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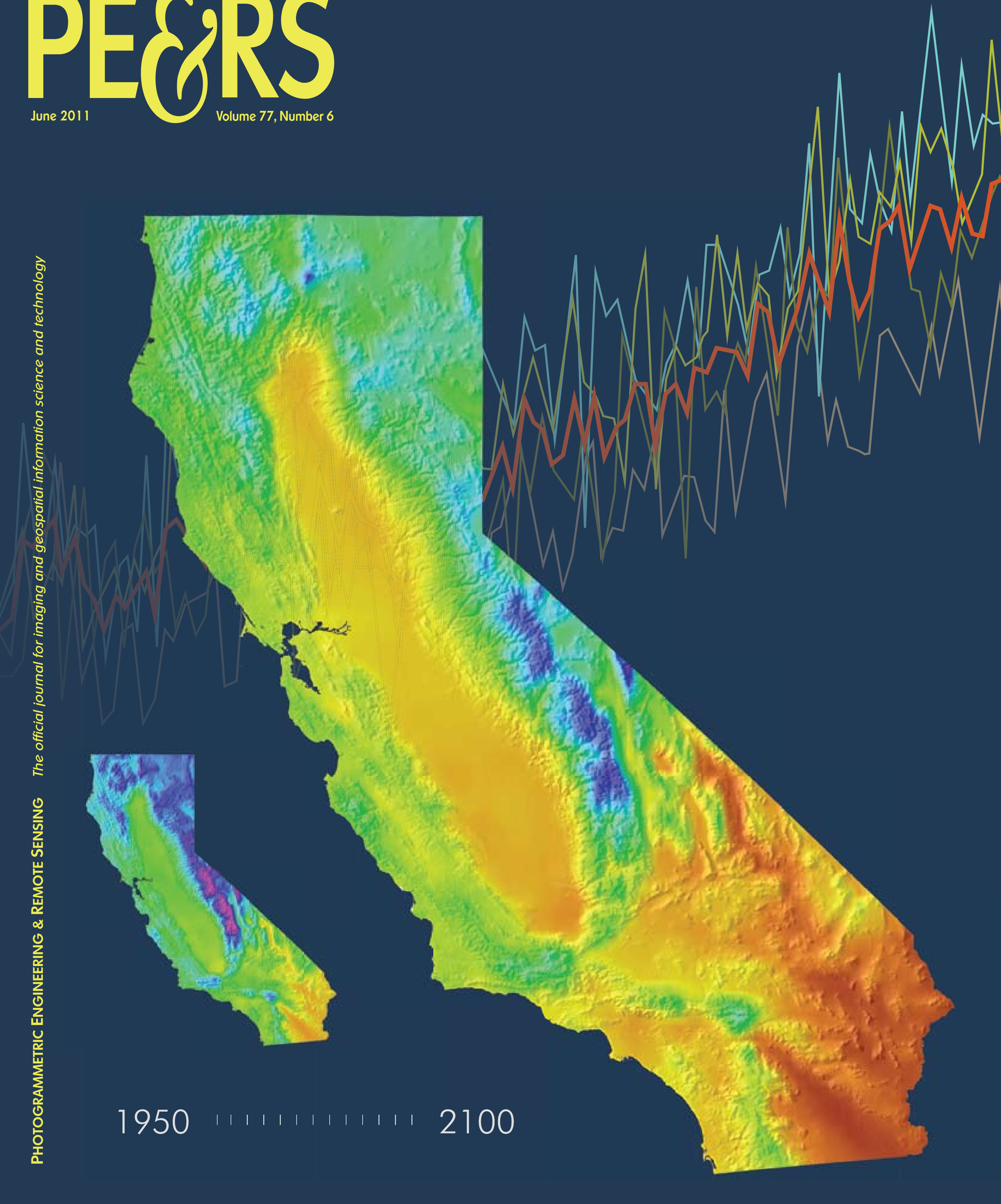

Cal-Adapt

Photos by Shannon Koy

Introduction

The Cal-Adapt (http://cal-adapt.org) web application has been developed to showcase the wealth of innovative climate change research being produced by the scientific community in California, as documented in the 2009 California Climate Adaptation Strategy (http://www.climatechange.ca.gov/adaptation). Through a combination of locally relevant information, visualization tools, and access to primary data, Cal-Adapt allows users to investigate how the climate is projected to change in their area of interest, and gives them tools to plan for these changes.

