RECOMMENDATIONS FOR ANTICIPATING SEA-LEVEL RISE IMPACTS ON LOUISIANA COASTAL RESOURCES DURING PROJECT PLANNING AND DESIGN

SUMMARY OF THE TECHNICAL REPORT FOR COASTAL MANAGERS

CPRA
Coastal Protection and Restoration Authority of Louisiana

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Introduction and Objectives of the Technical Report

Land changes in the coastal zone and high sea-level rise rates are exposing lowland areas to more frequent events of saltwater intrusion, flooding, and rapid shoreline erosion, magnifying the negative effects of coastal storms and storm surge. Louisiana is particularly sensitive to sea-level rise due to the unique geology of the State's Delta and Chenier Plains. There is a pressing need to integrate up-to-date sea-level rise data into planning and engineering activities to anticipate coastal land loss patterns, protect coastal communities and adequately design restoration projects.

Projections for future sea-level rise and concurrent coastal vulnerability estimates are numerous and variable. As sea-level rise projections are refined and confidence in future sea level rise estimates increase, policy development in state and regional planning efforts will become more mature. Until a more precise picture of sea-level rise trends emerges, adaptability and flexibility will be key components to ensure the incorporation of the most current and accurate sea-level rise projections into project planning and policy development for the Louisiana coast.

The objective of the technical report is to make recommendations for incorporating sea-level rise into the planning and engineering of habitat restoration and storm protection projects. Specifically the technical report is structured to:

- Deductively summarize the state of the science on the patterns of increase in the surface of the global ocean, regional Gulf of Mexico and local coastal waters to support a recommendation of the rate(s) of anticipated sea-level rise most appropriate for incorporating into project analysis and design, and

- Describe how recommended rate(s) of local sea-level rise should be combined with the highly variable spatial patterns in coastal subsidence and wetland vertical accretion to predict relative sea-level rise at specific points in the Louisiana coastal zone.

This summary provides an overview of the findings of the technical report and the recommendations that result from those findings. Both the summary and full technical report should be considered as 'living documents.' As global, regional and local estimates of sea-level rise are constantly changing as new data become available, CPRA Louisiana Applied Coastal Engineering & Science (LACES) Division plans to update this report as necessary.

Background

Sea-level rise is caused by a variety of dynamic interactions, and is influenced by atmospheric, geologic, oceanic, and astronomical changes, whether natural or anthropogenic. Estimates of past and projections of future SLR are dependent on the interplay between these factors. Challenges arise when attempts are made to identify changes in sea level that occur over varying time scales; therefore, it is important to isolate the long term historical trends from the background of regular natural cycles to make confident predictions about future trends.

Global sea level rise (GSLR) is a combination of thermal expansion, or the steric component, and the freshwater influx, or the eustatic component. To accurately determine the long-term historical trend of global sea level rise, researchers must first identify and remove the effects of natural forcings on the sea level observation data to evaluate the steric and eustatic components only. Natural forcings are generally cyclical in nature and can be caused by atmospheric, meteorological or alterations in the rotation of the earth and moon. Because these patterns are reflected in monitoring data and can mask long term trends, it is preferable to have data records long enough to encompass several years so that these patterns can be identified and removed from the analysis.

While it is important for coastal managers to consider GSLR, local sea level rise or relative sea level rise (RSLR) is more relevant in coastal planning. In any coastal zone, the actual rate of SLR is a combination of GSLR and local processes including natural cycles, glacial isostatic adjustment (GIA), subsidence, accretion and erosion of shorelines and coastal marshes. These influences result in a RSLR that may be quite different from GSLR. Therefore, it is necessary to evaluate GSLR trends and then to focus on local conditions in the Gulf of Mexico offshore of southern Louisiana to inform recommendations on estimating and incorporating local RSLR trends into project planning and design.

Sea Level Rise Measurement

Oceanographic data are gathered from three primary sources to determine the global sea-level rise rate: tide gauges, *in situ* measuring devices and satellite altimetry readings. In the United States, the National Oceanographic and Atmospheric Administration operate 128 long-term National Water Level Observation Network tide gauge stations that monitor monthly mean sea-level data. Measurements from this network are used in conjunction with other tide gauges around the globe to calculate the rate of global sea-level rise.

