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## 2017 Coastal Master Plan

# Attachment C2-1: Eustatic Sea Level Rise



Report: Version I

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## Coastal Protection and Restoration Authority

This document was prepared in support of the 2017 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every five years) and annual plans. CPRA's mandate is to develop, implement and enforce a comprehensive coastal protection and restoration master plan.

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## Executive Summary

For the 2017 Coastal Master Plan modeling effort, sea level rise (SLR) ranges were established on the basis of an extensive data and literature review. Although the full breadth of historical work on this topic was considered, emphasis was placed on new observations and predictive modeling generated between the 2010 completion of a similar review that informed the 2012 Coastal Master Plan models (as described in CPRA, 2012) and fall 2014. Only eustatic (global) or regional SLR rates were used, as the subsidence component of locally-specific relative SLR is accounted for separately in the 2017 modeling effort. To establish the full plausible range of future SLR, this review evaluated equally results from both process-based and semi-empirical predictive models (see discussion in Jones, 2013). This review also made no likelihood estimations of specific scenario values of future SLR to use in the 2017 Coastal Master Plan predictive models, and thus all values within the recommended range are considered equally plausible.

The low boundary for SLR is 0.31 meters by 2100, based on the minimum value reported in Church et al. (2013) following process-based climate modeling, followed by a regional adjustment of values for the Gulf of Mexico. The high boundary for SLR is 1.98 meters by 2100, and is a Gulf regional adjustment of results of semi-empirical modeling conducted by Jevrejeva et al. (2012). Both scenarios represent accelerations in rate beyond the historical linear rate of  $2.7 \text{ mm yr}^{-1}$  for a collection of Gulf Coast tide gauges in western Florida that serve to define Gulf of Mexico regional eustatic SLR, which would have resulted in a prediction of 0.29 meters of Gulf regional SLR by 2100, assuming a 1992 base year. For purposes of the actual sensitivity and production modeling to be performed for the 2017 Coastal Master Plan, these values represent a 2015-2065 Gulf regional SLR of 0.14 meters (0.46 feet) for the lower-bound scenario and 0.83 meters (2.72 feet) for the upper-bound scenario.

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## List of Abbreviations

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CMIP	Coupled Model Intercomparison Project
CPRA	Coastal Protection and Restoration Authority
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanographic and Atmospheric Administration
NRC	National Research Council
RCPs	Representative Concentration Pathways
SLR	Sea Level Rise
USACE	U.S. Army Corps of Engineers

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## 1.0 Introduction

Sea level change can cause a number of impacts in coastal and estuarine zones, including changes in shoreline erosion, inundation or exposure of low-lying coastal areas, changes in storm and flood damages, shifts in extent and distribution of wetlands and other coastal habitats, changes to groundwater levels, and alterations to salinity intrusion into estuaries and groundwater systems (CCSP, 2009). It is thus considered a key driver in coastal planning efforts and an important component of the 2017 Coastal Master Plan modeling effort.

Due to inconsistent usage of certain terms regarding sea level rise (SLR) in the past by some literature sources, the following text will clarify definitions used in this report.

- The use of the term eustatic SLR in this report will be limited to the discussion of the average change in global ocean surface due to changes in freshwater addition and temperature-induced thermal expansion of the oceanic water bodies.
- Regional SLR will refer to discussion of the change in sea surface at a more local level, such as for the aggregate Gulf of Mexico. Regional values may differ from eustatic SLR rates due to, for example, differences in geographic distribution of gravimetric loads, thermal loads to regional water bodies, and regional effects of specific global ocean currents.
- Relative SLR will refer to local perceived rates of SLR once regional SLR is combined with either uplifting or subsiding vertical land motions. Therefore, rates of local relative SLR may be less or greater than regional SLR depending on the nature and magnitude of those land motions.

This report mirrors the common method used in other literature of defining future eustatic SLR curves by defining both the historical rate of SLR and the predicted sea level at a point in the future. Both components are developed in this section. This report builds on the corresponding information regarding eustatic SLR in Appendix C of the 2012 Coastal Master Plan (CPRA, 2012), but focuses on new technical literature published since the preparation of that document that underlies modifications to the plausible range of eustatic SLR and the specific scenario values recommended for the 2017 Coastal Master Plan technical analysis.

## 2.0 Proposed Revisions to the Plausible Range for the 2017 Coastal Master Plan Models

### 2.1 Update of the Historical Rate of Eustatic SLR

The historical rate of SLR may be determined from a global network of tide gauges and/or more recent satellite altimetry datasets. A distinct advantage of the tide gauge networks is that they provide the only long-term observations of relative sea-level, since satellite altimeters have only been in service since 1992. However, because tide gauges do measure relative sea level, regional and local corrections must be made to individual gauge data records before those datasets can be aggregated into a calculation of either global or local mean sea level.

In comparison, the use of satellite altimeters benefits from the global nature of the observations from individual altimeter missions. However, there has been an attendant limitation in applying satellite altimetry data to coastal areas, due to the complex interactions between coastal landforms and oceanic water bodies. Significant efforts have been made to correct for these interactions and improve the applicability of altimetry datasets for coastal sea level predictions (Fernandes et al., 2003; also see the European ALTICORE project <http://www.alticore.eu/index.php>).

The period of record of any one individual data record (tide gauge or altimeter) is a critical aspect when examining sea level trends, on two fronts. First, the estimated rate of local SLR at an individual tide gauge is entirely dependent on the specific time period selected for analysis. Over the period of record the individual drivers of local sea level change, multi-decadal cycles in regional sea level overlay interannual variation and anomalous events can occur. The second aspect is the potential error associated with the readings because of the individual gauge period of record. As described in DeMarco et al. (2012),

“To obtain a robust estimate of the historic relative mean sea level change, a longer tide gauge station record is preferable, especially if that rate will be used to predict future SLR trends. A short record can make it difficult to fully account for the impacts of interannual and decadal variations in sea level resulting in misleading or erroneous sea level trends. The Intergovernmental Oceanographic Commission (2006) suggests that the duration of a tidal record should be at least two lunar nodal cycles (about 40 years) before being used to estimate a local relative sea level trend, while Douglas et al. (2001) claims that the length of record should be approximately 60 years and have 85% coverage during that time period to minimize variation. The uncertainty, or “noise” in data, from record lengths shorter than 40 years in duration can quickly outweigh any SLR projections of a few millimeters per year ...”