California can be characterized by a complex physical geography, unique biodiversity, and a growing and diverse population. As the climate changes, and our urban footprint continues to grow in the next century, the interplay between climate change and urbanization will increase the challenges faced by California citizens, local and state government officials, and planners. For example, the state's water resources are predicted to be vulnerable through changes in snow pack, timing and amount of precipitation, and increasing urban demand (Cayan *et al*., 2008b) (Figure 1). Extreme weather events, such as heat waves, are expected to increase in frequency (Knowlton *et al*., 2009). Climate change is also anticipated to compound the risk of catastrophic wildfire (Westerling and Bryant, 2008). Invasive species are likely to increase in range and impact on natural resources, as climate change creates new habitats and niches and eliminates existing ones (Loarie *et al*., 2008). In addition, the state's coastal and bay areas are at risk of flooding due to a rising sea level (Cayan *et al*., 2008a).

These projected increases in human population density and changes in climate highlight the need to coordinate regional planning efforts to promote conservation while also meeting the needs of all Californians for reliable and clean water, healthy communities, and food. In anticipation of these challenges, the California Energy Commission's Public Interest Energy Research (PIER) program has funded a variety of research projects throughout the state's universities and research centers. These projects have and continue to produce a robust suite of data and findings related to climate change. Cal-Adapt provides a resource for researchers, decision makers, and the general public, to access this wealth of information in order to better understand the risks posed by climate change. In turn, the localized analyses derived from this site may help to better inform effective climate change adaptation decisions and policies.

This Highlight article showcases the Cal-Adapt web application, developed by UC Berkeley's Geospatial Innovation Facility (GIF). The site crosscuts GIS, global change modeling, web GIS and participatory tools, in a spatial framework. Consequently, a number of innovative web technologies have been leveraged to provide useful information to a diverse audience of users, from general public to expert. Though Cal-Adapt is a centralized resource, all of the data and information populating it has been contributed from PIER's vast network of research centers and facilities around the state. Full attribution for each data set used in Cal-Adapt can be found on the site.

Audience

Cal-Adapt's target audience fits into three broad groups:

- general public interested in learning more about how climate change may affect California,
- city and regional planners and resource managers who need access to local level climate data to help their development strategies, and
- research experts interested in accessing climate data in a variety of formats.

Bringing Global Climate Change Data to a Local Application

By Kevin Koy, Sarah Van Wart, Brian Galey, Mark O'Connor, and Maggi Kelly

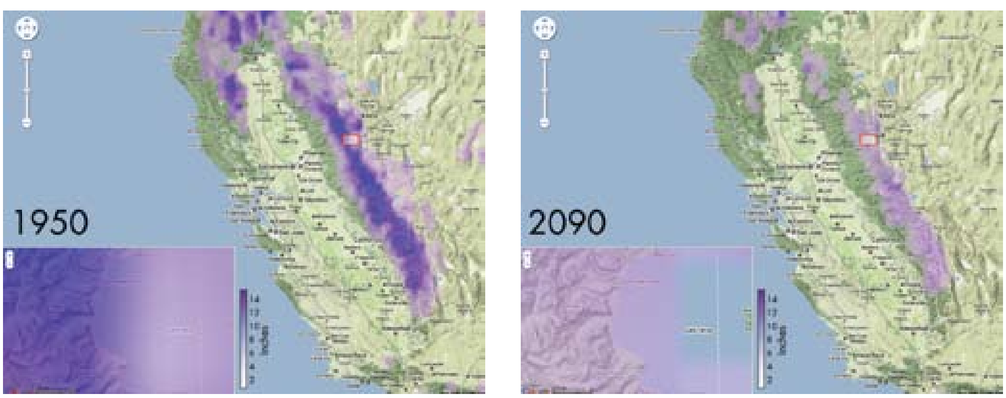

Figure 1a & b. Visualization of snow water equivalence (SWE) for the month of April 1950 vs. 2090 under the A2 high emissions scenario, GFDL model. Strong April snow pack measurements are vital for the state's water resources as they provide water throughout the summer dry season. The zoom tool is focused on the Lake Tahoe region.

