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Toward a modern topography of the coastal zone

The California coastal LiDAR project

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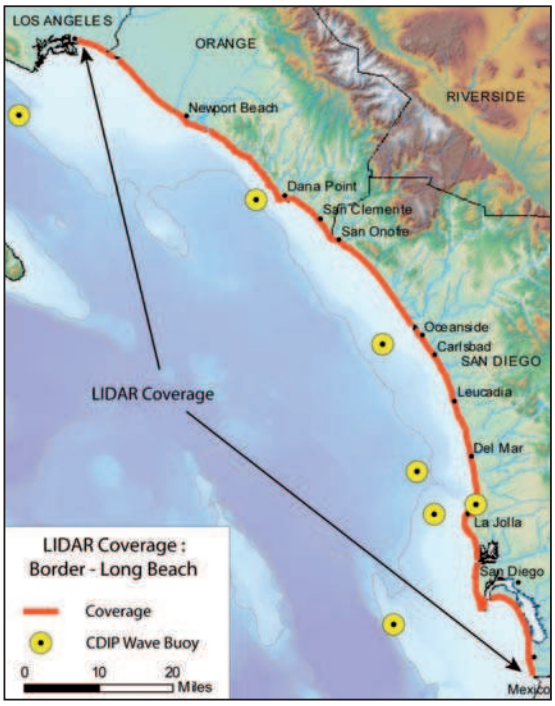
RISING SEA LEVEL will have significant impacts on California's coastline with some estimates up to a 1.4m sea level rise by 2100[1]. As stated in the California Climate Adaptation Strategy: "*Much of the damage from this accelerated sea-level rise will likely be caused by an increase in the frequency and intensity of coastal flooding and erosion associated with extreme weather events and storm surges.*"[2] While bays and estuaries are expected to experience the most dramatic modifications in the coming century, changes will be seen far inland from the immediate shoreline zone (for example, the upland migration of vegetation and sensitive habitat zones, or the relocation of coastal population, development and infrastructure).

A seamless, onshore-offshore high-resolution elevation map of the California coastal zone would benefit resource managers and coastal communities by providing information to assess potential impacts from sea level rise. Contour intervals of 30cm up to a topographic elevation of 10m (from mean sea-level) represent a desirable resolution over an area that will allow for the development of alternative response strategies to shoreline change and sea level rise. A modern elevation dataset would enable planners, scientists, engineers and decision-makers to:

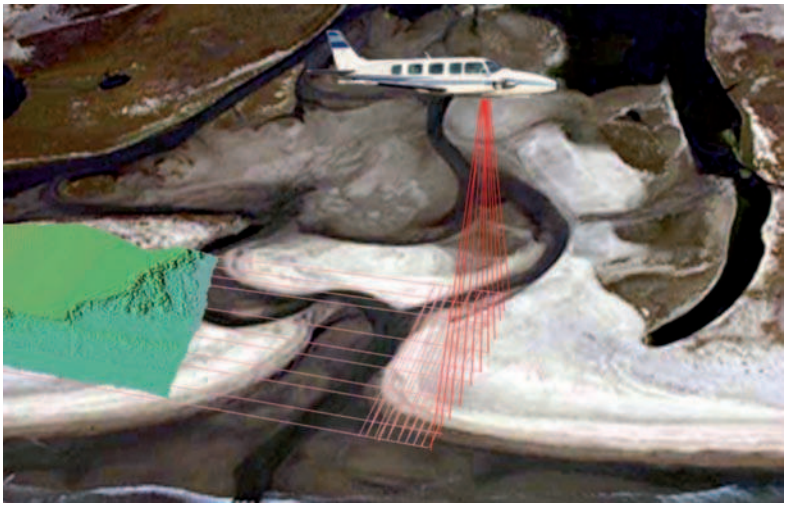
- Assess the need for adequate buffer areas around wetlands and estuaries.
- Identify and assess areas of potential retreat and relocation for affected development or infrastructure within communities.
- Evaluate potential shoreline/bluff erosion and retreat.
- Identify potential inundation zones (with flexibility to examine a range of inundation scenarios).
- Conduct risk assessments for impacts from storms and storm surges.
- Produce more accurate wave run-up models related to inundation and tsunami planning.