The estimated 95% confidence interval around a SLR projection increases substantially for periods of record shorter than 40 years (Figure 1). While it is a simple matter to parse out tide gauges from national or international networks that do not meet a 40- or 60-year period of record, the same cannot be said for the satellite altimetry record, which has only been available since 1992. This significantly limits the use of satellite altimetry datasets by themselves for estimating sea level trends. However, several recent papers have described the agreement between the global tide gauge and satellite altimetry data records where they overlap (Ablain et al., 2009; Prandi et al., 2009; Church & White, 2011), leading to a consideration of both datasets in aggregate as a proper estimate of sea level trends. This analysis will take a similar approach.

The last comprehensive attempt to reconstruct twentieth century sea levels from both tide gauge and satellite altimetry data was that of Church and White (2011), who calculated a widely-cited overall linear rate of global SLR for 1900-2009 of  $1.7 \pm 0.2$  mm yr<sup>-1</sup> (Table 1, Figure 2). However, those same authors showed that subsets of the overall 1880-2009 dataset showed increasing slopes moving through time (Table 1), reinforcing the earlier recognition that trend is highly dependent on period of record. In this case, the steady increases in rate with more contemporary periods of record show a pattern of acceleration. Church and White (2011) noted that deviations from the linear trend “... significantly different from zero at the 95% level.” Accordingly, they defined a nonlinear acceleration in the rate of 1880-2009 eustatic SLR of  $0.009 \pm 0.003$  mm per year.

The satellite altimetry data for 1993-2013 shows an overall global eustatic sea level of  $2.8 \pm 0.4$  millimeters per year (NOAA Laboratory for Satellite Altimetry (<http://ibis.grdl.noaa.gov/SAT/>))

multiple altimeter data, seasonal signals removed, accessed 29 April 2014). The scientific community has long-recognized, though, that the global SLR pattern is highly variable. Merrifield et al. (2009) stated that the satellite altimetry record is biased by generally higher values in the Earth’s tropical and southern oceans compared to the northern hemisphere. Variable spatial patterns are likewise obvious in the 1992-2013 satellite altimetry data (Figure 3).

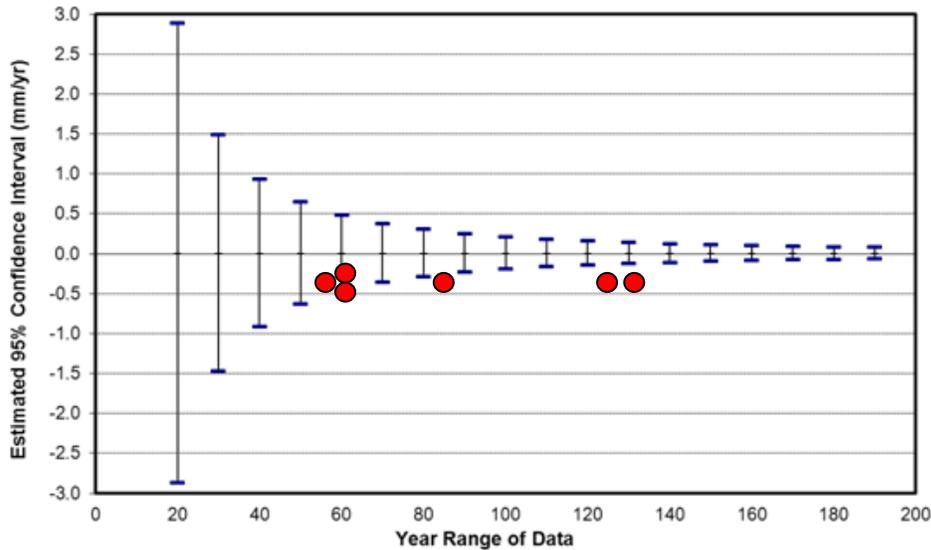
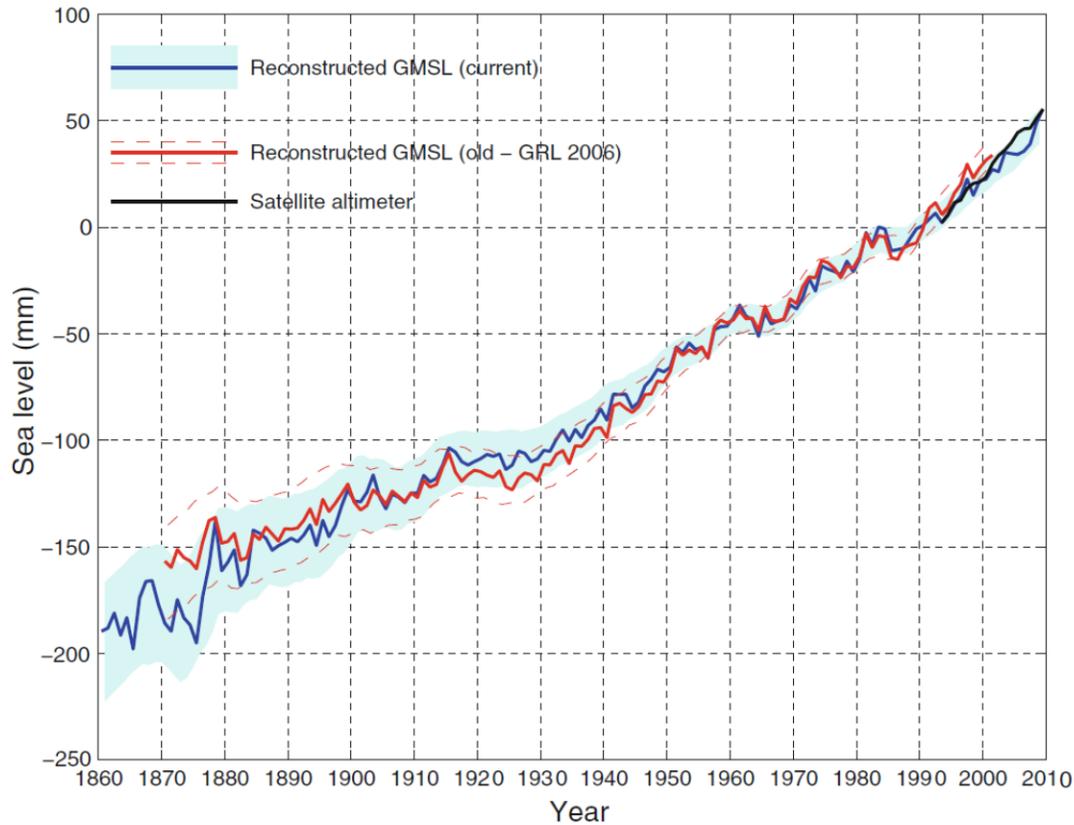


