State of California Sea-Level Rise Interim Guidance Document

Developed by the Sea-Level Rise Task Force of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), with science support provided by the Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust

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Background, Purpose, and Intended Use

This document provides guidance for incorporating sea-level rise (SLR) projections into planning and decision making for projects in California. Governor's Executive Order S-13-08, which was issued on November 14, 2008, included the following:

> *I direct that, prior to release of the final Sea Level Rise Assessment Report from the NAS* [National Academy of Sciences]*, all state agencies within my administration that are planning construction projects in areas vulnerable to future sea level rise shall, for the purposes of planning, consider a range of sea level rise scenarios for the years 2050 and 2100 in order to assess project vulnerability and, to the extent feasible, reduce expected risks and increase resiliency to sea level rise. However, all projects that have filed a Notice of Preparation, and/or are programmed for construction funding the next five years, or are routine maintenance projects as of the date of this Order may, but are not required to, account for these planning guidelines. Sea level rise estimates should also be used in conjunction with appropriate local information regarding local uplift and subsidence, coastal erosion rates, predicted higher high water levels, storm surge and storm wave data.*

The final report from the National Academy of Sciences (NAS) is unlikely to be released until 2012. The intent of this interim guidance document is to inform and assist state agencies as they develop approaches for incorporating SLR into planning decisions prior to the release of the NAS report and other technical reports (see below for information on planned updates to this document). Specifically, it provides information and recommendations that will enhance consistency across agencies in their development of approaches to SLR. We anticipate that, because of their differing mandates and decision-making processes, state agencies will interpret and use this document in a flexible manner, taking into consideration risk tolerances, timeframes, economic considerations, adaptive capacities, legal requirements and other relevant factors. (Refer to Recommendation #2 below for a discussion of risk tolerance and adaptive capacity.) Although the estimates of future SLR provided in this document are intended to enhance consistency across California state agencies, the document is not intended to prescribe that all state agencies use specific or identical estimates of SLR as part of their assessments or decisions.

Development of this Document

The Sea-Level Rise Task Force (SLR Task Force) of the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), led by the Ocean Protection Council (OPC), developed this document. This Task Force includes staff from the following state entities:

- Business, Transportation and Housing Agency,
- Coastal Commission,
- Department of Fish and Game,
- Department of Parks and Recreation,
- Department of Public Health,
- Department of Toxic Substances Control,
- Department of Transportation,
- Department of Water Resources,
- Environmental Protection Agency,
- Governor's Office of Planning and Research,
- Natural Resources Agency,
- Ocean Protection Council,
- San Francisco Bay Conservation and Development Commission,
- State Coastal Conservancy,
- State Lands Commission and
- State Water Resources Control Board.

Staff from these state entities worked collaboratively from July through October 2010 to develop this guidance document and reached agreement on the document's recommendations. Its underlying premise is that SLR potentially will cause many harmful economic, ecological, physical and social impacts and that incorporating SLR into agency decisions can help mitigate some of these potential impacts. For example, SLR will threaten water supplies, coastal development, and infrastructure, but early integration of projected SLR into project designs will lessen these potential impacts.

The SLR Task Force worked with the California Ocean Science Trust (whose Executive Director is the OPC's Science Advisor) to ensure this document was informed by the best available science. A sub-committee of select experts from the OPC's Science Advisory Team responded to questions posed by the SLR Task Force on September 1, 2010 (attached as Appendix A) and their responses informed the policy recommendations below. The following members of the OPC's Science Advisory Team participated in the sub-committee:

- Dr. Dan Cayan, Research Meteorologist, University of California, San Diego, Scripps Institution of Oceanography and U. S. Geological Survey,
- Dr. Gary Griggs, Director of the University of California, Santa Cruz Institute of Marine Science,
- Dr. Sam Johnson, Research Geologist, U.S. Geological Survey, Pacific Science Center, and
- Dr. Tony Haymet, Director of the University of California, San Diego, Scripps Institution of Oceanography.

In addition, OPC staff corresponded with Dr. Stefan Rahmstorf, Professor of Physics of the Oceans, Potsdam University and Mary Tyree, Scripps Institution of Oceanography, to obtain additional information and guidance. Guido Franco, Senior Engineer and Technical Lead for Climate Change

Research at the California Energy Commission provided modeling support to develop SLR values for dates prior to 2100.

Planned Future Updates

Because the science related to SLR is rapidly advancing, this guidance document will be regularly revised to reflect the latest scientific understanding of how the climate is changing and how this change may affect SLR. Some of the documents that may inform future revisions of this guidance document include, but are not limited to, the following.