Throughout the development of the site, members from each of these groups have been consulted through interviews and surveys to better understand their needs. Predictably, we have found that the information and tools that the site provides must offer a range of uses from simple and informative to complex and comprehensive. The valuable insights provided by our diverse testing pool have helped to enhance the site as we strive to make the wealth of climate change information more accessible.

Features

There are a variety of features available through the site that provide numerous ways to help people visualize and understand the changes that are projected to affect California. In summary, Cal-Adapt is comprised of tools designed to foster data visualization, primary data access, and community participation. As climate change is not projected to be evenly distributed, it is important to give users the ability to see how these changes may look in different locations around the state.

Some examples of applications that have been developed for this purpose include:

Local Fact Sheet

The Local Fact Sheet tool (Figure 2) provides quick access to some basic climate change information at the local level. Users can click on the web map, or enter an address, to receive some simple figures and charts that compare historic climate values to the projected future values. This tool currently gives users information regarding temperature, sea level rise,

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snow pack, and fire risk. These variables, and the information about them, will continue to be updated as new information becomes available. Along with on-screen visualization, this tool also produces a locally relevant PDF that lays out all of the information available for the given selected area, a feature that grew from the needs of many of the local government officers that we have interviewed.

Map animations

While users can get a quick view of the information available using the Local Fact Sheet, much more can be seen using map animations. Cal-Adapt hosts a variety of map animations that users can scroll through the modeled data over a 150-year period (1950–2099). These visualizations provide a compelling view of changes in temperature (Figure 3), a decline in Sierra snowpack, and increasing wild fire risk. Also included in the maps is a zoom tool allowing the user to easily visualize how a specific location changes in comparison with the rest of the state.

Data visualization

In addition to viewing projected climate change through map animations, we have developed dynamic chart features to help users visualize these large complex data sets in more meaningful formats. One of the unique and data-rich tools on the site allows users to click anywhere in the state, and a dynamic chart (Figure 4) detailing the monthly temperature values for 150 years is generated. These charts include data from different months, scenarios, and models, giving the user instant access to literally thousands of different charting configurations.

Figure 2. Example of the Local Climate Snapshot tool showing the temperature results for Fresno, CA.

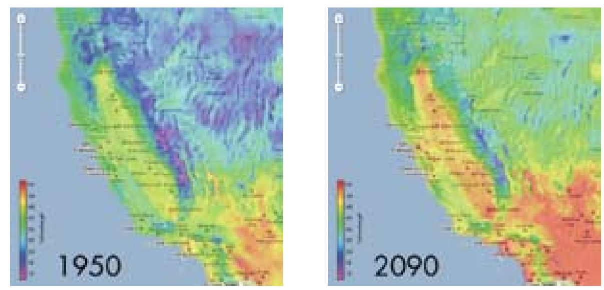

Figure 3. Example of the temperature charting tool showing the average annual low temperature readings for Sacramento under the A2 high emissions scenario. The blue line represents historic measured values (1950-2000), while four different model values for 2000-2099 are represented. The orange line represents the average of the four given model outputs.