Figure 1: Relationship between the size of the 95% confidence interval and the period of record of any SLR dataset (Zervas, 2009). Overlain on the general figure are the approximate periods of record for the Florida Gulf Coast tide gauges shown in Table 2, which allows for a prediction of the estimated confidence for each gauge.

Table 1: Eustatic linear SLR rates calculated by Church and White (2011) for various periods of record for the aggregate global set of tide gauges used to assemble Figure 2.

Period of Record	Linear Rate of Eustatic SLR (mm per year)
1880 - 2009	1.5
1900 - 2009	1.7
1880 - 1935	1.1
1967 - 1982	2.4
1993 - 2009	2.8



**Figure 2: The analysis of tide gauge and satellite altimetry data by Church and White (2011).** The red line references analysis of available data in an earlier 2006 publication by those authors, while the blue line references the analysis of data in the 2011 citation.

Variations in spatial distribution illustrate the need to estimate SLR of the regional water body. The satellite altimetry record of the Gulf of Mexico (Figure 4) indicates an overall 1993-2013 regional eustatic SLR rate not substantially different from the global mean mentioned above for the same period, especially considering the overlapping error terms. However, the same cannot be said for the tide gauge record. USACE's guidance document on accounting for SLR (USACE 2009, 2011) dictates that if "...there is a regional mean sea level trend ... that is different from the eustatic mean sea level trend of 1.7 mm/year (+/- 0.5 mm/year, IPCC, 2007a) ..." then a regionally-appropriate vertically-stable platform should be identified, and a new regional eustatic SLR rate should be calculated. Within the Gulf of Mexico, the carbonate margin of coastal Florida is widely considered geologically stable. The collection of tide gauge stations from that area, that also are of sufficient period of record, indicate a mean SLR value of  $2.4 \pm 0.04$  millimeters per year (Table 2).

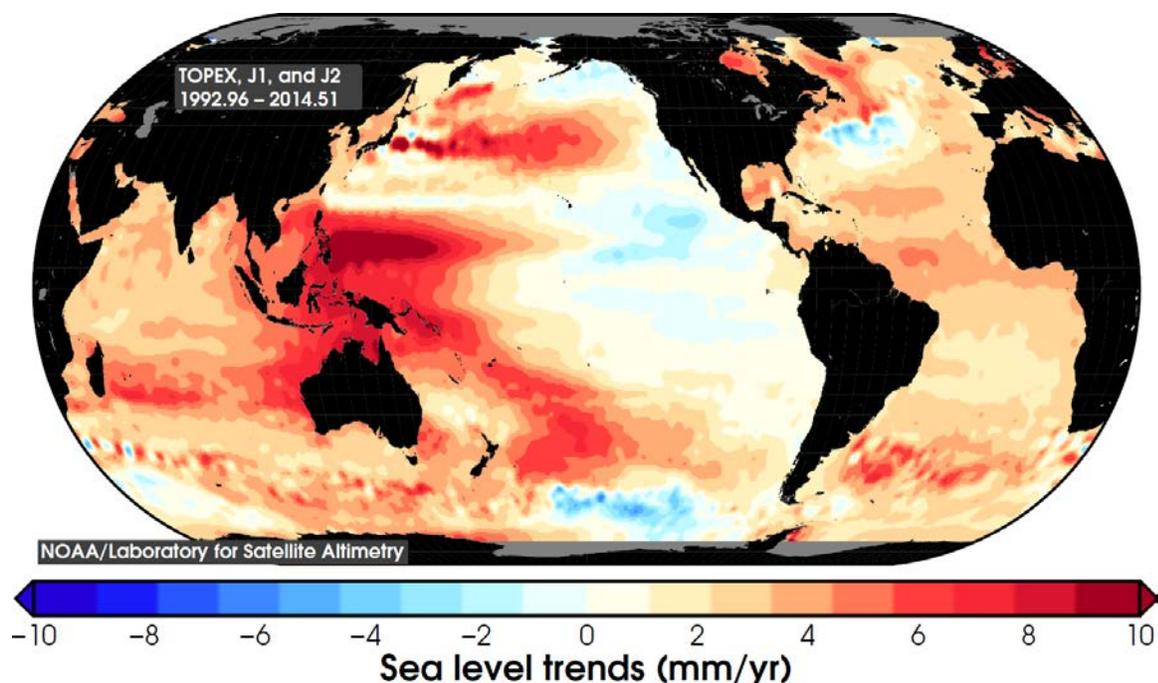


Figure 3: Geographical variation in the 1992-2014 global SLR, determined by satellite altimetry. Data from the NOAA Laboratory for Satellite Altimetry (<http://ibis.grdl.noaa.gov/SAT/>), accessed 21 July 2014.

Averaging the tide gauge record shown in Table 2 and the Gulf-specific satellite altimetry record shown in Figure 4. Results in a mean estimated historical regional eustatic SLR of 2.7 millimeters per year. This is greater than the 2.4 millimeters per year outlined in DeMarco et al. (2012) and the latest CPRA guidance for accounting for relative SLR in Master Plan projects. However, as mentioned above this estimate does reflect data updated through April 2014.