Summer 2011 Studies supporting the California Vulnerability and Adaptation Project, which includes the following:

1. Hourly sea-level projections[1] for San Diego, La Jolla, Los Angeles, San Francisco, and Crescent City, which include effects of tides, weather, El Niño/Southern Oscillation; and
2. 50 and 100 year coastal flood potential projections (wave run-up)[2] using nearby sea level estimates and a set of ocean wave simulations for the following sites: (1) Silver Strand Beach north of the Mexican border; (2) La Jolla Shores in the City of San Diego; (3) Santa Cruz Boardwalk in central California; (4) Ocean Beach in San Francisco; and (5) beach and harbor locations at Crescent City in northern California.

Summer 2012 Report from the National Academy of Sciences Expert Panel on West Coast SLR

Fall 2013 Fifth Assessment Report from Intergovernmental Panel on Climate Change, Working Group 1 (the Physical Science Basis)

If staff resources are available, it is likely that this guidance document will be updated annually to incorporate the latest scientific understanding of SLR.

Recommendations

The SLR Task Force reached agreement on the following policy recommendations based upon recent estimates of future SLR from the scientific literature and input from scientists as described above.

1. **Use the ranges of SLR presented in the December 2009 *Proceedings of National Academy of Sciences* publication by Vermeer and Rahmstorf[3] ("Vermeer and Rahmstorf publication") as a starting place and select SLR values based on agency and context-specific considerations of risk tolerance and adaptive capacity.** Table 1 (below) presents

[1] Work underway by Dan Cayan, Mary Tyree et al. at Scripps Institution of Oceanography, using, among other tools, the model published by Vermeer and Rahmstorf in the *Proceedings of the National Academy of Sciences,* 2009.

[2] Work underway by Peter Bromirski from Scripps Institute of Oceanography.

[3] Available at http://www.pnas.org/content/106/51/21527.full.pdf+html.

SLR projections based on the Vermeer and Rahmstorf publication[4], adjusted to use 2000 as a baseline[5]. There remains uncertainty in our understanding of and ability to model a changing climate; nonetheless, the Task Force developed the projections below using the best available science. Refer to Recommendation # 2 for a discussion of time horizon, risk tolerance, and adaptive capacity, which should be considered when choosing values of SLR to use for specific assessments.

Table 1. Sea-Level Rise Projections using 2000 as the Baseline

Year		Average of Models	Range of Models
2030		7 in (18 cm)	5-8 in (13-21 cm)
2050		14 in (36 cm)	10-17 in (26-43 cm)
2070	**Low**	23 in (59 cm)	17-27 in (43-70 cm)
	Medium	24 in (62 cm)	18-29 in (46-74 cm)
	High	27 in (69 cm)	20-32 in (51-81 cm)
2100	**Low**	40 in (101 cm)	31-50 in (78-128 cm)
	Medium	47 in (121 cm)	37-60 in (95-152 cm)
	High	55 in (140 cm)	43-69 in (110-176 cm)

Note: These projections do not account for catastrophic ice melting, so they may underestimate actual SLR. The SLR projections included in this table do not include a safety factor to ensure against underestimating future SLR. For dates after 2050, three different values for SLR are shown - based on low, medium, and high future greenhouse gas emission scenarios. These values are based on the Intergovernmental Panel on Climate Change emission scenarios as follows: B1 for the low projections, A2 for the medium projections and A1FI for the high projections.

2. **Consider timeframes, adaptive capacity, and risk tolerance when selecting estimates of SLR.** The timeframe identified for a project is important for SLR assessments and will affect the approach for assessing impacts. Until 2050, there is strong agreement among the various climate models for the amount of SLR that is likely to occur. After mid-century, projections of SLR become more uncertain, because the modeling results diverge and the SLR projections vary depending upon how quickly the international community reduces greenhouse gas emissions. Therefore, for projects with timeframes beyond 2050, it is especially important to consider adaptive capacity, impacts, and risk tolerance to guide decisions of whether to use low, medium, or high SLR projections. Due to differing agencies mandates, stakeholder input and other considerations, agencies may assess the adaptive capacity of a project or action differently.

[4] The projections by Vermeer and Rahmstorf are for global mean sea level; recent studies of regional mean sea level variability indicate that over long timeframes, sea level along the California coast tends to compare well with the global trends, so these values are not adjusted for regional differences.

[5] Vermeer and Rahmstorf's paper presents values using 1990 as a baseline. Here the values are adjusted by subtracting 3.4 cm, which represents 10 years of sea-level rise that has already occurred, at an average rate of 3.4mm/year.

