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ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Visualizing Climate-Related Risks to the Electricity Sector Using Cal-Adapt

Gavin Newsom, Governor

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The design and functionality of Cal-Adapt were developed with the insight from a variety of beta testers and technical advisory committee members, who provided valuable feedback throughout several iterations of updates. These individuals represent scientists and climate experts, planners and technicians, and leaders in development of local climate policy, as well as interested participants from the general public. The authors gratefully thank the current and past members of the Advisory Committee, whose thoughts and vision have greatly improved the climate data visualizations on Cal-Adapt.

Cal-Adapt has greatly benefited from the contributions of many dedicated staff members at the University of California's Geospatial Innovation Facility over the development of the website, and the authors acknowledge the efforts of Eric Lehmer, Kevin Koy, Falk Schuetzenmeister, Mark O'Connor, Sarah Van Vart, and Ankita Goyal.

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 CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & 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.

Visualizing Climate-Related Risks to the Electricity System Using Cal-Adapt is the final report for the Cal-Adapt project (Contract Number EPC-15-008) conducted by the Geospatial Innovation Facility. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

Energy-sector operations, management, and planning require rigorous information on projected climate and weather-related risks to maintain safe, reliable, and affordable energy for California's current and future populations. California's energy infrastructure — including electric transmission and distribution lines, thermal power plants and substations, and natural gas facilities and pipelines — is vulnerable to climate-related impacts and extreme weather that may differ considerably from historical records because of climatic changes. Research supported by the State of California has provided high-quality, peer-reviewed data and scientific analysis of climate-related factors that impact the energy sector, including sea-level rise, storms, wildfire, and heat waves. These data are free to the public through the Cal-Adapt web platform (https://cal-adapt.org), developed to provide stakeholders with information regarding climate-related risks through interactive, compelling, and useful visualizations and tools.

The University of California, Berkeley's Geospatial Innovation Facility built Cal-Adapt 2.0, which includes updates and enhancements that improve ease of use, information value, visualization tools, and data accessibility. Cal-Adapt offers an open-application programming interface that allows other organizations to access Cal-Adapt climate data and build their own visualizations and planning tools.

Cal-Adapt has made a difference in climate adaptation and policy planning by providing an easy-to-use, freely available tool that can serve as a resource for many climate resilience applications. Although Cal-Adapt is still under development to become an operational decision support tool, California's investor-owned utilities have already used it for applications that leverage data and visualizations from the website. Cal-Adapt has been recognized by California's legislature as a key resource to support local hazard mitigation efforts and has helped California move forward on climate policy by providing a point of access for data adopted by the state for energy sector planning and adaptation guidance.

Keywords: Cal-Adapt, energy sector climate resilience, climate services, climate tools, climate change adaptation, localized constructed analogs (LOCA)

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EXECUTIVE SUMMARY

Background

Electricity sector operations, risk management, and planning require the best available peer-reviewed data on projected climate and weather-related parameters to maintain safe, efficient, and reliable energy for California's current and future populations. California's energy infrastructure, including power plants and transmission lines, is vulnerable to future climate-related risks and extreme weather events that may differ from historical records due to a changing climate. Understanding projected climate-related risks that may cause disruption and energy vulnerability is critical to energy sector resilience and planning. Providing electricity system stakeholders with information through easy-to-use visualizations and tools to support decision making that can identify vulnerable populations and infrastructure locations at risk from climate-related factors is important for California's energy future.

No known alternative funding sources exist to support climate resilience tool development with the needs of California's electricity sector in mind. The visualizations and tools are freely accessible and were developed under this grant to serve electricity sector stakeholders and California ratepayers.

Project Purpose

Cal-Adapt – the state's resource for exploring climate change research – provides visualizations of many local climate-related risks that are critical to California's energy system, including projected changes in temperature, wildfire risk, snowpack, and sea level rise. Cal-Adapt is an extensive, interactive, publicly accessible web-based visualization tool developed at University of California, Berkeley Geospatial Innovation Facility with the support and oversight of the California Energy Commission (CEC). The tool enables decision makers to turn research results and climate projections into effective adaptation decisions and policies.

The project goal was to build on the Cal-Adapt platform through advanced, easy-to-use, and flexible data services; innovative web-based visualizations; custom analytical tools; and targeted outreach. These enhancements provide critical data on the changing climate and related effects on California's energy infrastructure. The Cal-Adapt team collaborated closely with the CEC and energy stakeholders, including investor-owned utilities (IOUs) and the California Independent System Operator, to develop Cal-Adapt 2.0 with enhanced targeted visualizations and tools for improved support for decisions around climate-related risks. Targeted visualization tools depict climate-related risks from various stressors on electricity infrastructure, enabling better resilience and reliability planning.

Project Approach

The Geospatial Innovation Facility created a website that solicited feedback from stakeholders throughout development of Cal-Adapt 2.0. Regular biweekly discussions with the CEC and biannual discussions with the technical advisory committee provided critical direction during tool development and beta testing. The team discussed initial design for new tools and features with the CEC and used its input to build a beta version of the web tool, which was shared with stakeholders for review and comment. The development team used its feedback on the preliminary visualizations and tools to refine the design.

Current and past technical advisory committee members included scientists and climate experts, planners and technicians, and leaders in developing local climate policy. Members under this funding included Pacific Gas and Electric Company (PG&E, Southern California Edison (SoCal Edison), and San Diego Gas & Electric Company (SDG&E), as well as representatives from local governments, climate consultants, and state agencies. In addition to regular communication with the CEC and the technical advisory committee, this grant included outreach to energy sector stakeholders through a user needs-assessment workshop, onsite meetings, and individual communications to introduce stakeholders to Cal-Adapt 2.0 and encourage them to identify additional features and tools that could increase site usability.

A key area planned for future enhancements to Cal-Adapt is to expand stakeholder engagement. Through this grant, the technical advisory committee identified user needs as did public workshops and targeted discussions with investor-owned utilities (IOUs). While these methods were useful, the highest level of direct feedback on user needs has come through on-site meetings and conference calls with IOUs. For future work, this type of stakeholder engagement is being expanded to include on-site meetings at each IOU. Quarterly public webinars are being added to present new tools and datasets and gather feedback earlier in the development stage. Further outreach will include additional user workshops and an on-line survey about site usability to identify gaps in design and function.

Project Results

Perhaps the most important sign of project success has been how much Cal-Adapt has been embraced as a tool to examine projected climate change impacts by the energy sector and policy makers in the state legislature. Cal-Adapt has already made a difference in adaptation practice and policy planning in California. Because it allows users to readily explore local climate-related risks at locations of interest, Cal-Adapt can communicate climate change in a way that is accessible to a variety of users. Beyond the energy sector, Cal-Adapt is also being used by public health agencies, water resource managers, local governments, educators, and many others to examine projected climate futures and advance resiliency.

Cal-Adapt's ability to provide a set of common climate scenarios that have been accepted by the state is of primary importance to stakeholders, so that the energy sector can move forward with research and planning. The need for common scenarios was expressed by the *2016 Integrated Energy Policy Report Update*, which assesses trends and challenges facing the energy sector and provides policy recommendations.