Light detecting and ranging (LiDAR) is a remote sensing technology that uses lasers to measure elevation and is a rapid, cost-effective source of high-quality topographic information. A complete baseline LiDAR dataset for the California coast would benefit resource managers and coastal communities. This dataset also would support the goals of Governor Schwarzenegger's executive order of November 2008 that directs all construction projects to consider sea level rise during design and requires the office of planning and research to provide state land-use guidance related to climate change.

A new high-resolution topographic dataset would allow better planning and response than older or lower resolution surveys. For example, the coastal bluff erosion that occurs in Goleta, Santa Barbara County, or in Pacifica, San Mateo County, is managed mostly during crises. Beach nourishment projects along the Orange and San Diego counties represent tens of millions of dollars in investment, despite extremely dynamic nearshore processes that constantly remove the placed sand. A new elevation dataset would encourage prioritisation for proactive mitigation strategies and evaluation of nourishment options.



Study area with LiDAR coverage of the coastal data information programme/Southern California beach processes study based at Scripps Institution of Oceanography. Courtesy of CDIP/SCBPS.

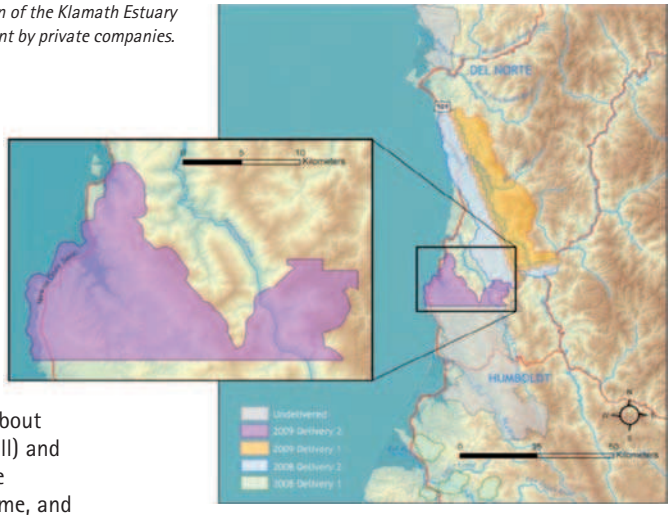


Toward a modern topography of the coastal zone: The California coastal LiDAR project. Courtesy of CDIP/SCBPS.

For California to most effectively monitor, understand and manage the coastal zone, a baseline LiDAR dataset should be collected to the highest possible standards that will satisfy as many users as possible. The survey should be performed and documented to allow repeatable LiDAR surveys, which will assure that a baseline survey is useful beyond mapping the current coastal land elevations.

LiDAR projects in California

Local aerial and ground-based LiDAR surveys are common throughout California when an agency, county or research group determines acquisition of elevation data is needed for projects or planning. The following are examples of the type of collection efforts a statewide baseline survey would support and from which lessons could be learned.