Consequences = Impacts x Adaptive Capacity

The consequences of failing to address SLR for a particular project will depend on both adaptive capacity and the *potential* impacts of SLR to public health and safety, public investments, and the environment. Figure 1 in Appendix B (appended to the end of this document) illustrates how adaptive capacity and potential impacts combine to produce consequences.

Adaptive capacity is the ability of a system to respond to climate change, to moderate potential damages, to take advantage of opportunities, and to cope with the consequences.[6] A project that has high adaptive capacity and/or low potential impacts will experience fewer consequences. For example, an unpaved trail built within a rolling easement with space to retreat has high adaptive capacity (because the trail can be relocated as sea level rises) and therefore will experience fewer harmful consequences. In contrast, a new wastewater treatment facility located on a shoreline with no space to relocate inland has low adaptive capacity and high potential impacts from flooding (related to public health and safety, public investments, and the environment). The negative consequences for such a project of failing to consider SLR would therefore be high.

Risk Tolerance

The amount of risk involved in a decision depends on both the consequences and the likelihood of *realized* impacts that may result from SLR. These realized impacts, in turn, depend on the extent to which the project design integrates an accurate projection of SLR. However, current SLR projections provide a range of potential SLR values and lack precision (see Table 1 above). Therefore, agencies must consider and balance the relative risks associated with under- and/or overestimating SLR in making decisions.[7]

Figure 2 in Appendix B illustrates this relationship for a project in which underestimating SLR in the project design will result in harmful realized impacts such as flooding. In this case, harmful impacts are more likely to occur if the project design is based upon a low projection of SLR and less likely if higher estimates of SLR are used. In situations with high consequences (high impacts and/or low adaptive capacity), using a low SLR value therefore involves a higher degree of risk.

[6]Definition of adaptive capacity used in the 2*009 California Climate Adaptation Strategy,* based upon definition provided in *Climate Adaptation: Risk, Uncertainty and Decision-mak*ing, UK CIP (2003), UKCIP Technical Report, Oxford, Willows, R. I. and R. K. Cornell (eds.).

[7] Examples of harmful impacts that might result from underestimating SLR include damage to infrastructure, contamination of water supplies due to saltwater intrusion, and inundation of marsh restoration projects located too low relative to the tides. Examples of harmful impacts that might from overestimating SLR include financial costs of over-engineering shoreline structures, locating in-water development in too shallow a depth to avoid navigational hazards, and marsh restoration projects located too high relative to the tides.

3. **Coordinate with other state agencies when selecting values of SLR and, where appropriate and feasible, use the same projections of sea-level rise.** For agencies that have jurisdiction over the same project, using the same SLR values will increase efficiency of analyses and promote consistency. As of the date of this guidance document, the State Coastal Conservancy (SCC) and the State Lands Commission (SLC) have adopted, and the Delta Vision Blue Ribbon Task Force Independent Science Board[8] has recommended, the use of 55 inches (140 cm) of SLR for 2100. The SCC and the SLC also adopted a policy of using 16 inches (41 cm) as the estimate of SLR for 2050. These values of SLR are not specifically referenced to a particular baseline year and agencies may revise these values as new scientific information becomes available. Agencies may select other values depending on their particular guiding policies and considerations related to risk, ability to incorporate phased adaptation into design, and other factors.

4. **Future SLR projections should not be based on linear extrapolation of historic sea level observations.** For estimates beyond one or two decades, linear extrapolation of SLR based on historic observations is inadequate and would likely underestimate the actual SLR. According to the OPC Science Advisory Team, because of non-linear increases in global temperature and the unpredictability of complex natural systems, linear projections of historical SLR are likely to be inaccurate.

5. **Consider trends in relative local mean sea level.** Relative sea level is the sea level relative to the elevation of the land. In California, the land elevation along the coast is changing due to factors including tectonic activity and subsidence. The National Oceanic and Atmospheric Administration provides a summary of the trends in the measured relative sea level at tidal gauges (water level recorders) in California that have been operating for at least 30 years. Predictions of future sea levels at specific locations will be improved if relative trends in sea level from changes in land elevation are factored into the analysis. http://tidesandcurrents.noaa.gov/sltrends/index.shtml

6. **Consider storms and other extreme events.** [9] Future sea level will be a starting point for many different types of analysis for project design. For example, in determining wave impacts, future mean sea level combined with tides, storm surge and El Niño-Southern Oscillation forcing will establish the elevated water level that will be the input for determining wave forces and wave run-up. Where feasible, consideration should be given to the extreme oceanographic conditions that can occur, given the highest water levels projected to result from SLR over the expected life of a project.

[8] Formerly the CALFED Independent Science Board.