California's climate change assessments contribute to the scientific foundation for understanding the state's vulnerability to climate change effects and directly inform state

policies, plans, and programs to safeguard California from climate change. Cal-Adapt supports California's Fourth Climate Change Assessment prepared in 2018 by offering easy-to-access explorations of possible climate futures through the recommended climate scenarios. Next-generation enhancements planned for Cal-Adapt will integrate additional research results from California's Fourth Climate Change Assessment and other climate-related data into tools that energy sector stakeholders can use to evaluate climate-related risks and vulnerabilities to California's energy infrastructure. The support capability of Cal-Adapt will be expanded by incorporating a distributed cloud-processing infrastructure into the existing web architecture of the tool, enabling increased computation power and advanced user-defined variables for data processing, visualization, and downloads.

Technology/Knowledge Transfer

In addition to regular communication with the CEC and the technical advisory committee, outreach to energy sector stakeholders under this grant included workshops, onsite meetings, and individual communication to introduce users to Cal-Adapt 2.0 and encourage users to participate in identifying additional features and tools that would increase site usability. Along with these efforts, the Cal-Adapt team has worked to introduce potential new users to the web platform, where tools and data are freely available. Outreach to the public and a broad range of potential climate data users have been made through presentations and live demonstrations of the features of Cal-Adapt. Presentations on Cal-Adapt have been made at state and national conferences and workshops.

Benefits to California

California's IOUs have begun to leverage Cal-Adapt climate tools and data to support resilience efforts, such as SDG&E's exploration of the climate dimensions of efforts to reduce the vulnerability of its systems and SoCal Edison's work on integrating climate projections into existing planning models. This research benefits California ratepayers through greater electricity reliability and increased safety by supporting electricity sector planning, management, and adaptation. These benefits result from enhanced Cal-Adapt visualization tools that allow integration of up-to-date, peer-reviewed scientific research on climate-related risk. Cal-Adapt provides a collection of integrated tools on a single website (https://cal-adapt.org) that supports interactive visualization and decision-making with a local and regional focus. These interactive tools allow users to understand the effect of their decisions in planning, develop shared understandings of complex spatial data, and support planners and managers as they plan for reliability and stability of their electricity infrastructures. Such integrated planning can contribute multiple benefits to California's electricity ratepayers by helping stabilize the grid, improve service reliability, and reduce financial losses associated with power outages.

Planned improvements to Cal-Adapt will better address a wider range of impacts, including an expansion of tools related to sea-level rise and wildfires, as well as new datasets and visualizations on extreme storm events, droughts, and other climate factors. An enhanced sea-level rise tool will help energy sector stakeholders consider decision-making and planning under uncertain conditions, providing a central place to reflect on multiple datasets related to risks from rising seas.

CHAPTER 1: Introduction

California's energy infrastructure—including electric transmission and distribution lines, thermal power plants and substations, and facilities and pipelines that store, transmit, and distribute natural gas—is vulnerable to climate-related impacts and extreme weather events that may differ significantly from historical records due to changes in our climate. Understanding potential climate-related threats, such as sea level rise, storms, wildfire, and extreme heat events, is critical to energy sector planning. Research supported by the California Energy Commission has provided high-quality, peer-reviewed data and analysis of many climate-related factors pertaining to the energy sector.

Cal-Adapt, the state's resource for exploring climate change research, provides data and visualizations of many local climate-related risks, including projected changes in sea level rise, wildfire risk, temperature, precipitation, snowpack, and more. Cal-Adapt is a comprehensive, interactive, publicly accessible web-based application developed by UC Berkeley's Geospatial Innovation Facility, with the funding support and advisory oversight of the CEC. The website was initially released to the public in 2011 as an online resource to showcase the innovative climate change research being produced by the scientific community in California, as documented in the 2009 California Climate Adaptation Strategy (Koy et al., 2016).

A revised and updated Cal-Adapt 2.0 was designed and built under this grant (EPC-15-008) in addition to California's Natural Gas Public Interest Energy Research (PIER) funding (500-14-003). Cal-Adapt 2.0 dramatically expands the capacities of the initial version of Cal-Adapt in four main ways: dynamic visualization of new higher-resolution climate projections, improved access to data, more powerful visualizations and tools, and the Cal-Adapt Application Programming Interface (API). A detailed report describing the many new advances of Cal-Adapt 2.0's development has been peer-reviewed and published as part of California's Fourth Climate Change Assessment (Thomas et al., 2018).

This report will point to sections of the Fourth Assessment paper where relevant, and will highlight key developments, particularly user outreach with electricity stakeholders, that add new and as yet unpublished information on Cal-Adapt.

CHAPTER 2:
Project Approach

Cal-Adapt provides stakeholders with actionable information through a combination of locally relevant information, visualization tools, and access to primary data that can help to identify vulnerable populations and infrastructure locations at risk from climate-related factors. Thomas et al., (2018) describes the development of Cal-Adapt 2.0, introduces the new data and features, and provides an overview of the web application's capabilities, as well as examples of how it has been used to aid resilience planning and policy in California. This report will include additional details relating to the electricity sector, particularly in the case of user outreach and engagement.

Web Architecture and API

Cal-Adapt 2.0 is built on a free and open-source web stack, using the Django web framework along with such supporting libraries as the Geospatial Data Abstraction Library (GDAL), NumPy, and Mapnik. The combined web framework allows for fast and dynamic temporal aggregation of time series data and spatial aggregation by different vector boundaries. This underlying structure enables users to interactively explore climate impacts for their specific region of interest.

Climate variables, including maximum temperature, minimum temperature, precipitation, wildfire, and snow water equivalent, are temporally aggregated into annual or monthly summaries and spatially aggregated using either pre-loaded vector boundary datasets (such as counties, climate regions, watersheds, census tracts, legislative districts, and more) or user-input boundary layers in different formats (ESRI shapefile, KML, GeoJSON). Data can also be reduced and downloaded in temporal and/or spatial subsets.

The user interface featured on Cal-Adapt 2.0 has been designed to allow users to easily interact with and explore key scientific research on climate change using modern JavaScript based libraries. Using open source tools, including Leaflet and D3 together, along with components from other libraries, as needed, provides a powerful framework for developing exploratory visualizations where users can explore different datasets and compare multiple scenarios to generate new information and insights.

The Cal-Adapt API has been developed for Cal-Adapt 2.0 and enables programmatic access to the climate data hosted on Cal-Adapt. The API allows developers, researchers, and climate specialists to access only the data they actually need, without having to download the entire dataset. The Cal-Adapt API is built on the Representational State Transfer (REST) framework, which provides a powerful and flexible toolkit for building web APIs. Compared to other forms of web services, the API's main advantages are simplicity, ease of use, and interoperability. An API enables different software applications to communicate effectively with each other by defining a set of requirements for how applications can share data and what actions can be taken, such as directly subsetting the climate data by a private uploaded boundary file.