## 2.2 Update on Future Scenarios

Linear extrapolation of the 2.7 millimeters per year Gulf-regional mean historical value into the future would result in an estimated regional SLR of 0.29 meters by 2100, assuming a base year of 1992 (a common assumption in the literature), or 0.24 meters by 2100 from present. Regardless, as discussed above, there is evidence that the overall twentieth century sea level record was not linear, so there is no reason to carry a linear assumption forward into the future. Looking to the literature for alternatives, several recent reports that address future eustatic SLR possibilities have been written since the 2010 review of sea level data for the 2012 Coastal Master Plan. These can generally be organized into several types of analyses that vary in their relevance as predictors of future sea level, which are described below.

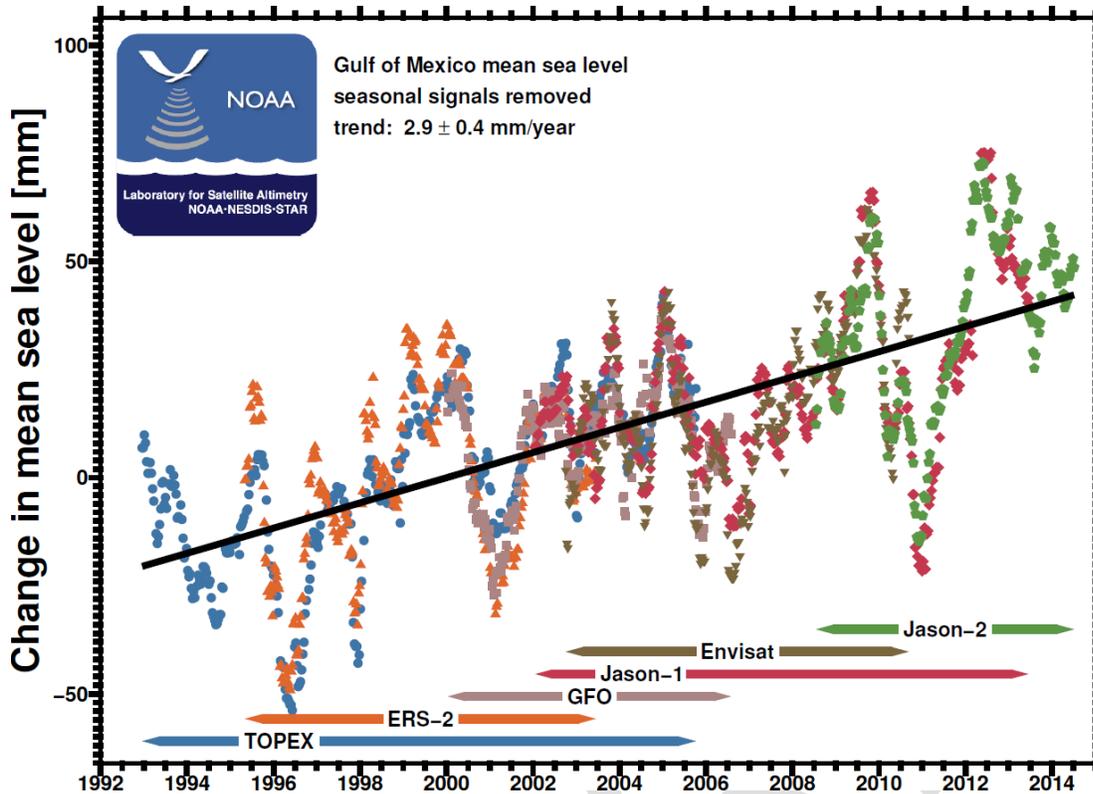


Figure 4: Gulf of Mexico satellite altimetry record, Seasonal signals removed, multiple altimeter missions, Accessed 21 July 2014 (<http://ibis.grdl.noaa.gov/SAT/>).

The first type of effort has generally sought to establish a wide range of SLR scenarios to assist planning and may be best described as expert opinion based on synthesis of the literature. These reports have not empirically estimated a best-guess of future sea level on their own, but instead established a range of plausible values corresponding to a range in risk based on reviews of the SLR modeling and science literature. Two examples are the revised USACE Engineering Circular #1165-2-212 on accounting for SLR in water resources project planning (USACE, 2011) and Parris et al. (2012), which established a set of SLR scenarios for the 2013 U.S. Climate Assessment. Establishing scenario values for SLR based on empirical estimates of future condition is equally of value to scenarios estimating tolerances to risk when the goal is to inform landscape modeling. The former, however, is arguably more important when one or several of those estimates will also inform protection and restoration project design. For example, preliminary design of 2012 Coastal Master Plan projects assumed the Less Optimistic Scenario value of 1 meter regional SLR by 2100, and both the Less Optimistic Scenario and the 2012 Moderate Scenario of 0.5 meters regional SLR by 2100 are informing more detailed feasibility analysis and design investigations currently being undertaken by CPRA.

**Table 2: Tide gauge data for stations in the Gulf coast of Florida generally considered geologically stable, and thus indicative of the Gulf regional rate of historical SLR.** Values shown are linear trends for the period of record to the year indicated (e.g. data for the Pensacola gauge show the linear trend from 1923-2006, 1923-2007, etc. Data from NOAA CO-OPS, checked on 21 July 2014.