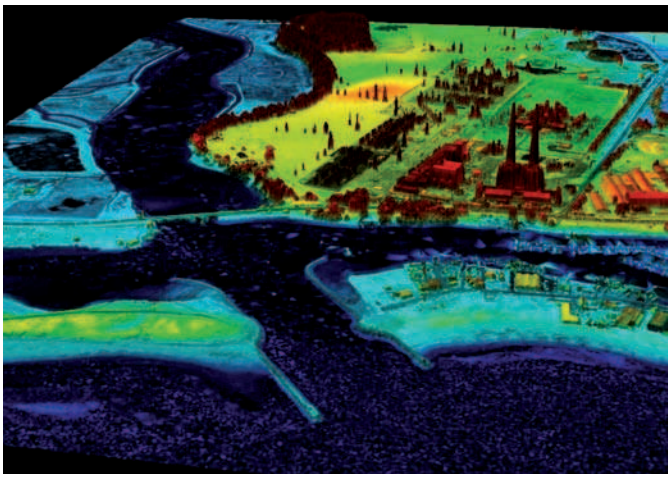
Regions of LiDAR collection in 2008-2009 to support restoration of the Klamath Estuary (light blue area). Additional regions are for resource management by private companies. Courtesy of the Yurok Tribal Fisheries Program.

Beach management

The Coastal Data Information Program and Southern California Beach Processes Study (SCBPS) at Scripps Institution of Oceanography is sponsored by the US Army Corps of Engineers and the California Department of Boating and Waterways. The programme monitors and models beach erosion, providing the knowledge base for more effective local and regional beach management.

SCBPS collects in situ and remote observations of sand level changes on nourished and natural beaches. Airborne topographic LiDAR has been used since May 2002 to survey the beach between the low tide waterline and the back-beach from Point La Jolla to Dana Point (about 79km), and from the Mexican border to Long Beach (about 170km). The surveys include the approximate times of maximum (early fall) and minimum (early spring) beach width, and are used to estimate alongshore variations in the seasonal cycle of changes in beach width and sand volume, and to identify long-term erosion trends.

Scientists then use the data to test and develop models for beach erosion and wave observations. Wave observations are combined with a numerical model to estimate the nearshore wave field. These field-validated models allow engineers to predict future beach evolution more confidently. For example, the model could be used to simulate erosion of a particular beach nourishment project under different scenarios for the intensity and frequency of future storms.



The Moss landing harbour in Monterey Bay. Courtesy of CDIP/SCBPS.

Restoration of the Klamath Estuary

The Yurok Tribal Fisheries Program is developing a prioritised, ecosystem-based restoration plan for the Klamath River estuary. The estuary and its associated marine, tributary, wetland and slough habitats serve as a nursery and staging area for spring and fall-run chinook salmon, coho salmon (listed as threatened under the *Endangered Species Act*), steelhead trout, coastal cutthroat trout, sturgeon, eulachon and lamprey. Anthropogenic activities, including the construction of major dams, during the last 150 years have drastically degraded estuary habitats and resulted in substantial declines to Klamath River fish runs.

Detailed maps and digital elevation models (DEM) of the estuary and its habitats are key to developing restoration strategies. The base map for this project is being generated from LiDAR, aerial imagery, and bathymetric and topographic surveys. GIS map layers depicting land ownership, flood and tsunami inundation zones, and conceptual watershed restoration designs will also be created for the project area.

The Yurok Tribe collaborated with nearby private companies to collect LiDAR in 2008 and 2009. The collection area contains large regions of privately-held lands so public access to this dataset is limited. However, the GIS map layers and DEMs generated for this project will be critical tools for developing the large-scale estuary restoration plan and assessing the effectiveness of future restoration actions and/or changes in river management.

Rapid post-storm assessments

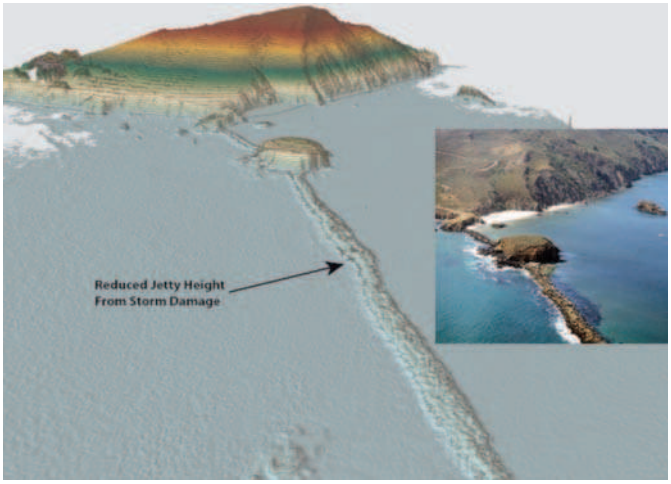
A series of storms hit California in January 2010 with large wave events and heavy rainfall. Beaches and cliffs throughout the state were subjected to large-scale erosion, including beaches that have received nourishment. To assess the damage and prioritise emergency responses for infrastructure in southern California, a collaborative effort for LiDAR collection was organised by Scripps Institution of Oceanography.