User Engagement and Outreach

The Geospatial Innovation Facility (GIF) employed a user-centered website development approach to Cal-Adapt 2.0 that solicited feedback from stakeholders throughout the process. Ongoing discussions biweekly with the CEC and biannually with the Technical Advisory Committee (TAC) provided critical direction during tool development and beta testing. Initial design for new tools and features was discussed with the CEC to build a beta version of the web tool, which was shared with stakeholders for review and comment. This iterative development of visualizations and tools allowed the development team to present initial tools to stakeholders, generate feedback, and then refine tool design.

Current and past members of the TAC have included IOUs (PG&E, SoCal Edison, and SDG&E) as well as representatives from local governments, nonprofit groups, climate consultants, and state agencies. TAC members under this grant are:

- Kathleen Ave (Sacramento Municipal Utility District)
- Chris Benjamin (PG&E)
- Jim Blatchford (California Independent System Operator)
- Brian D'Agostino (Sempra Energy, SDG&E)
- Erik DeKok (Ascent Environmental)
- Guido Franco (CEC)
- Michael McCormick (Governor's Office of Planning and Research)
- Kristin Ralff-Douglas (California Public Utilities Commission)
- Kif Scheuer (Local Government Commission)
- Andrew Schwarz (California Department of Water Resources)
- Adam Smith (Southern California Edison)
- Kerry Timmer (Sierra Business Council)
- Megan Walton (Governor's Office of Emergency Services)

In addition to regular communication with the CEC and the TAC, outreach to energy sector stakeholders under this grant has included workshops, on-site meetings, and individual communication to introduce Cal-Adapt 2.0 and to encourage user participation in identifying what additional features and tools would increase site usability. These efforts are described in more detail below.

Integrated Energy Policy Report Workshop (Sacramento, California; August 29, 2017)

CEC Commission Agreement Manager Susan Wilhelm made a presentation on Cal-Adapt at the IEPR workshop held in Sacramento on August 29, 2017. This event was the official launch of the new Cal-Adapt 2.0 website. In advance of this launch, the Cal-Adapt team prepared for switching the beta site to Cal-Adapt.org by publishing new blog entries introducing Cal-Adapt 2.0, including the difference between versions 1.0 and 2.0, a description of the process for selecting the 10 California Department of Water Resources (CDWR) models, and the four priority models. The beta site was transitioned to the main Cal-Adapt.org URL for the official launch.

Cal-Adapt Energy Sector User Needs Assessment Workshop (September 12, 2017)

The GIF and the CEC held a User Needs Assessment Workshop for Energy Sector stakeholders that was open to the public on September 12, 2017 in Sacramento. Participants at the workshop included energy sector stakeholders as well as diverse Cal-Adapt users from such sectors as local planners, academic institutions, state and local government, and nonprofits.

The Cal-Adapt team introduced Cal-Adapt 2.0 and offered a live demonstration of the web application to showcase the new features, tools, and data available through the updated site. After the introduction, workshop attendees separated into smaller break-out groups, designed to gather feedback on the current visualizations and tools, to elicit discussion, and to identify new tools, features, or visualizations that would help to effectively support energy sector climate resilience and adaptation.

These breakout groups were organized into four topics: climate tools; projected wildfire risks; snowpack, streamflow, and other hydrological projections; and the Cal-Adapt API. For each of these groups, facilitators planned some questions and allotted sufficient time for general questions and feedback. Each session began with general information about whether participants had experience using Cal-Adapt and how they used it. Many participants had used Cal-Adapt, and some participants had extensive experience. Prior uses of Cal-Adapt among participants included:

- Providing input for a dozen or more city, regional, and tribal climate change plans
- Providing supporting data for environmental impact reports
- Creating visualizations related to electricity utility vulnerability
- Analyses of how planning decisions, such as siting, play out under multiple scenarios
- Teaching undergraduate classes, where students work on projects for local planning
- As a data source for improving existing tools/analyses
- Pulling data from Cal-Adapt (100-year storm depth)
- Use of Cal-Adapt data and visuals in developing reports (environmental impact statements, climate adaptation plans, local plans) for local governments and clients
- Use of Cal-Adapt to assist the State Water Resources Control Board (SWRCB) in its consideration of climate impacts (The SWRCB regulates water quality and administers water rights.)

Feedback gathered during this workshop has been critical to prioritizing tool development and in planning for the next generation of Cal-Adapt. The full notes from each of these focus groups can be found online at the Cal-Adapt blog. Key highlights from each breakout group have been compiled across the major themes and are included here:

Feedback on Improvements to Existing Tools or Features

- Best practices guidelines for using climate change data and projections are needed to foster appropriate use of Cal-Adapt; for example, when users should look at models separately, when ensemble averages are appropriate, and when a 30-year average is desirable.

    - Additional information to clarify in very simple terms how the projections on Cal-Adapt 2.0 differ from those presented in the original (2011) release would be helpful, especially for those who have already trained staff to use the 2011 release.
- Enable access to climate data for multiple locations simultaneously. A tool to make bulk intersections by points with climate grids would allow users to access multiple points without having to use the API.
    - To more conveniently handle multiple locations, it would be helpful to support uploading spreadsheets (csv or Excel) directly with latitude/longitude columns in addition to the Geodata formats Cal-Adapt supports now, such as shapefile and others.
- In addition to batching of points and polygons, enabling the ability to intersect polylines, such as in road and transmission line networks would be advantageous.
- Users expressed an interest in having an easier method to calculate temporal summaries, such as monthly averages.
- Users sought improvements to Cal-Adapt's presentation of CalEnviroScreen data.
- Disaggregating the component layers of CalEnviroScreen data would be very helpful and participants encouraged Cal-Adapt to incorporate CalEnviroScreen indicator layers related to exposure (including ozone, PM2.5, and diesel particulate matter), environmental effect (such as groundwater threats and impaired water bodies), sensitive populations (including those with asthma and cardiovascular disease), and socioeconomic factors (such as educational attainment, housing burden, and poverty).
    - One commenter questioned the completeness of CalEnviroScreen in the context of assessing climate vulnerability and developing resilience options, but concurred that being able to explore component indicators on Cal-Adapt would address some concerns.
    - A helpful feature to integrate into Cal-Adapt would be the ability to add an additional layer provided by the user, such as for siting new infrastructure projects. Along these lines, interactively drawing the area of interest and highlighting the intersecting pixels for immediate feedback on which cells would be included in the aggregation would be beneficial.

Expanded Visualizations for Current Datasets

- Range of temperatures over 24 hours; also important for elasticity of construction materials
- Ability to view probability of climate variables
- Improvements to Cal-Adapt's new Wildfire tool were discussed in the wildfire breakout session. This session had the added benefit of including the main researcher on the wildfire data, Dr. LeRoy Westerling from UC Merced.
    - An additional chart generated through the monthly data would help users to understand the timing and severity of wildfires throughout the year.
    - In particular, being able to look at fire season length distribution over time, similar to the visualization of extreme heat, was suggested to determine whether

a shift in fire season starting time and length is predicted. Dr. Westerling noted that fire scenarios are based on ignition date rather than control date, so a tool would be more accurate for the start of fire season rather than for the end.