The distribution of the *in situ* devices, such as the Argo float array and the National Oceanographic and Atmospheric Administration's bathythermograph monitoring fleet are used to define the specific contributions of the eustatic and steric components of current sea-level rise measurements. If distribution of the *in situ* devices is sparse in certain water bodies, such the Gulf of Mexico, it becomes more difficult to establish the relative contribution of eustatic and steric components of current sea-level rise measurements and complicate predictions of future sea-level rise. Thus, the Argo float data is of limited use to Louisiana's coastal zone.

Satellite altimetry measurements can also be used to measure sea level change. A series of satellite missions beginning with TOPEX/Poseidon in 1992 and continuing today with Jason 1 and 2 provide estimates of global mean sea level rise. It should be noted, however, that satellite altimetry data must be processed and corrected to account for influences such as GIA and seasonality. Additionally, the relative short period of record for satellite altimetry data makes it difficult to discern long term trends in sea level change.

Historical Sea-Level Rise Rates

Estimating a historical rate of global sea-level rise is entirely dependent on the specific time period and measurement method. Much of the debate about calculating historical sea-level rise trends, including rates and acceleration, results from which stations are chosen and over which specific time period they are analyzed.

Most efforts to calculate an average rate of global sea-level rise for the 20th century have concluded a value of less than 2 mm/yr (0.08 inches/yr; e.g. Church et al. 2004; Church and White 2006). In comparison, NOAA's Laboratory for Satellite Altimetry has calculated an estimated overall 1993-2010 global sea-level rise rate of 2.8 ± 0.4 mm/yr (data accessed on 9 September 2011). It is important to note that these calculations assume an equal and constant sea-level rise trend. However, examination of the historical and a large body of recent literature point to a rate of global sea-level rise since the late nineteenth century that has been accelerating.

To illustrate this point, Figure S1 shows the data set by which Church and White (2006) calculated the frequently-cited 1.7 ± 0.3 mm/yr (0.067 ± 0.012 inches/yr) average global sea-level rise for the twentieth century. That conclusion was down-revised to 1.5 mm/yr (0.059 inches/yr) for the whole 1860-2009 time period in Church and White (2011). In those two papers Church and White discussed that in the least any linear analysis needed to recognize several visually-obvious inflection points in the data in the mid-1930s, the 1960s and the 1980s, and that rates calculated for the intervening years between those points might differ significantly. However, in both their 2006 and 2011 papers Church and White also defined a non-linear, accelerating fit to the full data set. Acceleration in the historical data was also documented by Jevrejeva et al. (2008) and Woodworth et al. (2009). Differences in forecasting a linear vs. accelerating function into the future can become significant and the use of one prediction over another should be carefully considered.

Satellite altimetry data specific to the Gulf of Mexico do show a slightly lower rate of sea surface elevation change than the global average over the past twenty years (Figure S2). To improve future estimates of future Gulf-wide sea-level rise, we are exploring the reasons for this observation. Satellite altimetry-based estimates of sea-level rise in the Gulf of Mexico are also highly variable at more local levels, with the general pattern of higher rates of sea-level rise in the center of the Gulf and lower rates in both the eastern and western margins.

At a more local level, there appears to be a strong east-west gradient in derived 1992-2010 Gulf of Mexico sea-level rise values for the near-shore coastal waters in southern Louisiana (Figure S3), with values ranging from a high southeast of the Balize Delta and consistently decreasing both westward to a low south of the mouth of the Sabine River and northward into the Lake