As of writing, participants included Scripps, the US Army Corps of Engineers, California Department of Boating and Waterways, US Geological Survey (USGS) and the San Diego Association of Governments. The collection, over a similar region as the SCBPS, occurs within weeks of the storm events to capture the damage before natural processes begin to rebuild beaches.

California coastal LiDAR project

The California Ocean Protection Council initiated the California coastal LiDAR project (CCLP) in December 2008. The primary objectives were to:

- Gather agency needs for a LiDAR dataset.
- Discuss technical and geographic specifications.



Port San Luis. Courtesy of CDIP/SCBPS.

Example of framework map developed by state agencies for the CCLP geographic extent. The red hatched area extends from the shoreline to the 10m topographic contour. The light brown coastal strip indicates the shoreline to 0.5km inland region collected by the US Army Corps of Engineers as part of the national coastal mapping programme.

- Determine how to obtain the most widely accessible and useful dataset.
- Begin collaborations with multiple stakeholders.

Collection of agency uses continued until February 2009, and identified many overlapping and complementary needs. The top most commonly requested needs for a modern topographic dataset were related to sea level rise inundation studies, tsunami studies, beach morphology studies (beach erosion, accretion, dune migration and so on) and detection of invasive species. Other uses included updating coastal flood hazard, infrastructure and national wetland inventory maps, identifying shoreline change and assisting in setting jurisdictional boundaries.

Despite the collective efforts of many agencies to pursue a multi-purpose modern LiDAR dataset, the economic downturn and California's financial crisis prevented the Ocean Protection Council or any state agency from investing funds in a collaborative collection of coastal LiDAR. As of this publication, no direct state funding for collecting LiDAR data has been identified.

LiDAR in 2009

Technical and geographic specifications

In April 2009, representatives from the Ocean Protection Council, Department of Water Resources, Coastal Commission and the San Francisco Bay Conservation and Development Commission produced a set of state standards for the CCLP to satisfy their compiled needs.

These specifications matched those used by the Department of Water Resources for LiDAR collection in the Sacramento-San Joaquin Delta and in the Central Valley in 2007, and were developed in consultation with experts from the National Oceanic and Atmospheric Administration (NOAA), USGS and Scripps Institution of Oceanography. The preferred vertical and horizontal accuracy standards would allow high-detail elevation maps to be produced.