    - Comparison to baseline: a visualization tool similar to the wildfire tool (Fire Risk Map) on the original Cal-Adapt site that looks at the projected increase in potential burn area would be helpful. The earlier Cal-Adapt tool showed the ratio of additional fire risk for an area as compared to the expected burned area for each grid cell.
- Participants expressed interest in a visualization of extreme precipitation events, similar to extreme heat occurrences. In addition, they would like to see what part of precipitation falls as snow versus rain.

New Datasets

- Additional streamflow data are needed. More work and discussion would need to be done to evaluate which locations are priorities for the electricity and other sectors.
- Projections of how climate will affect water supply were requested.
- Data would be beneficial on storm water runoff and damage from flooding.
- Input from DWR, with FEMA and/or U.S. Army Corps of Engineers (USACE) revising 200-year flood plains as potential data layers for Cal-Adapt would help.
- Development of probability distribution functions for all projected climate parameters, similar to how long-term regional sea level rise is being expressed in several California-specific efforts, would be advantageous.
- Local hazard mitigation planning would help to identify and map critical facilities to support Local Hazard Mitigation Planning, such as transmission corridors.
- Integrating existing data related to the heat island effect, such as CalEPA's data quantifying the urban heat island effect index, would be particularly useful in exploring extreme heat events.
- Observed historical wildfire data would be useful on Cal-Adapt; Dr. Westerling noted that there is gridded observed data from 1984 to recent time.
- The inclusion of additional data sets like the urban heat island index, canopy coverage, and CoSMoS sea level rise would be useful in adaptation planning efforts.

Potential Areas for Future Research

- Determine whether existing variable infiltration capacity (VIC) data could be used to explore freeze and thaw cycles, which is relevant for infrastructure maintenance and construction, such as in the transportation sector
- Data portraying risks associated with compounding influences of wildfire/flooding/water quality
- Developing "hot spot" visualizations that aggregate climate-related impacts; would involve substantial further research on how to assess, aggregate, and appropriately represent implications of multiple climate impacts

- Atmospheric rivers: Cal-Adapt already serves daily precipitation data, but visualizes precipitation on the annual scale only. Several participants indicated that visualizations showing projected changes in atmospheric rivers and extreme precipitation events would be very useful.

On-Site Meeting with Pacific Gas and Electric Company (December 6, 2017)

The GIF development team and the CEC facilitated an on-site Cal-Adapt briefing at PG&E. The format provided an excellent opportunity to get direct feedback from energy sector users on the current site and ideas for future development. The meeting included a presentation and live demonstration of Cal-Adapt, with a focus on generating ideas and listening to comments and questions from the PG&E team. Key feedback from that meeting included:

- Discussion over data access and formats, including common use cases for PG&E. The utility typically has geographic information system (GIS) analysts working within their internal GIS system on fast turnaround requests.
    - Difficulty working with Network Common Data Form (NetCDF) data due to the lack of ReadMe or metadata files, such as with UC Merced's wildfire data
    - Helpful to know the expected frequency of data updates or when new datasets become available. Suggested having a "coming soon" feature where users can see what is in the pipeline.
- Open discussion over some of the specific tools and datasets available through Cal-Adapt:
    - Interest in wildfire data, include Westerling's forthcoming work on emissions. PG&E questioned the observed historical data in Westerling's work, which is from MODIS data.
    - Other wildfire data sources to include on Cal-Adapt: California Public Utilities Commission (CPUC) wildfire high-risk map, and RE-AX wildfire model.
    - Interest in "blue sky days," or typical days unaffected by climate extremes, such as baseline sea level rise on non-storm days.
    - Interest in a drought tool; currently using Data Basin for drought indices.

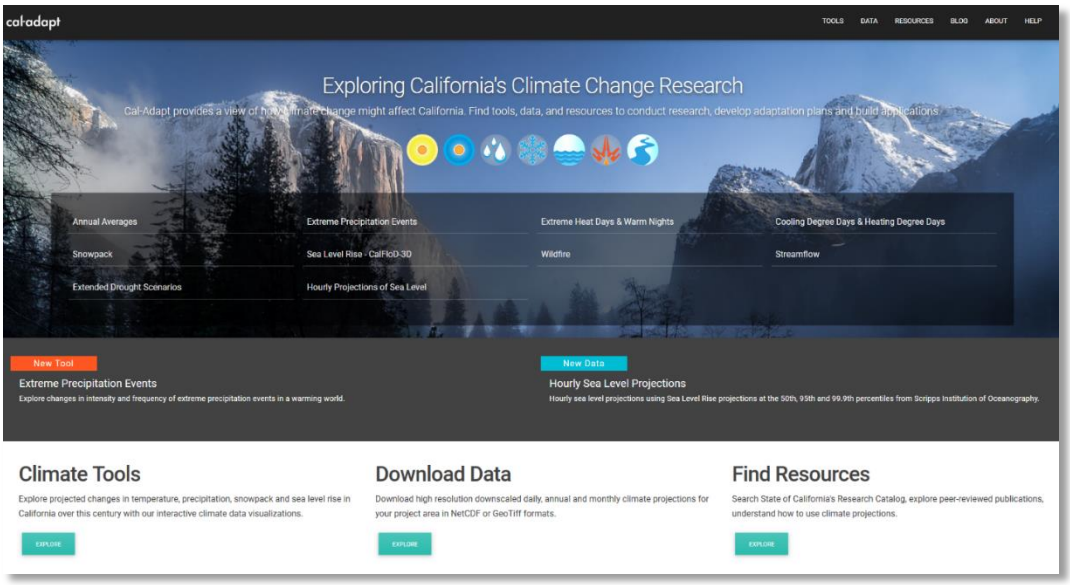
CHAPTER 3:
Project Results

Cal-Adapt 2.0 presents peer-reviewed science on regionally downscaled climate change in California through interactive, graphically compelling, and useful data visualizations. Cal-Adapt directly addresses energy sector needs by providing easy access and exploration of high-resolution, regionally downscaled climate projections based on global climate models and emissions scenarios that are sanctioned at the state level for energy research and planning.

Cal-Adapt Web Application

Cal-Adapt delivers fast, interactive, and dynamic access to the best-available climate data, allowing users to explore how climate is projected to change in their region of interest. Cal-Adapt 2.0 is built on an entirely free and open source web platform and includes a new publicly available API that enables programmatic access to climate data hosted on Cal-Adapt (Figure 1). New features allow users to aggregate data both spatially and temporally through pre-loaded boundary files or for their own private data via a boundary file upload function, or directly through the API.

Figure 1: Cal-Adapt 2.0 Landing Page



The landing page for Cal-Adapt.org is designed so that users can quickly access climate tools, download data, or view additional resources. As Cal-Adapt is continually evolving, the most recent tools and datasets are clearly highlighted on the main page.