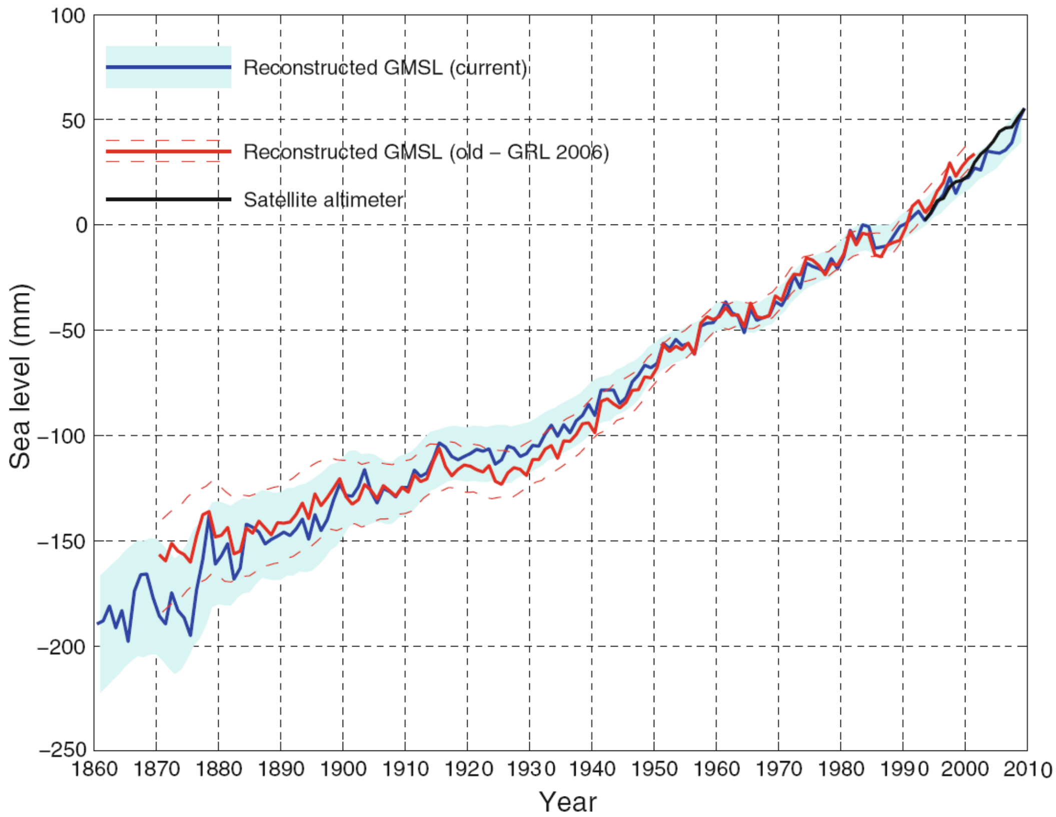

Figure S1. Sea-level rise data from Church and White (2011) for the 1860-2009 time period was used to calculate an 1880-2009 linear trend of 1.5 mm/yr (0.059 inches/yr) and the non-linear, accelerating trend discussed in the text of the Technical Report.

Borgne and Lake Pontchartrain systems. The range of values is significant, with the highest derived sea-level rise rates being 58% higher than the lowest values.

Projections of Future Sea-Level Rise

The largest uncertainty in predicting eustatic sea-level rise over the next century is how ice sheets will respond to changes in temperature (Allison et al. 2009. Since satellite altimetry and gravimetric data have become available, researchers are able to more clearly investigate the dynamics of ice sheets. Current estimates for global sea-level rise by 2100 range from 0.5 to 2 meters (1.6' – 6.6'; Grinsted et al. 2009; Pfeffer et al. 2008; Rahmstorf 2007; Vermeer & Rahmstorf 2009). Much weight recently has been placed on the Rahmstorf (2007) predictions of a range in global sea- level rise of 0.5-1.4 meters (1.6' – 4.6') by 2100, with 1 meter (3.3') being the most likely. With respect to sea level rise rate acceleration, we have chosen to follow the weight of scientific opinion that sea-level rise is in fact accelerating. However, LACES will follow this issue closely in the future and will revision our recommendations accordingly.

In comparison to the projections of global sea-level rise, there has been very little work done to predict the specific change in the Gulf of Mexico water surface for the rest of this century. Until these regional investigations are performed, anticipated sea-level changes in the Gulf of Mexico