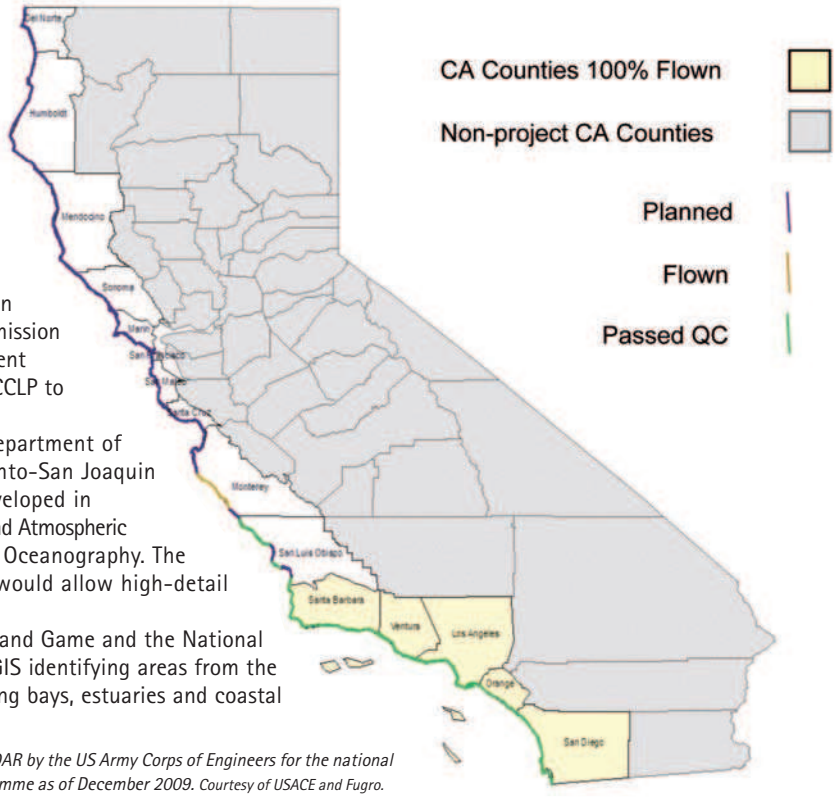
Several agencies, including the Department of Fish and Game and the National Park Service then constructed a statewide map in ArcGIS identifying areas from the shoreline to the 10m topographic contour, encapsulating bays, estuaries and coastal watersheds. The CCLP map encircles areas that may be subject to large potential threats due to inundation from sea level rise and tsunamis.

Coastline collection

The US Army Corps of Engineers began a coastal aerial LiDAR collection in October 2009 as part of a national coastal mapping programme. The programme is designed to collect LiDAR of ocean and Great Lakes coastlines and nearshore bathymetry, and is executed by a partnership among the army, NOAA and naval organisations. The mission of the programme is to support regional sediment management, construction, operations and regulatory functions in the coastal zone.

Geographic coverage of coastal topography in California is from the shoreline to 0.5km onshore at 1m spacing; bays and estuaries are not included (for example inside San Diego or San Francisco bays). Bathymetric data have been collected from the shoreline to 1km offshore or laser extinction (whichever occurs first) at 5m spacing in some southern California locations.

Currently the counties of San Diego, Orange, Los Angeles, Ventura, and Santa Barbara have been surveyed; portions of San Luis Obispo (62%) and Monterey (43%) counties have also been surveyed. Data for these counties have been quality checked and no reflights are needed. Winter weather conditions have delayed further collection efforts until spring 2010 when the remaining coastline (San Luis Obispo to Del Norte counties) will be surveyed. Data delivery from the California portion of the national programme is expected by December 2010.



Collection of coastal LiDAR by the US Army Corps of Engineers for the national coastal mapping programme as of December 2009. Courtesy of USACE and Fugro.