Source: Geospatial Innovation Facility

Data Available through Cal-Adapt

The various datasets available through Cal-Adapt and associated data access points are presented in detail in Chapter 3 of Thomas et al., (2018). Interested readers are encouraged to explore further data of interest there or directly on Cal-Adapt.org. The main data are briefly listed here:

- Localized Constructed Analogs (LOCA) downscaled climate projections
- Historical gridded data
- Additional climate variables derived from the VIC model (Liang et al., 1994)
- Sea level rise CalFloD-3D
- Wildfire
- Extended drought scenarios
- Streamflow
- Vector boundaries: In addition to climate data, Cal-Adapt also includes vector datasets representing administrative boundaries, hydrological boundaries, and the LOCA model grid.

Climate Data Visualizations and Tools

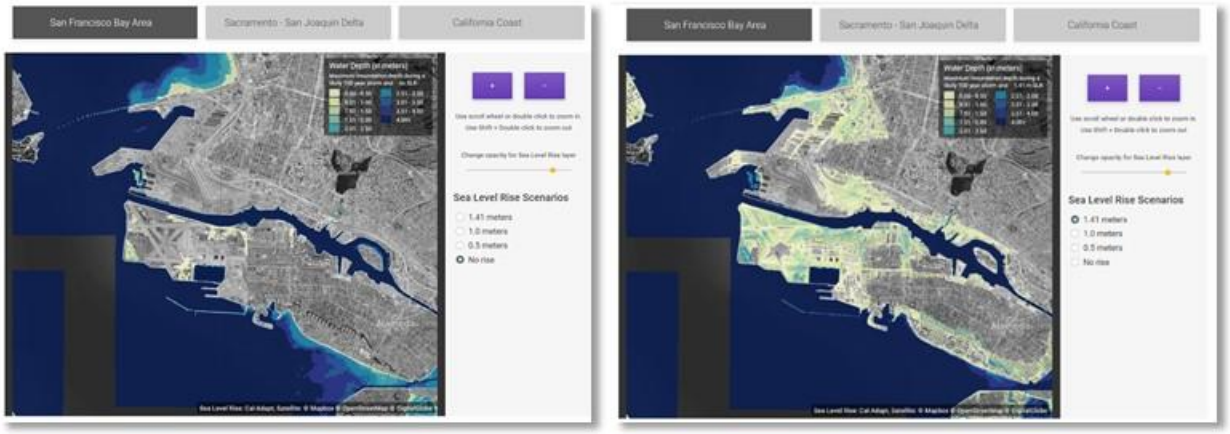
Cal-Adapt provides a suite of visualization tools that depict climate-related risks to a location of interest for stakeholders who are responsible for protecting energy infrastructure and planning for future reliability. Users are able to explore charts, maps, and data of observed and projected climate variables for California. The tools show projections for two possible climate futures—one in which emissions peak around 2040 and then decline (RCP 4.5), and another in which emissions continue to rise throughout the 21st century (RCP 8.5).

Development of Cal-Adapt 2.0 has included many enhanced and updated features that improve climate data exploration, as detailed in Chapter 3.3 of the Cal-Adapt Fourth Assessment Report (Thomas et al., 2018). A subset of tools on Cal-Adapt designed for energy sector use are highlighted below.

Sea Level Rise Tool

The Sea Level Rise viewer allows users to explore the CalFloD-3D model through maps of inundation location and depths for the San Francisco Bay area, the Sacramento-San Joaquin River Delta, and the California coast during extreme storm events occurring in conjunction with different sea level rise scenarios (no rise, 0.5 meters [m], 1.0m, 1.41m). Details are described in Radke et al., (2016). The San Francisco Bay and Sacramento-San Joaquin Delta are modeled at spatial resolutions ranging from 3m x 3m to 12m x 12m tiles. Due to the large extent of the California shoreline, coastal areas are modeled at a coarser resolution of 50m x 50m tiles and do not include surface object elevations. The data is available for download in GeoTIFF format and can be accessed through the Cal-Adapt API.

Figure 2: CalFloD-3D Model



The Sea Level Rise Tool allows users to explore different sea level rise scenarios through the CalFloD-3D model. In this example, the user can compare potential flooding around the Oakland airport in a major (100-year) storm event. The viewer on the left shows flooding extent under a No Sea Level Rise scenario, while the viewer on the right shows the same location under a projected 1.41 meter Sea Level Rise.

Source: Geospatial Innovation Facility

The CalFloD-3D research is unique and innovative in its dynamic spatial detail and the fact that it incorporates real, time series water level data from past (near 100-year) storm events to capture the dynamic effect of storm surges in modeling inundation using 3Di, a three-dimensional hydrodynamic model along with high resolution earth surface models (Stelling, 2012). Users of the tool on Cal-Adapt can explore inundation location for their region of interest under different sea level rise scenarios (see Figure 2 for an example)

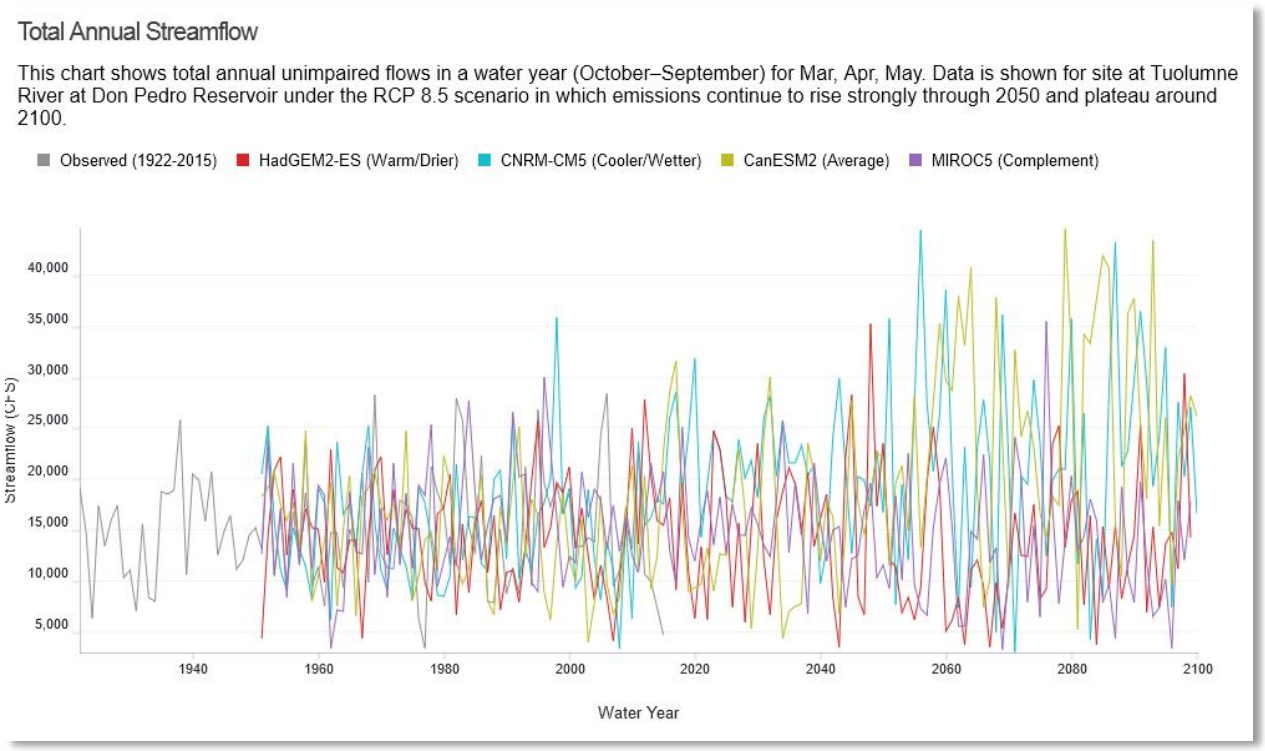
Streamflow Tool

This tool allows users to interactively view charts of VIC-routed and bias-corrected streamflows driven by LOCA downscaled temperature and precipitation at 11 streamflow gauging stations in California. As temperatures increase and snowpack diminishes, streamflows are also projected to shift in their timing. Of particular concern in California is the spring snowmelt, which feeds streamflow when it is needed most for irrigation and energy purposes. This tool enables the user to explore the timing and magnitude of streamflow in selected months of the water-year, which runs from October 1 to September 30 (water year 2018 runs from October 1, 2017 to September 30, 2018).