Tide Gauge	First Reported	Last Reported	Period of Record	Gauge Linear Trend from Install to Year Shown (mm per year)							
				2006	2007	2008	2009	2010	2011	2012	2013
			(years)								
Pensacola, FL	1923	2013	89	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2
Clearwater Beach, FL	1973	2013	39	2.4	2.4	2.4	2.6	2.6	2.6	2.9	3.0
St. Petersburg, FL	1947	2013	65	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.5
Fort Meyers, FL	1965	2013	47	2.4	2.3	2.3	2.4	2.4	2.4	2.5	2.6
Naples, FL	1965	2013	47	2.0	2.1	2.1	2.2	2.2	2.2	2.3	2.4
Key West, FL	1913	2013	99	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Tide Gauge Mean											2.5
Standard Error											0.1

USACE (2011) mandated the use of a range in eustatic scenario values of SLR of 0.2 to 1.5 meters by 2100 for its public works projects, while Parris et al. (2012) examined a range of 0.2 to 2 meters eustatic SLR values by 2100. These documents also differ from the state- or region-specific efforts described below by their intent to be nationally-applicable. Given the absence of best-guess determination or new empirical work, while these reports provide a range of sea-levels for scenario testing, they are of little use on their own towards informing a plausible range of expected regional sea levels that could govern project design.

DeMarco et al. (2012) provides a summary of sea level science for coastal Louisiana conducted by CPRA, and estimated a best-guess of future sea level, established within a wider plausible range of values still informed more by likelihood than risk. DeMarco et al. (2012) also established a process for incorporating SLR science into project planning and design. That review included data up to August 2011 and for Gulf regional sea level, recommended primary planning and design for 1-meter SLR by 2100. These recommendations were adopted by CPRA senior management and incorporated into a project planning document in use by CPRA as of April 2014.

The second class of reports conducts novel predictions of future eustatic SLR. For example, the Intergovernmental Panel on Climate Change, or IPCC, uses mechanistic, process-based global climate models. These are in contrast to semi-empirical models, which have developed mathematical relationships between historical values of sea level and environmental drivers, and then rely on predictive models of those drivers to serve as the basis for SLR predictions. For example, Vermeer and Rahmstorf (2009) predicted SLR on the basis of a very significant relationship ( $R^2 = 0.98$ ) between sea level and historical temperature, which is derived from global climate change scenarios. Process-based model critics complain of a failure to capture the full range of processes necessary to replicate observations of past SLR. Semi-empirical model critics note that the validity of future predictions depends on the same relative influences of environmental drivers being carried into the future, which is in question (Jones, 2013). This data synthesis effort will not take sides in that argument, and will instead use input from both the process-based and semi-empirical model results to establish a plausible range of future SLR values.

The National Research Council estimated 2100 SLR for the U.S. mainland Pacific Coast (NRC, 2012) and included an estimate of eustatic SLR. NRC, (2012) utilized outputs from the Coupled Model Intercomparison Project Phase 3 (CMIP3) for the steric component of eustatic SLR, with a primary projection based on the A1B emissions scenario (all scenarios as per IPCC, 2000), bracketed with estimates for the B1 and A1F1 emissions scenarios on the low and high end respectively. In order, the B1, A1B, and A1F1 emissions scenarios represent less to more carbon-intensive scenarios and thus SLR (Barker et al., 2007). The NRC (2012) did not directly model the contributions from glaciers and the Greenland and Antarctic ice sheets, but instead used values based on the literature. Land water storage was not included in their analyses, as the authors felt the overall contribution was negligible given the state of the science at the time. The NRC (2012) calculated a global eustatic SLR A1B estimate of 0.8 meters by 2100, with a B1-A1F1 range in values of 0.46 to 1.46 meters by 2100 (Table 3). The NRC (2012) also used the Vermeer and Rahmstorf (2009) semi-empirical model to predict an A1B scenario estimate of 1.21 meters by 2100, with a B1-A1F1 range of 0.78-1.75 meters, based on CMIP3 scenario-specific estimates of temperature.

**Table 3: Component contributions and overall eustatic SLR by 2100 modeled by NRC (2012) were used to underlie regionally-specific SLR predictions for the US Pacific coast data.** Boesch et al. (2013) adapted the NRC (2012) eustatic predictions with regional scaling factors appropriate for the US Mid-Atlantic coast. The bottom set of data show results of a similar regional adaptation of the NRC (2012) eustatic data for the northern Gulf of Mexico. It is important to note that the NRC (2012) values are scaled to a base year of 2000, not 1987 or 1992 like other analyses.

Application	Components of Predicted Eustatic or Regional SLR					
	(all values are meters by 2100)					
	Thermal	Glaciers	Greenland	Antarctica	Dynamic	Sum
<b>NRC (2012) Eustatic Estimate</b>						
2100 Low (B1)	0.10	0.13	0.15	0.08	.	0.46
2100 Projection (A1B)	0.24	0.14	0.20	0.24	.	0.82
2100 High (A1F1)	0.46	0.19	0.34	0.47	.	1.46
<b>Boesch et al. (2013) Regional Prediction for Maryland</b>						
Scale Factor		0.9	0.5	1.25		
2100 Low	0.10	0.12	0.08	0.10	0.13	0.52
2100 Projection	0.24	0.13	0.10	0.30	0.17	0.94
2100 High	0.46	0.17	0.17	0.59	0.19	1.58
<b>Northern Gulf Coast Regional Prediction Using Boesch et al. (2013) Adaptive Approach</b>						
Scale Factor		0.95	0.85	1.10		
2100 Low	0.10	0.12	0.13	0.09	.	0.44
2100 Projection	0.24	0.13	0.17	0.26	.	0.81
2100 High	0.46	0.18	0.29	0.52	.	1.45

The State of Maryland Climate Change Commission's Scientific and Technical Working Group amended the NRC (2012) eustatic estimates for a tighter prediction of Mid-Atlantic regional SLR by including a factor for local dynamics resulting from nearshore interactions between the Gulf Stream, which diverges from a long-shore northward orientation just south of the Chesapeake Bay, and water from the North Atlantic Ocean (Boesch et al. 2013). They also adjusted the ice-sheet and glacier contributions based on recent literature on differential spatial response of regional sea levels to changes in Earth's gravimetric field. The resulting best estimate for regional sea level calculated by Boesch et al. (2013) was 0.94 meters by 2100, with a range from 0.52 – 1.58 meters (Table 3). Following the Boesch et al. (2013) approach of regionally modifying the

NRC, (2012) eustatic prediction, we would anticipate the Gulf-specific adjustment factors shown in Table 3 based on data in Mitrovica et al. (2001, 2011) and the resulting estimates of future regional eustatic SLR of 0.81 meters by 2100, with a range of 0.44-1.45 meters. The IPCC Assessment Report 5 (AR5) used an updated set of 21 global climate models defining the Coupled Model Intercomparison Project Phase 5 (CMIP5). The new IPCC effort also changed their scenario approach, switching to Representative Concentration Pathways (RCPs) to define future environments (Table 4).