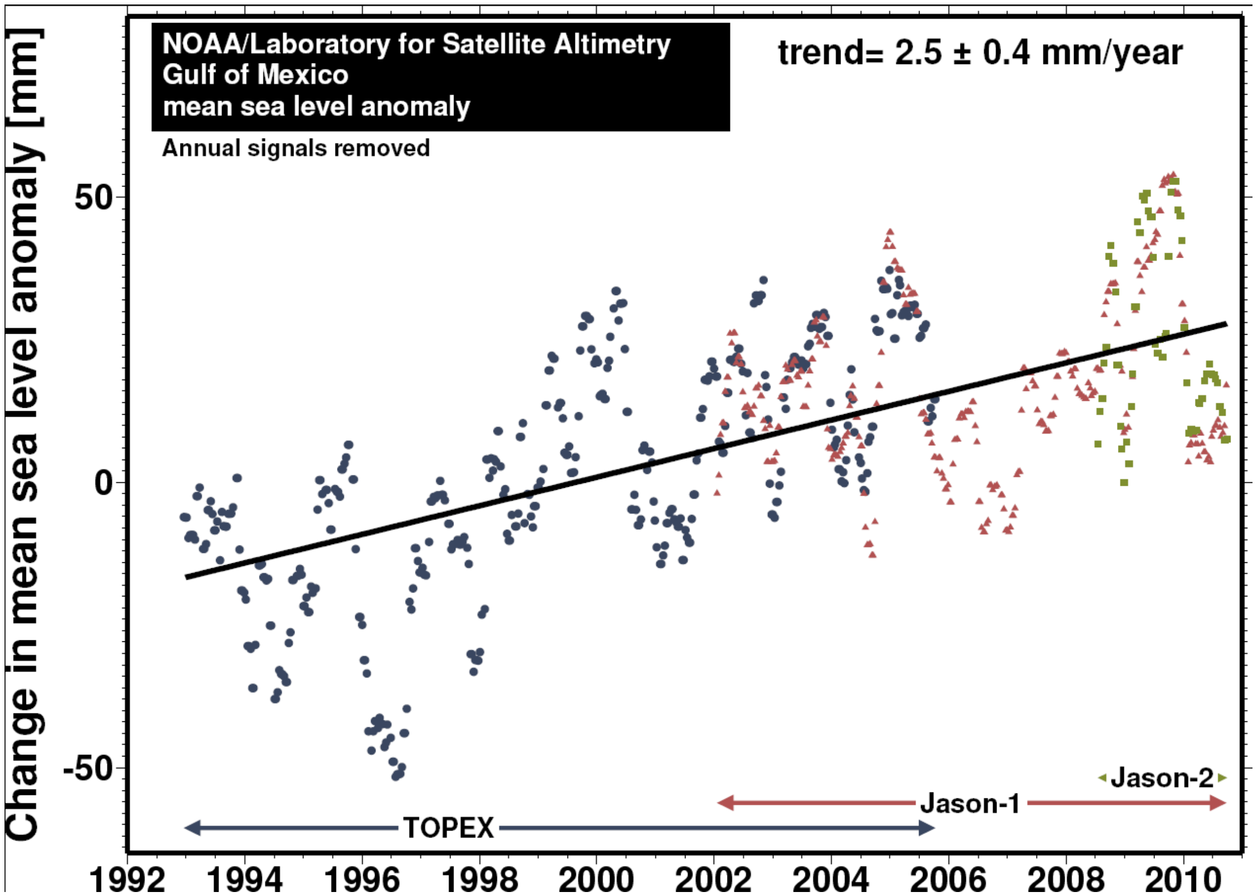

Figure S2. Gulf of Mexico sea level values sourced in satellite altimetry data from the National Oceanographic and Atmospheric Administration's Laboratory for Satellite Altimetry, accessed on 11 March 2011, illustrate an overall sea-level rise rate for the Gulf of Mexico lower than the global sea-level rise trend calculated for the same time period (2.8 ± 0.4 mm/yr).

must be primarily extrapolated from satellite altimetry or tide gauges, which can be less reliable due to the limited period of record. Modeling of global climate change scenarios suggests that the Gulf of Mexico will respond similarly to the global ocean (Meehl et al. 2007), and it appears that projections of global sea-level rise are appropriate to carry into the region.

In order to calculate a predicted future sea-surface elevation offshore of coastal Louisiana, and based on the literature review above, the Technical Report recommends that CPRA staff assume that Gulf sea-level rise will be 1 meter (3.3') by 2100, with a bounding range of 0.5 – 1.5 meters (1.6' – 4.9'). While this recommendation results from the independent assessment of the available data presented in the Technical Report, it is also consistent with similar efforts ongoing in other states. This recommendation is only part of the overall prediction of future relative sea-level rise, and must be combined with predictions of subsidence and marsh vertical accretion.