California's major watersheds have been altered by such large-scale projects as dams and diversions, which enable management of water to meet needs related to agriculture, urban uses, energy, and ecology. Therefore, it would be misleading to do a straight comparison of observed streamflows at a given point. This obstacle is overcome by calculating natural or unimpaired flows, which are flows that would occur if they were not subjected to storage in reservoirs or to such diversions as irrigation, power generation, water supply. Additional details on the unimpaired flows at the 11 locations can be found in CDWR (2016).

Development of the Streamflow tool required designing new visualization strategies to showcase point data. A map showing the point locations is included in the main viewer. A drop-down menu allows users to select which location they would like to explore through charting options. This design has since been implemented on other tools that visualize point locations rather than raster data, including the Hourly Projections of Sea Level tool.

Figure 3: Streamflow Viewer



The Total Annual Streamflow viewer allows users to explore projected changes in monthly streamflow at 11 locations in California. The Save Chart option, which is available on all Cal-Adapt tools, was used to create the image file shown here. This includes the text description including location (in this example, a site at Tuolumne River at Don Pedro Reservoir) and the selected models and emissions scenario (RCP 8.5, 4 recommended CA models). The Streamflow tools also included the Quick Stats widget that shows an expected increase in Average Annual Unimpaired Flow at this location, from the model historical average of 14,767 cubic feet per second to 17,847 cubic feet per second (averaged over the four recommended California models) by the end of the century.

Source: Geospatial Innovation Facility

The streamflow tools includes two main charts: the total annual streamflow shown in Figure 2 and Monthly Averages charts, which each require different controls (sliders, month lists) and different Quick Stats information. The Monthly Averages charts show monthly average unimpaired flows for selected water years. This chart includes the Runoff Midpoint value for the observed historical data as well as for each model selected. The Runoff Midpoint is the time of year when half of a year's precipitation leaves the mountains as runoff.

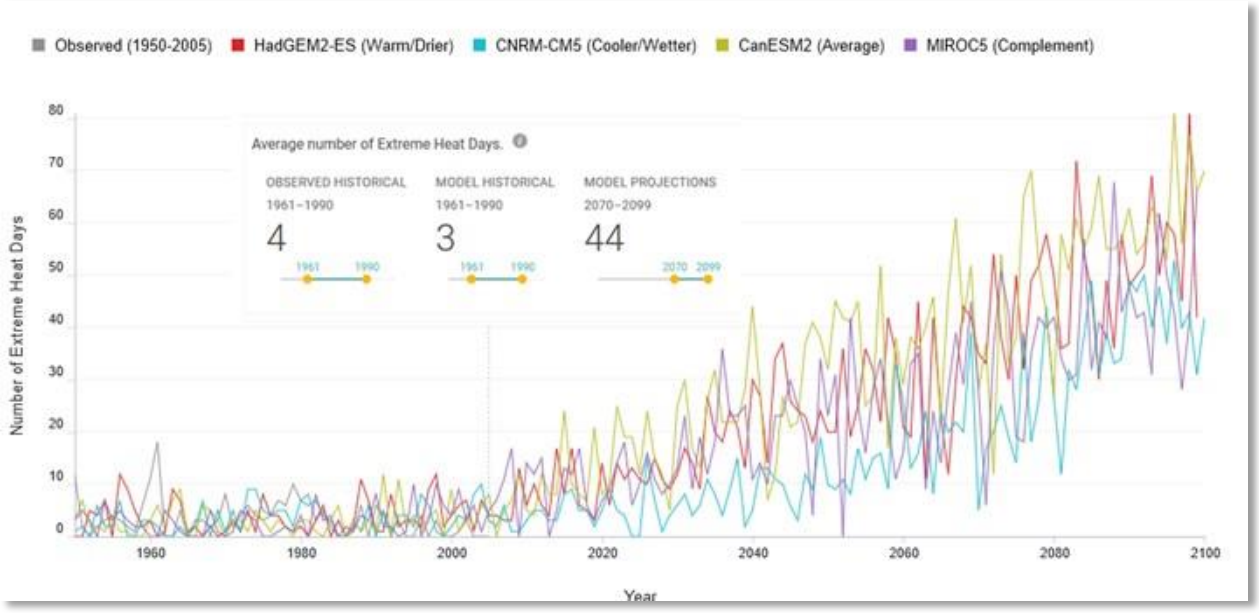
Extreme Heat Days & Warm Nights Tool

The Extreme Heat Days & Warm Nights tool allows users to explore how the frequency and timing of extreme heat days and warm nights is expected to change under different emission scenarios. For most areas in California, the climate models project a significant rise in the number of days exceeding what is now considered extremely hot for a given area. The data is derived from daily climate projections that have been downscaled from global climate models from the Coupled Model Intercomparison Project (CMIP5) archive, using the LOCA statistical technique developed by Scripps Institution of Oceanography.

The Extreme Heat Day charts show the number of days per year that exceed a threshold temperature, which by default is defined as a day in a year when the daily maximum/minimum

temperature exceeds the 98th historical percentile of daily maximum/minimum temperatures based on observed historical data from 1961–1990 between April and October. Users can set a different value for threshold temperature or reset back to the 98th percentile value.