**Table 4: Global average carbon dioxide concentrations predicted for the four Representative Concentration Pathways (RCPs) used in the 2013 IPCC reports.**

RCP	2100 CO <sub>2</sub> Concentration (ppm)
2.6	421
4.5	528
6.0	670
8.5	936

In the AR5 chapter on SLR, Church et al. (2013) presented median and likely (66-100% probability) ranges for 2081-2100 eustatic sea-levels compared to 1986-2005 based on the CMIP5 outputs (Table 4). They estimated individual components for the overall eustatic SLR, but the net overall predictions are not fully comparable to those calculated by NRC (2012) due to the lack of a Land Water Storage component by NRC that was calculated by Church et al. (2013). Thermal expansion and glacier contributions predicted by NRC (2012) were higher than the corresponding RCP2.6-6.0 estimates but slightly less than that calculated for RCP8.5 (Church et al., 2013). However, the original contributions calculated by NRC (2012) for the Greenland and Antarctica ice-sheet dynamics were much higher than those used by Church et al. (2013). Even with the inclusion of the Land Water Storage component, Church et al. (2013) estimates of total eustatic SLR are lower than those of NRC (2012) and Boesch et al. (2013) because of the differences in ice-sheet dynamics under all RCPs.

Acknowledging geographic variability in SLR, however, Church et al. (2013) predicted inconsistent geographical distribution of the RCP4.5 scenario eustatic SLR prediction (Figure 5). While modeling was limited to RCP4.5, Church et al. (2013) stated that the "... first order is representative for all RCPs", so the adjustments were applied to all four RCP predictions. That analysis predicts that percent deviation from the global mean predicted SLR for the Gulf of Mexico could be +10 to +20% (i.e. Gulf regional eustatic SLR could be 10-20% greater than the global mean). The lower end of the range of 2100 predicted SLR for each scenario was thus increased by 10% and the upper end of the range increased by 20%, resulting in the "Revised Ranges" shown in Table 5. Splitting the difference, the 2100 sum value was increased 15% and is shown in Table 5 as "Revised Sum", for pre-emptive consideration of scenario values. The plausible range in values for Gulf regional eustatic SLR by 2100 from the application of the process-based CMIP5 models used by Church et al. (2013) is thus 0.31-1.18 meters.

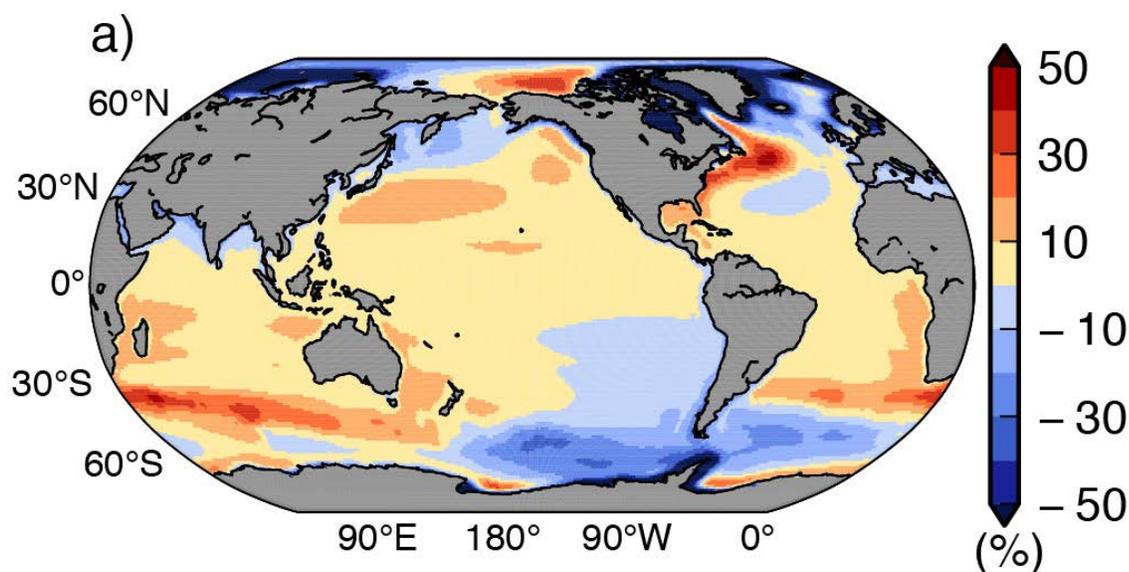
**Table 5: Results of global climate change modeling of predicted SLR under four Representative Concentration Pathway scenarios as described in Table 13.5 of Church et al. (2013).** Estimates are shown for components and sum of eustatic sea level in the 2081-2100 period relative to 1986-2005, as well as specific predictions of mean overall eustatic SLR in 2100. Data for Green and Antarctic ice sheets are aggregated for both surface mass balance and raid dynamics estimates from Church et al. (2013). All values are meters.