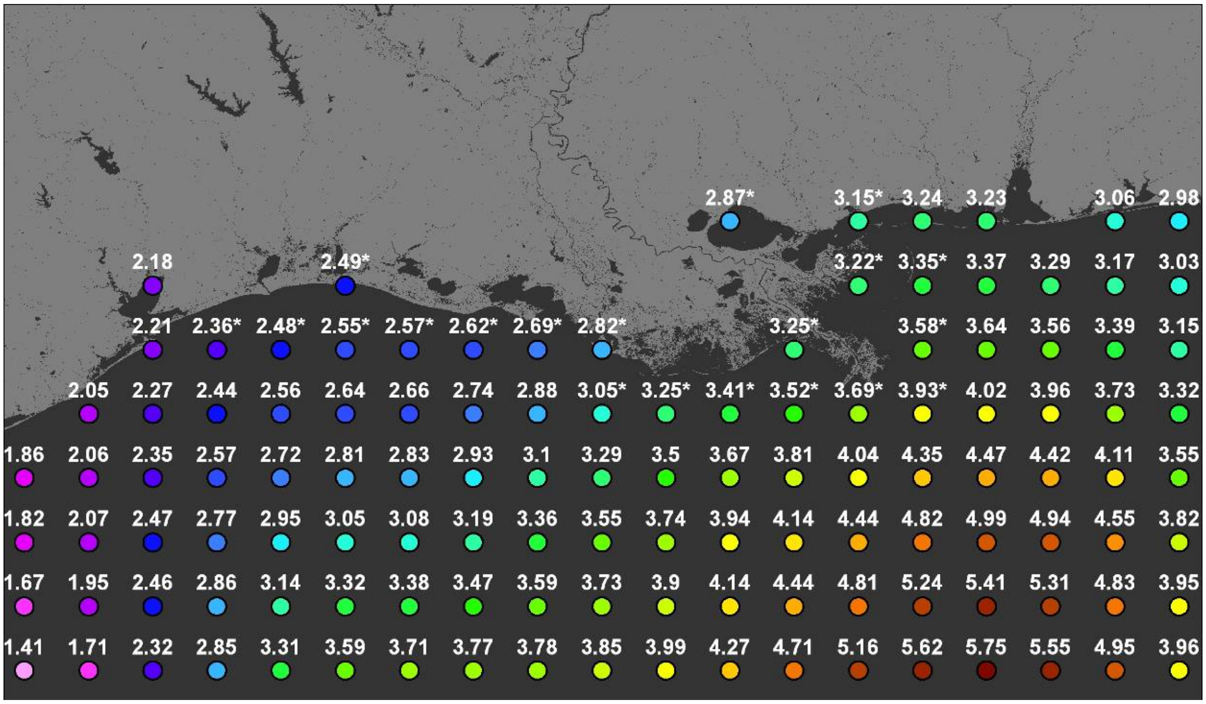

Figure S3. Sea-level rise rates for discrete points offshore of southern Louisiana show significant east-west variation, with values highest offshore of the Balize Delta and trending lower moving west across the front of the Chenier Plain. Data were derived by USGS from satellite altimetry data for center points of the analysis grid shown in Figure 12 of the Technical Report, covering the 1992.96-2010.01 period of record. Figure from the Project Effects Modeling Team addressing the 2012 revision of the Louisiana Integrated Master Plan.

Having discussed global sea-level rise projections, any effort to confidently incorporate potential sea-level rise impacts on coastal wetlands into planning must account for the sum of factors influencing relative sea-level rise: 1) the change in the surface elevation of the Gulf of Mexico, which is the primary topic of this document; 2) local land surface elevation change, which in Louisiana is exclusively represented as subsidence; and 3) marsh vertical accretion, which can offset some sea-level rise impacts.

Subsidence is a significant driver of relative sea-level rise in southern Louisiana, and is most likely the principal driver in southeast Louisiana for the near-term. While rates of subsidence are highly variable across the Louisiana coastal zone (Figure S4), our understanding of the exact rates of subsidence at the local level is very limited. Ongoing work by the Louisiana Geological Survey, commissioned by LACES, will summarize our understanding of the geological framework underlying south Louisiana as well as provide an overview of historical rates of subsidence across the landscape. This work will further build on the summary report *Understanding Subsidence in Coastal Louisiana* (Reed and Yuill 2009), prepared for the State and the US Army Corps of Engineers by the Louisiana Coastal Area Science and Technology Program Office. This information, together with monitoring data from the Coastal Wetland Planning, Protection and Restoration Act Program's *Coastal Reference Monitoring System - Wetlands* stations, will help to determine the predicted ranges of subsidence.