Figure 4: Number of Extreme Heat Days by Year



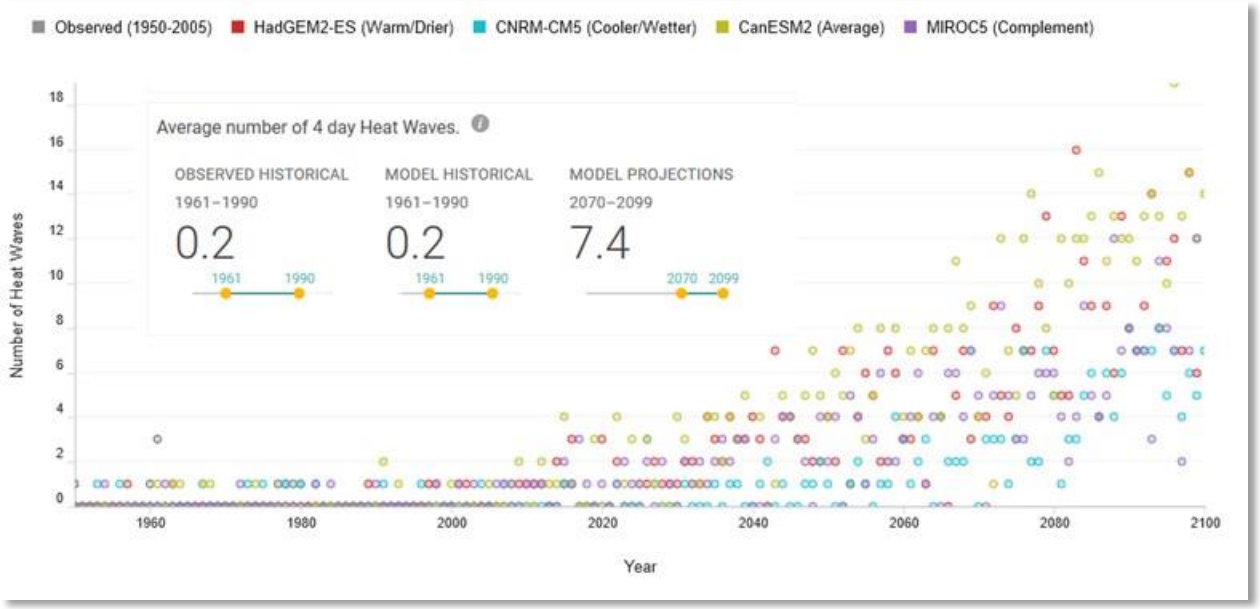
This chart shows the number of days in a year when daily maximum temperature is above the extreme heat threshold of 107.2 F. The data is shown for a Census Tract in Bakersfield, California with a CalEnviroScreen 2.0 percentile of 96-100% under the RCP 8.5 scenarios.

Source: Geospatial Innovation Facility

This tool allows users to explore many aspects of a warming climate, including the varying times of extreme heat events and heat waves. As the climate changes in California, one of the more serious threats to the public health of residents will stem primarily from the higher frequency of extreme conditions, principally more frequent, more intense, and longer heat waves. An increase in heat waves may increase the risk of heat stroke and dehydration. Cal-Adapt users are encouraged to find out how to become better prepared and more resilient to increasing temperature and extreme heat events through a link to Preparing California for Extreme Heat, a report put together by California Environmental Protection Agency (CalEPA) and the California Department of Public Health (CDPH).

Heat waves are characterized as periods of sustained extreme heat, although there is no universal definition of a heat wave. For purposes of this tool, a heat wave is defined as a period of four consecutive extreme heat days or warm nights when the daily maximum/minimum temperature is above the extreme heat threshold. Each four-day/night period is tallied; if extreme temperatures persist for 10 consecutive days/nights, it counts as two heat waves. Users have the option of choosing a different value for the number of consecutive days/nights.

Figure 5: Number of Heat Waves by Year



The Heat Wave Frequency chart shows the number of heat waves in a year when daily maximum temperatures are above the extreme heat threshold. Users can define their own extreme heat threshold and the number of days that define a heat wave. In this example, the default values are used, with four-day heat waves and the default extreme heat threshold of 107.2 F at a Census Tract in Bakersfield, California under the RCP 8.5 scenario. The number of four-day heat waves is projected to increase from the observed historical value of less than one heat wave per year to more than seven heat waves annually by the end of this century.

Source: Geospatial Innovation Facility

Cal-Adapt's Impact on Climate Adaptation Practice and Policy in California

Perhaps the most important sign of this project's success has been the extent to which Cal-Adapt has been embraced as a tool to examine projected climate change impacts by the energy sector and by policy makers in the Legislature. Cal-Adapt has already made a difference in adaptation practice and policy planning in California. Because it enables users to readily explore local climate-related risks at locations of interest, Cal-Adapt has provided a means of communicating climate change that is accessible to a variety of users.

Of primary importance to stakeholders is Cal-Adapt's ability to provide a common set of climate scenarios that have been sanctioned by the state so that energy sector actors can move forward with research and planning. The need for common scenarios was expressed by the 2016 Integrated Energy Policy Report Update, which assesses trends and challenges facing the energy sector and provides policy recommendations (California Energy Commission, 2016).

Many Cal-Adapt use cases, both in and beyond the energy sector, have been described in detail in Chapter 4 of California's Fourth Climate Change Assessment titled *Cal-Adapt: Linking Climate Science with Energy Sector Resilience and Practitioner Need* by Thomas et al., (2018). The energy sector examples from that report are included below:

- California's IOUs have begun to leverage Cal-Adapt climate tools and data to support resilience efforts, such as SDG&E's exploration of climate dimensions of system

hardening projects and SoCal Edison's work on integrating climate projections into existing planning models. IOUs also have employed Cal-Adapt tools and data to support vulnerability assessment as part of their participation in the U.S. Department of Energy's Resilience Partnerships. Examples of these vulnerability assessments include:

  - PG&E used Cal-Adapt's extreme heat tool to explore intensity and duration of projected mid-century heat waves.
  - SoCal Edison used Cal-Adapt in conjunction with spatial overlays of infrastructure and as a basis for exploring uncertainty.
  - SDG&E used Cal-Adapt to support a comprehensive, GIS-based vulnerability study.

- Moving beyond vulnerability assessments, California IOUs have used Cal-Adapt to support on-the-ground resilience efforts, including:
  - SDG&E: used Cal-Adapt 2.0 to support climate-resilient design of a compressor station in Blythe, California, to investigate implications of climate related to SDG&E's design standards, and to explore climate dimensions of system hardening projects.
  - SoCal Edison: data available on Cal-Adapt 2.0 improved analyses regarding projected climate (Mesa Substation Project in Monterey Park, California); plans to integrate climate projections into existing planning models.

CHAPTER 4:
Technology/Knowledge Transfer Activities

In addition to the stakeholder outreach efforts detailed in Chapter 2, the Cal-Adapt team has also worked to introduce potential new users to the tools and data that are made freely available through the web application. Outreach to the public and diverse potential climate data users has been made through presentations and live demonstrations of Cal-Adapt's features. Presentations on Cal-Adapt have included state and national level conferences and workshops.

Conferences and Workshops

California Adaptation Forum (September 6-8, 2016)

Cal-Adapt was featured as part of the Tools Salon at the California Adaptation Forum. The GIF hosted a table with live demonstrations of the Cal-Adapt website to introduce potential new users to the site.

American Planning Association (October 22-25, 2016)

Thomas presented Cal-Adapt 2.0 in a panel session at the American Planning Association meeting, which included a video demonstration of the tool functionality. This session included Sonia Ziaja from the CEC speaking about the state's focus and Erik de Kok from Ascent Environmental presenting user cases for Cal-Adapt.

American Geophysical Union (December 12-16, 2016)

Project Manager Thomas presented Cal-Adapt 2.0 at the American Geophysical Union in a session titled "New Approaches to Sustained Climate Assessment in the U.S.: Progress, Collaborations Across Scales, and Tools." This talk focused on how Cal-Adapt supports the Fourth Assessment work and acts as an essential bridge between rigorous scientific research on climate change and making that research easier to understand and use at a local level for planning.