Component	RCP2.6	RCP4.5	RCP6.0	RCP8.5
<b>Estimated SLR in 2081-2100 Relative to 1986-2005</b>				
Thermal Expansion	0.14	0.19	0.19	0.27
Glaciers	0.10	0.12	0.12	0.16
Greenland	0.07	0.08	0.08	0.12
Antarctica	0.05	0.05	0.05	0.03
Land Water Storage	0.04	0.04	0.04	0.04
Sum	0.40	0.47	0.47	0.63
"Likely Range"	0.26-0.55	0.32-0.63	0.33-0.63	0.45-0.82
<b>Estimated SLR by Year 2100</b>				
Sum	0.44	0.53	0.55	0.74
"Likely Range"	0.28-0.61	0.36-0.71	0.38-0.73	0.52-0.98
Revised Sum	0.51	0.61	0.63	0.85
Revised Range (see text)	0.31-0.73	0.40-0.85	0.42-0.88	0.57-1.18

Church et al. (2013) compared results of these process-based models with several semi-empirical models (and combinations of calibration datasets) for the RCP4.5 scenario. In comparison to the 0.32-0.62 meter prediction from the process-based model, the temperature-based semi-empirical models resulted in a range from 0.43 – 1.24 meters eustatic SLR by 2100. The 50<sup>th</sup> percentile values from those nine separate model runs averaged  $0.79 \pm 0.05$  meters by 2100 ( $\pm 1$  SE). If the regional correction for the Gulf of Mexico shown in Figure 5 is applied to these semi-empirical model outputs, this would result in a range of values from 0.47 – 1.49 meters and a mean of  $0.90 \pm 0.05$  meters by 2100 for the Gulf of Mexico. Church et al. (2013) did not report calculations based on any additional RCP scenarios beyond those for RCP4.5.

Jevrejeva et al. (2012) separately modeled all four RCP scenarios using their semi-empirical model (which was one of the semi-empirical models that Church et al. (2013) modeled with three different radiative forcing calibrations which Jevrejeva et al. 2012 averaged across), and determined a range of estimated global SLR of between 0.36 – 1.65 meters by 2100, with 50<sup>th</sup>

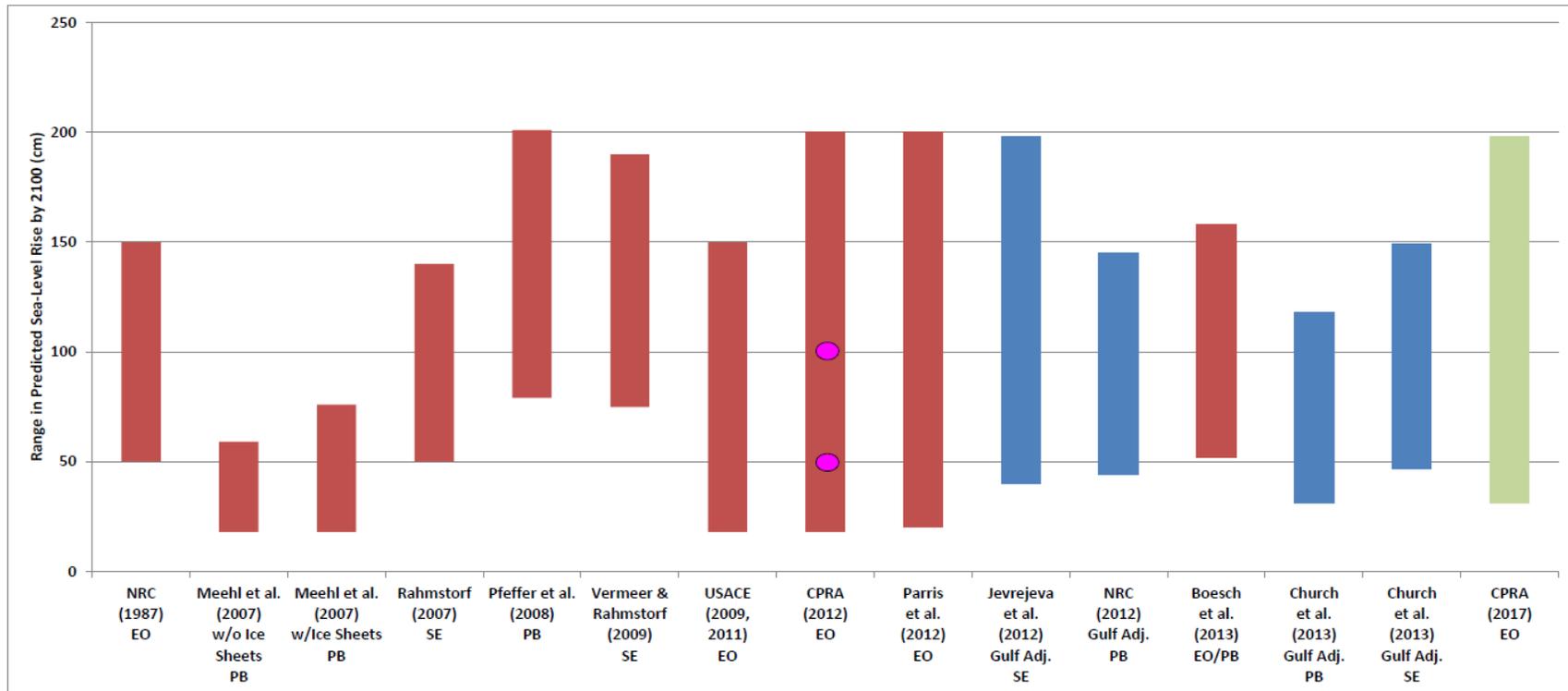
percentile values averaging  $0.81 \pm 0.11$  meters by 2100. The same Figure 5 regional adjustment for the Gulf of Mexico discussed above results in an adjusted range 0.40-1.98 meters by 2100 and an adjusted 50<sup>th</sup> percentile mean of the four RCP scenarios of  $0.93 \pm 0.13$  meters.



**Figure 5: Predicted geographical distribution of deviation from the global mean of net eustatic SLR between 1986-2005 and 2081-2100 for the IPCC AR5 WG1 RCP4.5 scenario.** The regional SLR for the Gulf of Mexico is predicted to be up to 10% greater than the global mean under this scenario. Figure 13.21 from Church et al. (2013).