[9] OPC plans to coordinate with agencies to identify methods to use to evaluate storms and other extreme events. At this time, there is not a consistent approach and the methodology will depend on many factors.

7. **Consider changing shorelines.** California's very dynamic coast will evolve under rising sea level and assessments of impacts from SLR to shoreline projects must address local shoreline changes. For example, there could be less significant coastal change due to SLR in areas of high sediment supply (e.g., offshore of large northern CA rivers), whereas the coast may recede or change very dramatically in other areas (low sediment supply, presence of eroding bluffs or dunes, etc.). Existing resources for assessing future erosion/accretion rates include: U.S. Geological Survey report on shoreline changes for California's beach habitat[10] http://pubs.usgs.gov/of/2006/1219/, U.S. Geological Survey report on shoreline changes for California's bluff habitat[11] http://pubs.usgs.gov/of/2007/1133/.

[10] Cheryl Hapke et. al, *National Assessment of Shoreline Change Part 3: Historical Shoreline Change and Associated Coastal Land Loss along Sandy Shorelines of the California Coast* (U.S. Geological Survey Open File Report 2006-1219, 2006).
[11] Cheryl Hapke et. al, *National Assessment of Shoreline Change Part 4: Historical coastal cliff retreat along the California coast* (U.S Geological Survey Open File Report 2007-1133, 2007).

APPENDIX B

FOR ILLUSTRATION PURPOSES ONLY

Figure 1. Consequence = Impacts x Adaptive Capacity

	Low Adaptive Capacity	Medium Adaptive Capacity	High Adaptive Capacity
High Impact	HIGH CONSEQUENCES	HIGH CONSEQUENCES	MEDIUM CONSEQUENCES
Medium Impact	HIGH CONSEQUENCES	MEDIUM CONSEQUENCES	LOW CONSEQUENCES
Low Impact	MEDIUM CONSEQUENCES	LOW CONSEQUENCES	LOW CONSEQUENCES

This figure demonstrates how the consequences of a decision are determined by the amount of impact and by the adaptive capacity. There are higher consequences when there are greater impacts and lower adaptive capacities.

Figure 2. Example of:
Risk = Consequence x Likelihood

For projects where too much sea-level rise would cause project impacts such as flooding,

	if use lower estimates of sea-level rise	if use medium estimates of sea-level rise	if use higher estimates of sea-level rise
	Higher Likelihood Impacts	Medium Likelihood Impacts	Lower Likelihood Impacts
High Consequence	HIGH RISK	HIGH RISK	MEDIUM RISK
Medium Consequence	HIGH RISK	MEDIUM RISK	LOW RISK
Low Consequence	MEDIUM RISK	LOW RISK	LOW RISK

This figure demonstrates how the amount of risk is determined by the consequences (impacts and adaptive capacity) and the likelihood of impacts occurring. In this example, using higher SLR estimates lower the project risks."

RESPONSES TO QUESTIONS FOR CALIFORNIA OCEAN PROTECTION COUNCIL'S SCIENCE ADVISORY TEAM FROM THE SEA-LEVEL RISE TASK FORCE OF THE OCEAN AND COASTAL WORKING GROUP OF THE CALIFORNIA CLIMATE ACTION TEAM (CO-CAT)

September 1, 2010

Process for Including Guidance from the OPC-Science Advisory Team

This Interim Guidance Document was informed by a sub-committee of select experts from the OPC Science Advisory Team (OPC-SAT):

1. Dr. Dan Cayan, Research Meteorologist, UC San Diego Scripps Institution of Oceanography & U.S. Geological Survey
2. Dr. Gary Griggs, Director of the UC Santa Cruz Institute of Marine Sciences
3. Dr. Sam Johnson, Research Geologist, USGS Pacific Science Center
4. Dr. Tony Haymet, Director of the UC San Diego Scripps Institution of Oceanography

Dr. Gary Griggs served as chair of the SLR Interim Guidance subcommittee. In this role, he received a list of questions compiled by OPC staff and the OPC science advisor. Dr. Griggs forwarded the questions to identified experts within the OPC-SAT, and subcommittee members were asked to identify any potential conflicts of interest or limits to their expertise when answering questions. Members of the subcommittee communicated with Dr. Griggs as they developed responses to questions, and Dr. Griggs himself responded to questions. Dr. Griggs received responses from subcommittee members and compiled and synthesized all responses into a single document that was disseminated to subcommittee members for comment and consensus. The document was provided to the OPC staff and science advisor, then disseminated among the CO-CAT SLR Task Force members.