California Climate Change Symposium (January 25-26, 2017)

The Cal-Adapt development team from GIF presented two posters on Cal-Adapt 2.0 at the California Climate Change Symposium in Sacramento on January 25-26, 2017, one general poster on Cal-Adapt 2.0 features, and another showcasing the new snowpack tool.

CalGIS/Location Tech Conference (May 22-24, 2017)

The Cal-Adapt development team from GIF presented training materials in a Juypter notebook format for using the Cal-Adapt API, along with updated and improved API documentation, and web developers Mukhtyar and Galey taught a hands-on workshop on using the Cal-Adapt API at the CalGIS/Location Tech conference.

California's Fourth Climate Change Assessment Quarterly Meeting (November 15, 2017)

The Cal-Adapt development project manager presented highlights of the improved tools, features, and datasets in Cal-Adapt 2.0 during the Fourth Assessment in-person quarterly meeting in Sacramento on November 15th, 2017.

California Public Utilities Commission: Climate Adaptation Prehearing Conference & Workshop (August 6, 2018)

Thomas gave a presentation and live demonstration of Cal-Adapt at this prehearing meeting and workshop. The CPUC is working on an ongoing Order Instituting Rulemaking to Consider Strategies and Guidance for Climate Change Adaptation (Rulemaking 18-04-019). This prehearing conference and workshop was designed to help frame the discussion of possible adaptation working group topics that may be taken up by the CPUC for this rulemaking, which will develop recommendations on how the CPUC and IOUs should identify and utilize appropriate climate-related inputs for planning and operations purposes.

The National Academies of Sciences: Making Climate Assessments Work: Learning from California and Other Subnational Assessment Efforts (August 14-15, 2018)

Thomas was an invited speaker for this workshop on Subnational Climate Assessments. The session was titled "Moving from Assessment to Action." It highlighted how Cal-Adapt has been used to support California IOUs in preparing vulnerability assessments and on-the-ground resilience efforts. Thomas also facilitated a break-out group during this workshop that gathered feedback from participants on "What tools and resources would be most useful to assist regions, states, and local governments to conduct climate assessments?"

CHAPTER 5:
Conclusions and Recommendations

Cal-Adapt has already been a factor in affecting climate change practice and policy in California and has provided a basis and resource for moving forward in an integrated manner across sectors. Legislation, as outlined in Thomas et al., (2018), points to Cal-Adapt as a key resource to support local hazard mitigation efforts and resilience planning. While Cal-Adapt is already being used throughout the energy sector and beyond, additional work remains to more fully support climate planning and adaptation through targeted visualizations and tools. Cal-Adapt development in support of the energy sector is continuing under two grants through the CEC (EPC-17-033 and PIR-17-012).

A key area of improvement under these new awards is to further expand on stakeholder engagement. Although the outreach efforts described in Chapter 2 generated critical feedback and suggestions from users, increased early engagement of stakeholders in tool development would be valuable. With this grant, user needs have been identified through communication with the TAC, public workshops, and targeted discussions with IOUs. While all of these methods have been extremely useful, the highest level of direct feedback on user needs has come through on-site meetings and conference calls with IOUs. Under the new grants, this type of stakeholder engagement is being expanded to include on-site meetings at each IOU. In addition, quarterly webinars that are open to the public are being added to present new tools and datasets and to gather feedback earlier in the development stage. Further outreach efforts will include an on-line survey on site usability to identify gaps in design and function, and additional user workshops.

Several ideas generated from user feedback discussed in Chapter 2 are being implemented under these new grants to further improve usability and accessibility for energy stakeholders. For example, stakeholders shared that more training and direction are required for users to exploit the advanced functionality available through the Cal-Adapt API. Energy sector users are interested in accessing an array of climate variables at a large number of private assets. This type of task can be successfully handled through the API but requires a certain level of computer programming skill. The Cal-Adapt team will build more outreach materials around using the API and also to create additional intermediary tools so users can more easily implement this functionality.

CHAPTER 6:
Benefits to Ratepayers

Cal-Adapt offers easy access to key climate models and scenarios that have been sanctioned by the state for energy planning and adaptation guidance, helping California ground its climate policy in the best available information. It has also been explicitly recognized by California's legislature as a key resource to support local hazard mitigation. Moreover, Cal-Adapt has helped provide the state with a robust source of information for resilience planning in California's energy sector and other sectors.

California IOU electricity ratepayers benefit from safer and more reliable electricity supplies, now and in the future. A critical facet of the energy sector is the ability to protect ratepayers from service interruptions and from larger service failures that may occur from events such as heat waves or sea level rise. The ability to identify locations that may be at risk from sea level rise or extreme events can better prepare the energy sector to safeguard vulnerable populations and ratepayers.

Cal-Adapt.org provides a collection of integrated tools on one website that supports interactive visualization and decision-making with a local and regional focus. These tools allow users to determine interactively the impact of their decisions in planning processes, to develop shared understandings of complex spatial data, and to support planners and managers as they protect and plan for future electricity infrastructure reliability and stability. This integrated planning will contribute multiple benefits to California's electricity ratepayers by helping to stabilize the grid, improve service reliability, and reduce financial losses associated with power outages.

California IOUs have employed Cal-Adapt tools and data to support vulnerability assessment as a part of their participation in the U.S. Department of Energy's Resilience Partnerships, including PG&E's use of Cal-Adapt's extreme heat tool to explore intensity and duration of projected mid-century heat waves. California IOUs have also used Cal-Adapt to support on-the-ground resilience efforts. For example, SDG&E has used Cal-Adapt 2.0 to support climate-resilient design of a compressor station in Blythe, California, to investigate implications of climate change for SDG&E's design standards, and to explore climate dimensions of system hardening projects.

GLOSSARY AND ACRONYMS

Term/Acronym	Definition
API	Application Programming Interface
CalEPA	California Environmental Protection Agency
California ISO	California Independent System Operator
CDPH	California Department of Public Health
CDWR	California Department of Water Resources
CEC	California Energy Commission
CMIP5	Coupled Model Intercomparison Project Phase 5: using a suite of General Circulation Models (GCMs), CMIP5 provides a standard set of climate change projections and model experiments that are aligned with the IPCC's Fifth Assessment Report.
CPUC	California Public Utilities Commission
D3	Commission Agreement Manager
FEMA	Federal Energy Management Agency
GIF	Geospatial Innovation Facility
IEPR	Integrated Energy Policy Report
IOU	Investor-owned utility
Leaflet	A modern open-source JavaScript library for mobile-friendly interactive maps.
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
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PM	Particulate matter
ReST	Representational State Transfer: an open source architecture for providing internet-based services
SDG&E	San Diego Gas & Electric Company
SoCal Edison	Southern California Edison
SWRCB	State Water Resources Control Board
TAC	Technical Advisory Committee
USACE	U.S. Army Corps of Engineers
VIC	Variable infiltration capacity

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