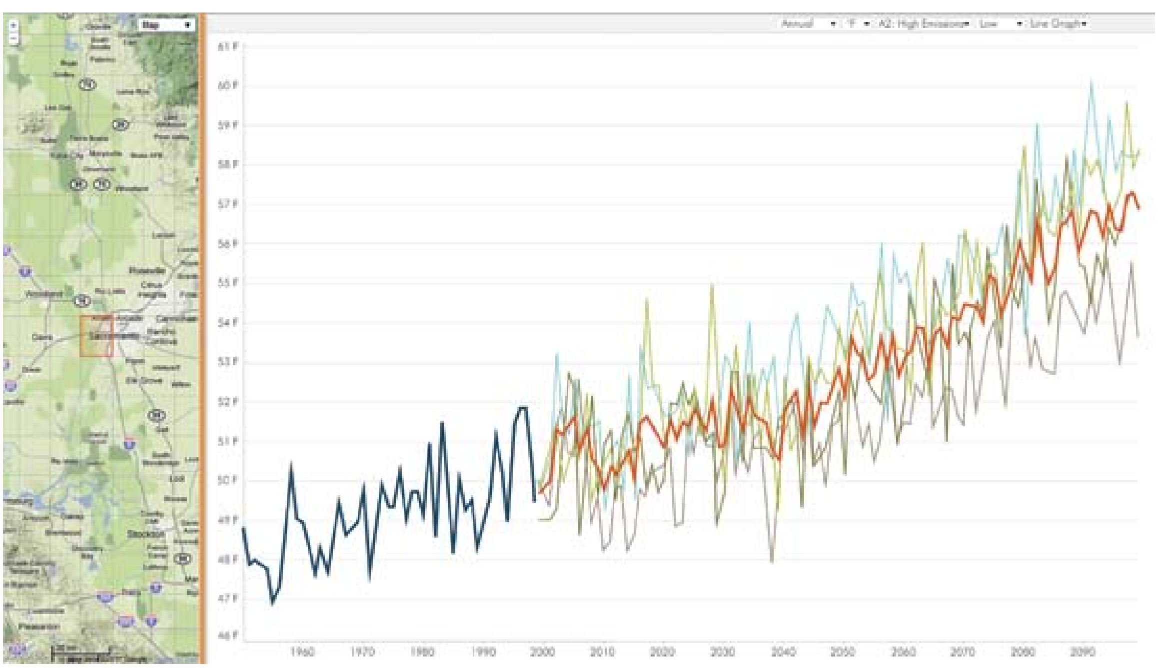

Figure 4. Visualization of average annual temperature from 1950 vs. 2090 under the A2 high emissions scenario, CCSM3 model.

Data Downloads

The underlying data behind the Cal-Adapt visualization tools are also available to download in raw raster and tabular formats. We have developed a data download application where users can select from the different types of data and time periods available, and download data for a particular area of interest.

Community Tools

In order to further engage the public, and promote a dialogue between the state's climate experts and interested community members, we have developed tools for participatory science and feedback. One tool will allow users to monitor and report the timing of lilac blooms, so that they may add to the data scientists have been collecting on this phenomenon for many years. Another encourages users to find the location of where historic landscape photos were taken so that they may be reshot. These new photos can then be compared to the historic images for change detection.

Data

The data served by Cal-Adapt are primarily raster based, and extremely numerous. Given that no one knows exactly what the future will look like, scientists from the Intergovernmental Panel on Climate Change (IPCC) have developed a series of outcomes which attempt to represent the variety of possibilities we may encounter. These scenarios can be defined by the potential pace of CO_2 emissions into the future, development of new technologies that may help to alleviate emissions, and varying levels of economic and population growth throughout the world.

At this time, two global emissions scenarios are used in Cal-Adapt: B1 and A2.

- B1 - The lower emissions scenario (B1) characterizes a world with high economic growth and a global population that peaks by mid-century and then declines. There is a rapid shift toward less fossil fuel-intensive industries and introduction of clean and resource-efficient technologies. Heat-trapping emissions peak about mid-century and then decline; CO_2 concentration approximately doubles, relative to pre-industrial levels, by 2100 (Nakicenovic, 2000).
- A2 - The medium-high emissions scenario (A2) projects continuous population growth and uneven economic and technological growth. The income gap between now-industrialized and developing parts of the world does not narrow. Heat-trapping emissions increase through the 21st century; atmospheric CO_2 concentration approximately triples, relative to pre-industrial levels, by 2100 (Nakicenovic, 2000).

In addition to these emissions scenarios, several different General Circulation Models (GCM) have been developed by different organizations around the world. Each of these models attempts to capture an accurate portrayal of what the future global climate will look like based on a number of factors. UC San Diego's Scripps Institute of Oceanography has downscaled a number of these models, using different statistical and dynamic techniques, to make them more locally relevant to California.

At this time Cal-Adapt offers four different models, including:

- NCAR - National Center for Atmospheric Research Parallel Climate Model (PCM1)
- CCSM - Community Climate System Model Version 3.0 (CCSM3)
- GFDL - Geophysical Fluids Dynamic Laboratory (GFDL) CM2.1
- CNRM - Centre National de Recherches Météorologiques

It is important to give users access to a variety of different scenarios and models, so that they may visualize the differences and uncertainty present throughout them. Of course, this presents interesting challenges in developing engaging tools while still using as many relevant sources as possible. Table 1 details the variety and amount of data used to power the temperature charting tool described above. The volume of data provides a unique set of challenges with more being produced all of the time. The next section gives a brief overview of what's driving this application.