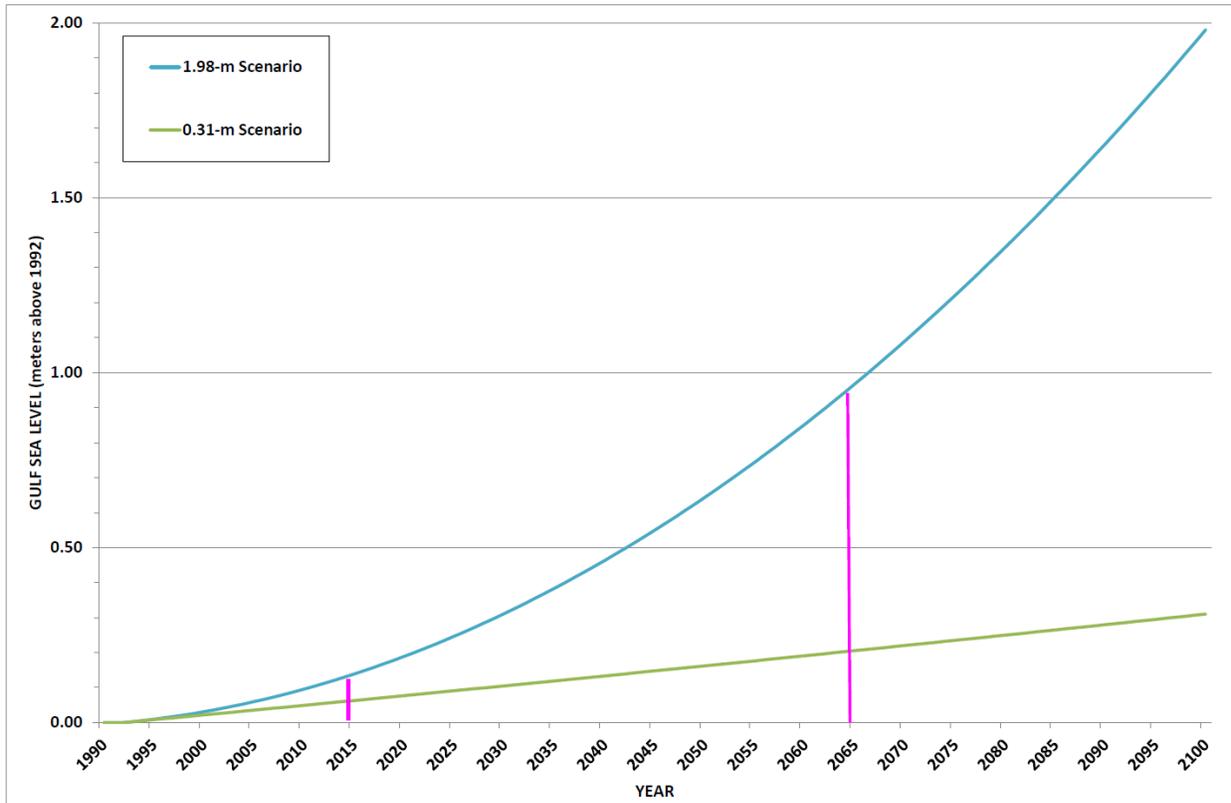
## 2.3 Summary of Recommendations and Initial Discussion of Proposed Scenario Values

The amended NRC (2012) approach for the northern Gulf coast and Church et al. (2013) running of the RCP4.5 scenario using the semi-empirical models suite described therein, once adjusted for a Gulf regional prediction of SLR, gave consistent results of 0.44-1.45 meters by 2100 and 0.47-1.49 meters by 2100, respectively. In comparison, the regional adjustment of predictions by Church et al. (2013) using the CMIP5 model suite gives a lower range of 0.31-1.18 meters by 2100. The range is largest adjusting the results of Jevrejeva et al. (2012), for a full range of values of 0.40-1.98 meters. Aggregating all of these results gives a full range in values of 0.31-1.98 meters Gulf of Mexico regional SLR by 2100 (Figure 6). This discussion assumes equal likelihood across this range, i.e. no effort is made in here to discuss or establish differential probability of values.



**Figure 6: Relationship between past predictions of SLR and Gulf of Mexico regional regional adjustments of contemporary SLR predictive model outputs.** Adaption of DeMarco et al. (2012), Figure 20, itself an adaptation of a USGS figure ([wh.er.usgs.gov/slr/sealevelrise.htm](http://wh.er.usgs.gov/slr/sealevelrise.htm)), showing the relationship between past predictions of SLR (red) and Gulf of Mexico regional regional adjustments of contemporary SLR predictive model outputs (blue) described in this paper, to establish the plausible range of Gulf regional SLR values for use in the predictive modeling for the 2017 CPRA Coastal Master Plan (green). Note that the magenta dots on the CPRA (2012) predictive range indicate the values chosen for use in the Moderate (0.5 meters) and Less Optimistic (1 meter) Scenarios for the eustatic SLR uncertainty. All values shown are centimeters eustatic or regional SLR by 2100. EO indicates sources where range was established as a result of expert opinion, PB indicates establishment as a result of the use of process-based models, and SE indicates establishment as a result of the use of semi-empirical models.

Assuming the 0.31-1.98 meters Gulf SLR range of values has a base year of 1992 (not fully true – see discussion of the NRC 2012 document especially – but a simplifying assumption in this case), the regional SLR curves for the lower and upper bounds of that range can be represented as in Figure 7. The regional SLR over the 2015-2065 time period, which will remain the period of analysis for the 2017 Coastal Master Plan predictive models, is 0.14 meters (0.46 feet) for the lower-bound scenario and 0.83 meters (2.72 feet) for the upper-bound scenario. As both curves are non-linear, the acceleration constant for the lower-bound scenario is  $1.5775 \times 10^{-6}$  meters per year<sup>2</sup>, while the acceleration constant for the upper-bound scenario is  $1.44753 \times 10^{-4}$  meters per year<sup>2</sup>.



**Figure 7: Graphical representation of Gulf regional SLR of 0.31 meters and 1.98 meters by 2100, both from a base year of 1992, that represent the plausible range of Gulf regional SLR for subsequent analysis using the 2017 Coastal Master Plan predictive models. The green line denotes Gulf regional SLR of 0.31 meters and blue line denotes 1.98 meter scenario. The magenta lines indicate the lower and upper bounds of the 2015-2065 period of analysis for that modeling effort.**

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