Introduction to OPC-SAT Responses to SLR Task Force Questions

The CO-CAT has raised a number of specific questions about future sea level rise, including the different models or projections that have been put forward in recent years, what assumptions are involved in those models, and their particular strengths and weaknesses. A group from the OPC's Science Advisory Team who work in this area or in related disciplines have reviewed and responded to these questions.

Most of the questions posed focus on global sea level rise rates, which is certainly one important consideration. Along the California coastline, however, which is tectonically active, an equally important question is the local sea level rise rates. Global and local sea level trends differ because the former are directly related to the volume of the world's ocean, while the latter are based on long-term water-level measurements relative to the land at fixed locations. Just as water levels rise and fall as the ocean volume decreases and increases with climate change, the Earth's surface in many areas also moves up and down adding or subtracting from the global sea level trend. Measured local or regional sea level trends provide an important parameter to government agencies concerned with coastal erosion and inundation or flooding in the next several decades.

There are presently 12 coastal tide gages or water level recorders maintained by NOAA, which extend from Crescent City to San Diego, or one about every 85 miles. These stations range in the length of their historical record from 33 to 113 years; eight stations have at least 50 years of record and six have over 75 years of data. With two exceptions (along the north coast), each of these tide gauges has recorded average sea level rise rates that fall in the range of 0.83 to 2.22 mm/yr, a surprising narrow range considering these gauges span 725 miles of tectonically active coastline. The two exceptions are Humboldt Bay's North Spit where an average rate of 4.72 mm/yr has been recorded over the past 33 years, and Crescent City, where the rate is a negative 0.65 mm/yr over the last 77 years. The record at Humboldt Bay shows sea level is rising at a rate higher than the global value indicating land subsidence. The record at Crescent City, 100 miles north, reveals a slight drop in sea level indicating uplift of the land surface in this area is occurring at a rate greater than global sea level rise.

Short-term local increases in sea level will no doubt be of greater concern to coastal infrastructure and development in coastal areas over the next several decades than sea level rise rates. The coast of California has experienced two very large El Niño events over the past 20 years, in 1983 and 1997-98, with hundreds of millions of dollars in storm damage to private property and public infrastructure. The damages occurred from a combination of elevated sea levels and large storm waves, which often coincided with high tides. During the 1983 ENSO event, sea levels were the highest ever recorded in San Diego, Los Angeles and San Francisco, 11.4 in., 12.7 in., and 21.2 in., respectively, above predicted high tides. Over the short-term, these events will be more damaging to the coastline than the gradual sea level rise we are experiencing.

We are also on a sea level rise curve with an upward slope that will continue far into the future, most likely at an increasing rate. We cannot predict precisely what the slope of the curve will be 50 or 100 years into the future, because the curve will depend to a large degree upon future global greenhouse gas emissions. In the short term however, say between now and 2050, there are not major differences in the projections of the most commonly referenced or cited studies.

Responses to Questions posed to the OPC Science Advisory Team

1. What are the strengths and weaknesses of the following approaches for identifying ranges of future mean global SLR?

a. Methods that correlate air temperature and global mean sea levels
    i. California Energy Commission's Public Interest Energy Research (PIER) 2009 Scenarios Project - Dan Cayan et.al http://www.energy.ca.gov/2009publications/CEC-500-2009-014/CEC-500-2009-014-F.PDF
    ii. Using the full range of IPCC scenarios and the SLR modeling described in the Proceedings of the National Academies of Science December 2009 Vermeer and Rahmstorf http://www.pik-potsdam.de/~stefan/Publications/Journals/vermeer_rahmstorf_2009.pdf
    iii. Choosing specific IPCC emission scenarios (e.g. A2, A1F1) and using the SLR ranges associated with those emission scenarios based on the Vermeer and Rahmstorf 2009 report

All of these methods are empirical, being run offline using output derived from global climate models (GCMs). A strength is that they are tied to observed sea level and global climate. A weakness is that they are very coarse approximations, and are based upon the previous decades where some processes that may become much more important such as ice melt from Greenland and Antarctica have been relatively inactive. The premise that the historically observed relationship between global temperature and sea level rise will be maintained through the next Century is somewhat shaky, and probably becomes less valid as global warming advances and climate begins to depart farther from its 20th Century state. Details of ice melt—where the largest sources are/will be, what thresholds exist, catastrophic changes due to wholesale slumps and fractures are all factors that will require the development of highly resolved, physically based models that are coupled to the climate models.