What Makes it Work

Cal-Adapt has been developed using all free and open-source software (FOSS), hosted on virtual private servers (Steiniger and Bocher, 2009). Using Django, a flexible Python-based web framework, we are able to knit together each of the site's technology components, highlighted in Table 2, to create a cohesive and unified user experience.

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Table 1. Data sources used to populate the dynamic temperature charting tool.

Data source	Scenarios	Months	Years	Measurements	Layers
Historic	1	12+1 annual	50 (1950–1999)	3 (low, avg, high)	1950
CCSM3	2 (A1, B2)	12+1 annual	100 (2000–2099)	3 (low, avg, high)	7800
CNRM	2 (A1, B2)	12+1 annual	100 (2000–2099)	3 (low, avg, high)	7800
GFDL	2 (A1, B2)	12+1 annual	100 (2000–2099)	3 (low, avg, high)	7800
PCM1	2 (A1, B2)	12+1 annual	100 (2000–2099)	3 (low, avg, high)	7800
				Total grid layers:	33,150
				Number of queryable grid cells	6,924
				Total rows of tabular data	229,530,600
				Number of unique charts that can be generated	540,072

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Table 2. Cal-Adapt software stack.

Application/Library	Version
Ubuntu	10.04 LTS Server Edition
Apache HTTP Server	2.2
PostgreSQL	8.4
PostGIS	1.5
Django	1.2
MapServer	5.6
TileCache	2.11
Memcached	1.4
Google Maps API	3
Google Chart API	-
jQuery	1.4

MapServer provides the cartographic engine driving most of the map-based visualizations. Given the highly temporal nature of the data, MapServer's flexibility via parameter substitutions and support for WMS-T (Web Map Service-Time) have been a tremendous advantage as each HTTP GET request may contain time values, in addition to further optional parameters. Beyond support for web services such as Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS), request modes provide access to dynamic image tiles or static map output utilized in the local climate snapshots and HTML templates to generate map legends.

NumPy, a Python package for scientific computing, provides the web application with quick access to the enormous wealth of data highlighted in the temperature chart example above. To support the graph-based tools, each model-scenario combination is saved as a NumPy binary file and can be read directly into the server's memory as a multidimensional array. This format greatly simplifies access to individual raster cells and ad-hoc statistics based on arbitrary time slices, as Python's concise array slicing syntax makes it trivial to query 150 years of modeled data. Cal-Adapt also takes advantage of Memcached, a mechanism that allows client requests to be cached on the server, to reduce the amount of work the server must perform for subsequent requests for the same data.

To support a responsive and dynamic user interface, data requests and responses are communicated between server and client using Asynchronous JavaScript and XML (AJAX) calls, which in turn populate JavaScript-based visualization controls, such as Google Maps, Google Charts, and other JQuery widgets. For the time-series animations, these JavaScript controls were extended to support smooth image transitions.

Building upon the wealth of innovation from the FOSS community has made the complex task of providing local access to a huge amount of data, and presenting these data in compelling ways, much more manageable. These systems will be put further to the test as we develop new tools that incorporate the daily climate layers now available for each model.

What's in Store for the Future?

Though Cal-Adapt has much to offer today, it is very much a work in progress as we plan to continue building upon the tools and information already available. New data and findings are being produced by California's climate scientists, and we intend to continue to add new tools for users to access and interpret the latest information. In the near term, we are developing tools that will incorporate the daily downscaled model data produced for the state. These data can be used to populate a new "extreme heat event" tool that will allow users to see the expected number of days that exceed the threshold of a heat wave. This tool may be valuable to public health officials who plan for the health-related implications of more frequent heat waves in each locality. Future tools will attempt to add more relevant information, such as extreme heat, so that more meaning may be derived from the data.

We also plan to further incorporate local findings into the site so experts can share their data more freely with colleagues throughout the state. Many municipalities have developed, or are developing, their climate action plans. These plans hold valuable information, and may serve as a foundation for other areas just beginning to explore how climate change may affect their region.

The development of Cal-Adapt has challenged our team to explore the opportunity of presenting highly temporal spatial data to a large audience. At the moment, there is no single solution to this problem, however we believe that we have found a captivating visualization format that utilizes several available open technologies. We hope that this site may serve as an example to other projects that attempt to offer a spatial representation of a highly temporal subject. Given the exponential rate that new climate data sets are being produced, this framework can help to disseminate new information quickly and effectively.

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