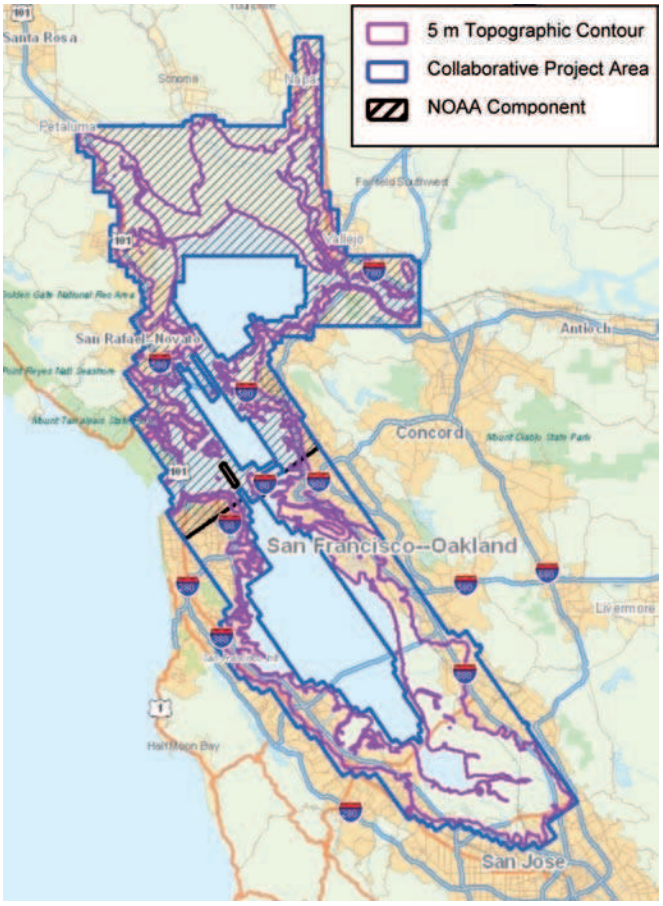
San Francisco Bay area collection
A collaborative project between USGS and NOAA was developed in 2009 to conduct LiDAR surveys of the San Francisco Bay area extending from the Carquinez Strait to outside the Golden Gate. These agencies are interested in acquiring new elevation data to support sea level rise investigations and coastal management decision making. For example, USGS requires the data for assessing:

- The current shoreline position relative to historical locations.
- Habitat impacts due to modifications of tidal wetlands, salt ponds and tidal marshes.
- Vulnerability of this region to future sea level rise and powerful winter storms.

The geographic coverage extends from the shoreline to the 5m topographic contour. The collection will occur in two phases with the NOAA portion in early 2010 and the USGS portion in mid-2010. The datasets, which will be publicly available, are expected by December 2010.

Momentum for the future

Collaborations in 2010
The efforts of the US Army Corps of Engineers, USGS and NOAA will be completed in 2010. Once winter weather clears the coastline, the army collection will restart with a scheduled completion of early summer. Delivery of the processed data is anticipated by December 2010. Collection of the San Francisco Bay Area under the joint NOAA/USGS programme is scheduled to be completed by mid-year and processing of the data should be completed by December 2010.



Collection area for collaborative NOAA/USGS LiDAR project. The black hatched area will be collected first by NOAA in early 2010 and the remainder by USGS later in 2010. Courtesy of BCDC.

California's fiscal crisis is expected to continue to negatively affect the ability of the Ocean Protection Council to invest in a collaborative LiDAR project in the near future. Staff consider this project a top priority, however, and will continue to explore funding opportunities to augment the ongoing federal projects. Collaboration has been a successful method in the California Seafloor Mapping Program and a similar approach could be adopted for the CCLP. The goal is to identify partners who seek to acquire the best data that serve multiple purposes.

In addition to data acquisition, the Ocean Protection Council plans to investigate how best to address data gaps and data exchange. The lack of a central database of California LiDAR datasets was highlighted by many state and federal agencies as a substantial barrier to project planning and geographic prioritisation. One immediate short-term solution could be to use a wiki (a web-based database for creating, browsing and searching through information) to consolidate and facilitate information exchange among interested parties.

Beyond the California coastal LiDAR project
Many groups are acquiring LiDAR datasets as the technology has established itself for cost-efficient topographic and habitat mapping. The increasing number of LiDAR datasets, when combined with other geospatial data, is contributing to an ever-growing volume of data. Management of these datasets, including accessibility and sharing, is an emerging challenge for California. In 2009, the Ocean Protection Council and NOAA investigated the need for, and barriers to, interagency data sharing and collaboration for effective ocean management. This investigation consisted of interviews with a number of state agencies with coastal and marine jurisdiction. The interviews revealed that a broad range of stakeholders, such as federal agencies and NGOs, agreed that geospatial data management needed to improve and that a collaborative approach was necessary for comprehensive ocean planning.