Cayan et al. 2009 employed the semi-empirical method of Rahmstorf 2007 to estimate global sea level rise, and also considered the possible effects of dam-filling as described by Chao et al. 2008. Cayan et al 2009 employed a set of 12 global climate simulations from 6 GCMs, each having two emissions scenarios (SRES A2 and SRES B1), which is a subset of the available IPCC GCM runs. The Rahmstorf 2007 scheme has since been revised by Vermeer and Rahmstorf (2009) using a similar method, but accounting for 2nd order warming effects. The Vermeer and Rahmstorf (2009) scheme, when applied to the same climate simulations as Rahmstorf (2007) result in higher amounts of sea level rise by 2100, with the upper portion of the range of estimates exceeding 1.5m sea level rise by 2100.

b. Methods adopted by U.S. Army Corps of Engineers, which estimate the "intermediate" and "high" rates of local mean sea-level change using the modified National Research Council method and the most recent IPCC projections and adds those to the local rate of vertical land movement.

http://140.194.76.129/publications/eng-circulars/ec1165-2-211/entire.pdf

This is a quantification that was derived from information that was available at the time USACE prescribed the "intermediate" and "high" rates. The USACE intermediate and high rates exceed those put forward by the IPCC, acknowledging the possibility of substantial contributions from the melting of land ice. Newer estimates (than employed by USACE) from empirical estimates that Rahmstorf describes in his summary paper, would perhaps lead to a higher "high" sea level rise rate. Also, this is a categorization. For some applications, it may be useful to consider an estimate of sea level rise that is identically tied to a given climate simulation—this is possible using empirical schemes such as Vermeer and Rahmstorf 2009, but that is not the case for the USACE categorical guideline rates.

The weakness of the USACE report is that it relies on an approach and models developed for a 1987 NRC report. Without reading that report, we assume some of the basic data and models it relied on have been significantly updated. On the other hand, the USACE adapts the NRC data to develop a range of 50 to 150 cm for RSL by 2100, not significantly different from the recent reports cited in Rahmstorf (2010). A strength of the USACE approach is that it incorporates recent SLR trends and vertical land-level changes in SLR assessments, and provides a step-by-step schematic for downscaling to local site-specific projects. It also acknowledges that regular updates will be needed as new information and models are developed.

c. Projections of historical rates of SLR
    i. Linear projections
    ii. Non-linear projections

Given non-linear increases in global temperature and the unpredictability of complex natural systems, linear projection of historical SLR is not valid. Non-linear projections are based on models - their output will be as good as the model input and algorithms (i.e., some better than others).

It should be noted that estimates from observed in situ and remotely sensed sea level indicate that the rate of sea level rise has increased over the last several decades—remotely sensed estimates during the last 15 years or so suggest that global sea level is rising at a rate that exceeds 3mm/year. This increase in the rate of sea level rise, along with the physical consideration that the ice melt contribution to sea level rise will increase as warming advances, is a strong argument that linear extrapolations of the sea level record itself is inadequate for time scales beyond a decade or so. Very likely, the change in sea level rise will be non-linear, but it will be difficult to achieve a fit to this rate that maintains its accuracy into the future. To base a projection on sea level alone, ignoring external variables such as global temperature, seems inferior to methods that include these driving variables, in that the latter offer at least a coarse mechanistic perspective and they allow for scenarios that are tied directly to global climate simulations.

d. Other Methods such as those referenced in "A New View on Sea Level Rise" article by Stephen Rahmstorf (**Nature Reports Climate Change** Vol. 4, April 2010.)

Other empirical techniques exist, as illustrated in Rahmstorf's Review in April 2010 *Science*. For example, Grinsted et al 2009 use paleoclimate observations/estimates in addition to observations from the historical instrumental record in their empirical technique. Interestingly, the range of sea level rise that results from their scheme is quantitatively similar (though a bit wider) to that obtained using the Vermeer and Rahmstorf (2009) technique.

2. Which approach or combination of approaches would you recommend for estimating ranges or mean global sea levels?

It is important to acknowledge that many (if not most) of the current approaches (except the one used by IPCC which ignores any contribution from ice melt) are giving similar results (~75 to 150+ cm of SLR by 2100), with the large range reflecting uncertainties in both emissions scenarios and the evolving science of short-term climate change modeling. Beyond two decades or so, the present state of the art from empirical techniques such as Vermeer and Rahmstorf provide useful guidance, presumably accounting for the contribution from ground-based ice melt from Greenland and Antarctica.

Both global warming and SLR will continue to be investigated intensively in the next decade and beyond, and SLR estimates will fluctuate and change as models improve and new data are generated. Semi-empirical approaches described in Rahmstorf (2010) that build models based on historical data seem valid but are limited in their ability to incorporate nonlinear phenomena such as large, rapid ice melts and surges.

3. What is the SAT's recommendation regarding the use of linear projections of SLR based on historic observations (method "c(i)" listed above)?

