modeling System
CPUC	California Public Utilities Commission
CSUC	California State University Chico
EC2	elastic compute cloud
EPIC	Electric Program Investment Charge
ERA	Eagle Rock Analytics
Fourth Assessment	California's Fourth Climate Change Assessment
Fifth Assessment	California's (forthcoming) Fifth Climate Change Assessment
GCM	Global Climate Models
GEV	generalized extreme value distribution
GIF	UC Berkeley's Geospatial Innovation Facility
GIS	geographic information system
HadISD	Hadley Centre's Integrated Surface Database
ICARP	Integrated Climate Adaptation and Resiliency Program
IGIS	Informatics and GIS Program
IOU	investor-owned utility
IRB	Institutional Review Board
KBDI	Keetch-Byram Drought Index
LCSS	Local Climate Change Snapshot

Term	Definition
LOCA	Localized Constructed Analogs: a method for statistically downscaling climate model simulations of daily temperature and precipitation over western United States.
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OPR	Office of Planning and Research
PACE	Partners Advancing Climate Equity
PG&E	Pacific Gas and Electric
PIER	Public Interest Energy Research
RCP	Representative Concentration Pathway
REST	representational state transfer
SCAG	Southern California Association of Governments
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SGC	Strategic Growth Council
SLR	sea level rise
SPEI	Standardized Precipitation-Evapotranspiration Index
SPUR	San Francisco Bay Area Planning and Urban Research Association
TAC	technical advisory committee
TFS	transportation fuel sector
UC	University of California

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