Since then there have been calls for the creation of a state geospatial information policy. The policy would define California's commitment to geospatial data management and establish a leadership role within each agency to further that policy. Key elements in the policy should be:

- Improved communication and coordination for data sharing efforts between agencies with marine and terrestrial jurisdiction and interests.
- Improved data accessibility for all agencies and an assessment to determine information needs and preferences about how to retrieve and share data as part of a data-sharing framework.

Ideas for tools to support this framework included a web portal, data clearinghouse and a search tool able to access various agency databases. The state can build upon existing relationships between academics, NGOs and private organisations to develop data and metadata standards for useful research products and to prioritise research needs to fill data gaps.

Efforts to organise and coordinate by California agencies complement activities by a federal interagency working group on ocean and coastal mapping, which was established in June 2006 with the mission to:

> *"...engage the national mapping community, including providers and users, to promote the efficient and effective development and application of ocean and coastal mapping to support informed decision making."*[3]

The working group published a strategic plan in January 2009 with three objectives to build communication, coordination and collaboration within the national mapping community:

1. Build a national ocean and coastal mapping (OCM) community
Focus on increasing awareness, building advocacy, shared priorities and practices, and supporting implementation of integrated ocean and coastal mapping.
2. Provide the tools and expertise to promote an effective national OCM community
Focus on providing the national OCM community with critical geospatial data, mapping tools, and expertise to promote the efficient and effective advancement and application of OCM to support informed decision making.
3. Demonstrate and build upon success
Focus on developing and promulgating models for effective collaborative development and implementation of mapping programs, and on communicating the value and impact of successful collaborative OCM activities.

The strategic plan is guiding the development of many tools, including the vertical datum transformation tool (VDatum) for transforming elevation data from one vertical datum into another and for blending bathymetric and topographic data sets into the multipurpose marine cadastre — a multi-year interagency effort to build a GIS-based marine information system for the outer continental shelf and state waters.

One project highlighted in the working group's strategic plan is the California seafloor mapping programme[4]. This project involves the Ocean Protection Council, USGS, NOAA and California State University, and is acquiring high-resolution bathymetric and habitat maps of the seafloor from the shoreline to three nautical miles offshore (California jurisdictional boundary). The programme started in 2005 and data collection is expected to be completed by 2012. It will provide bathymetric elevation maps to which data from the CCLP could be integrated to produce a seamless onshore-offshore dataset and fulfill the goal of the agencies responsible for managing California's coastal zone.

Conclusion

For California to be prepared for climate change impacts and better manage the coastal zone, a modern topographic map must be developed. Data from the CCLP coupled with the results from the seafloor mapping programme can generate a seamless onshore-offshore map to assess sea level rise, tsunami hazards, coastal storm surge hazards and better plan wetland restoration.

Collaboration among state, federal and local agencies will be essential to successfully acquire the necessary LiDAR data to produce a statewide map that will be useful to as many users.

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[1] Cayan Dan, Mary Tyree, Mike Dettinger, Hugo Hidalgo, Tapash Das, Ed Maurer, Peter Bromirski, Nicholas Graham, and Reinhard Flick (2009). *Climate Change Scenarios and Sea Level Rise Estimates for the California*, 2008, Climate Change Scenarios Assessment. PIER Research Report, CEC-500-2009-014, Sacramento, CA: California Energy Commission
[2] *2009 California Climate Adaption Strategy*, Natural Resources Agency, http://www.climatechange.ca.gov/adaptation/index.html.
[3] *National Ocean and Coastal Mapping Strategic Action Plan*, Interagency Working Group on Ocean and Coastal Mapping, Joint Subcommittee on Ocean Science and Technology, January 2009
[4] CSMP websites: USGS - http://walrus.wr.usgs.gov/mapping/csmp/ California State University, Monterey Bay - http://seafloor.csumb.edu/csmp/csmp.html