For estimates beyond one or two decades, linear extrapolation is inadequate and would likely underestimate the actual sea level rise. The SAT does not recommend this approach.

4. If a SLR projection method is chosen that uses IPCC emissions scenario information, would it be appropriate to eliminate the B1 scenario (lowest IPCC

emission scenario) from consideration given current greenhouse gas emissions and apparent lack of political resolve to reduce them in the near future?

The reason there are different scenarios for emissions and other climate and societal factors is that we cannot be certain what pathway the future will take. Thus, it seems advisable to consider a broad range of scenarios. Low SLR projections (all approaches) should be continuously adjusted upward based on upward-revised, low-end emissions scenarios and changes in global temperature. Also, IPCC SLR scenarios should not be considered realistic because of their failure to incorporate contributions from ice melt.

It should be pointed out that, for a given global climate model, the difference between global and regional temperature produced by different emissions scenarios remains relatively small until about 2050. It takes decades for the cumulative effect of different emissions pathways to become distinct, vis-a-vis the atmospheric greenhouse gas concentration, its effect upon radiative forcing and resultant global warming.

5. What are pros and cons of using the following options for the outputs from the suite of models used in assessments such as Dan Cayan et al. 2009 and Vermeer and Rahmstorf 2009:
    a. Average the outputs for all scenarios

Perhaps ok for certain applications, but this of course obscures the underlying emission scenarios and GCMs and possibly the sea level schemes that are averaged if multiple sea level models are employed. It also erases the distribution of outcomes.

This is fluid and fertile science and the shelflife of models is relatively short- for example, compare Rahmstorf (2007) with Vermeer and Rahmstorf (2009) (Figure 1 in Rahmstorf, 2010). Further changes are highly likely, especially as better understanding develops of the land-ice response to global warming. Averaging the most recent peer-reviewed, published model outputs could provide an important "snapshot" of current thinking, but will almost certainly change in the next several years. (b) and (c) have the same issues as (a).

This raises two important issues: (1) selecting which SLR models to incorporate in an assessment of SLR ranges or extremes; (2) any such assessment will likely change in the next few years.

    b. Full range of outputs for all scenarios,

This provides more information to the decision maker so they are aware of the distribution and, for what its worth, to the underlying climate models and emission scenarios that are considered.

It is important to note, though that this distribution, even though populated according to several simulations/scenarios, is very likely not the true distribution.

c. Use the extremes (highest and/or lowest values) from the full range of outputs?

This brackets the set of model solutions, but the extremes are continually changing as new sea level models or schemes come available. Also, it is not clear, if the entire distribution is not presented, how “rare” the low or high extreme that is selected may be. Again, the choice of which solutions to use in guiding decision-making depends on application—how much risk is the decision maker or agency willing to take?

6. What is the SAT’s recommendation regarding how to incorporate likelihood of certain amounts of SLR occurring at certain dates and how to incorporate consideration of risk as part of the assessment of the amount of SLR to consider for different state agency decisions?

This is a moving target, because the science of sea level modeling is rapidly developing but present estimates applying V/R or another recent empirical technique to a ensemble of climate simulations are probably a good place to start. Where possible, the recommendation is to adopt an adaptive strategy, which leaves room for course corrections as new information emerges (it will surely do so).

The second part of the question, concerning SLR and risk, is a different topic than the first part and raises several important questions. *"How will the CA coast respond to SLR? What will be the physical, ecosystem, and economic impacts of such responses? What can we model/predict? What new science or experiments are needed to guide predictions and models? What are appropriate human responses and their feedbacks, and how will they affect coastal evolution as well as hazard and risk assessments, etc."* As with other natural hazards (e.g., earthquakes), risk assessment requires a solid scientific foundation. A whole new era of coastal science and engineering will be needed to inform SLR risk assessment and confront the SLR challenge.

7. In addition to predicting future sea levels, other factors may also be important. What research or methods could help identify possible future changes in
    a. Tidal amplitude and/or phase, and
    b. Extreme events (e.g. high water due to storm surges, ENSO events)?
        - What is the SAT’s assessment of superimposing historical extreme event departures from mean on projected mean sea levels to estimate future values?

The full set of sea level dynamics is crucial to consider—tides, weather, ENSO and other shorter range factors must be considered in evaluating extremes, return periods, and related issues. As mentioned in the introductory statement, elevated sea levels during the last two major El Niño events (1983 and 1997-98) were important factors in the storm damage that California experienced and, in the short term, will be significantly larger than sea level rise values.

Superimposing historical extreme event departures on projected higher sea levels seems like a reasonable starting point, however this approach misses an important intermediate step. There must also be an understanding/prediction of how the coast, which is very dynamic, will evolve under rising sea level. For example, there could be less significant coastal change due to SLR in areas of high sediment supply (e.g., offshore large northern CA rivers), whereas the coast may recede or change very dramatically in other areas (low sediment supply, presence of erodible bluffs or dunes, etc.). The impact of extreme events under SLR may be much less in the first case than in the second. Once coastal evolution is considered/predicted/understood (which is not easy), then an informed assessment of the run-up and impact/risk of extreme events under SLR can proceed.

8. Are there additional investigations/modeling efforts, research, etc., presently underway that would inform this discussion?

Basin scale sea level variability must be better understood. Observational and modeling studies are needed to understand large scale decadal structure such as the recent pattern we have been observing, wherein the eastern North Pacific has experienced little or no sea level rise during the last decade while the far western Pacific has exhibited rates of sea level rise that more than double the global rate.

Dynamics and structure of how sea level changes are manifested in the San Francisco Bay/Sacramento-San Joaquin Delta, which contains crucial infrastructure and is the critically important hub for California’s water supply conveyance.

There is obviously and appropriately a lot of emphasis on how much SLR to expect and plan for. However, there needs to be equal emphasis placed on how the coast will evolve under SLR, including feedbacks and impacts of different human responses. As stated above, a whole new era of coastal science and engineering will be needed to confront the SLR challenge and CA coastal zone managers need to acknowledge and prepare for that.

9. What other questions should we be asking that we haven’t asked? What other considerations should be brought to bear on this topic?

More modeling and analysis is need to evaluate the contributions of fresh water floods, along with high oceanic sea levels, to water levels along certain coastal segments and especially in the San Francisco Bay/Delta.

Continued observations and modeling of wind waves are needed to better understand variability and changes in wave climate and significant wave events. Further work is needed to couple the waves with tides and sea level, shallow water bathymetry and coastal topography, leading to understanding beach run-up. The critical period for California is nearly always associated with winter storm phenomenon, particularly during ENSO events, but warm season conditions should also be assessed.

The continuing retreat and evolution of the coastline, as well as the hazards that individual areas are exposed to, varies along the length of California's coast depending upon factors such as :

1) *Geomorphology* (steep rugged terrain such as Big Sur or Humboldt and Mendocino counties, which is generally undeveloped); low bluffs and raised terraces that are typically intensively developed (much of northern San Diego, Orange, Santa Barbara, Santa Cruz and San Mateo counties); coastal lowlands (much of the Santa Monica Bay to Newport Beach area, and the San Diego area, for example).

2) *Coastal uplift or subsidence*. Although much of the California coast south of Cape Mendocino is slowly being uplifted, the rates are too low to significantly mitigate for SLR. The situation is different north of Cape Mendocino, where an expected plate boundary earthquake is likely to produce coseismic uplift near Cape Mendocino (because of proximity to the deformation front) and coseismic subsidence farther north. These regional tectonic differences are evident in the tide gauge records from Crescent City and Humboldt Bay discussed earlier.

   Thus, the combined affects of global warming and tectonics on SLR may be greatest (by a large amount) in northernmost California - this needs further consideration and study.

Coastal hazards will therefore vary geographically and will result from a combination of sea level rise and tectonic uplift or subsidence, as well a changing storm wave climate. California has several different coastal environments, which are exposed to different risks, risks that will in all likelihood increase in the future. Each of these needs to be understood, their risks assessed and adaptation measures developed.

a. **Inundation or coastal flooding along the low lying portions of the open coast-** About 300 miles of California's coast consists of low relief coastal plains fronted with beaches. Much of the beach development of these low lying areas is concentrated in Southern California, but also in Monterey Bay, where homes, hotels, infrastructure as well as state parks have been built at beach level. These have all been damaged in recent years by storm waves during ENSO events with elevated sea levels and it is realistic to expect that the frequency of these incidents will almost certainly increase in the future as sea level continues to slowly rise.

b. **Inundation of low-lying areas around San Francisco Bay**- San Francisco and Oakland airports and portions of the South Bay will suffer major inundation with 3 feet of sea level rise. This is a major issue but clearly a different problem than the open coast faces.

c. **Coastal erosion of cliffs, bluffs and dunes:** this process has been going on for the past 18,000 years since the last Ice Age ended. Sea level has risen about 350-400 feet during this period as the ice sheets melted and glaciers retreated. This process and the landward migration of the coastline is continuing today at average rates of a few inches to as much as 10 feet per year, depending primarily on local geologic conditions, wave energy and sea level rise. All evidence indicates that these rates will rise in the future.