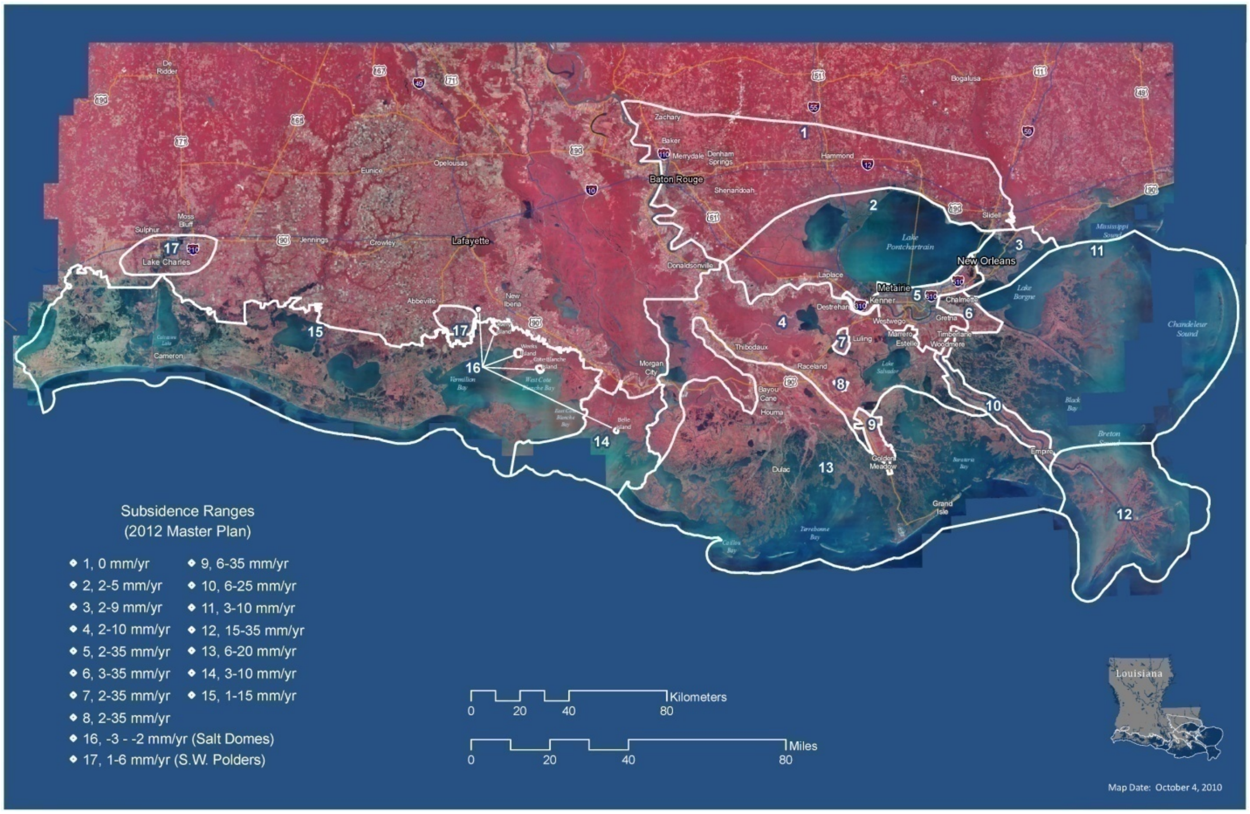

Figure S4. Map of projected subsidence ranges for south Louisiana generated by the Subsidence Advisory Panel for the Louisiana CPRA Master Plan 2012 Update, following a meeting on 14 October 2010.

Our understanding of marsh vertical accretion is likewise evolving. The ability of marshes to keep up with moderate levels of sea-level rise via accretion of both mineral and organic soil material has long been understood (see summary in Mitsch and Gosselink 2000). Typically coastal marshes have a range of “optimum depth” and, within this range, the marshes will respond positively to a sea-level rise. Once they reach an estuary specific rate of rise where accretion is no longer possible, the marshes will then drown. While this science is nascent at present, it promises to be a significant contribution to predicting local net relative sea-level rise in Louisiana’s coastal wetlands.

This paper has focused on global and regional sea level rise. However, the natural processes of accretion and subsidence are critically important to how the coast will evolve over time. As the science continues to evolve and we begin to get a better understanding of how the processes of accretion and subsidence will affect our coastal zone, future research and synthesis papers will be prepared to address these two issues.

Summary and Recommendations

The scientific literature indicates that the rate of global SLR (GSLR) has been increasing steadily over the past several centuries. This may be seen in an increase from a 20th Century linear average based on tide gauge data of 1.7 ± 0.4 mm/yr.(0.070 ± 0.016 inches/yr.) to a linear estimate for the past eighteen years of 2.9 ± 0.4 mm/yr.(0.11 ± 0.016 inches/yr.) in the Gulf of Mexico based on satellite altimetry. Although direct comparison of the two techniques supports the validity of the altimeter readings, there is some concern regarding the short period of record for the altimetry data. However, evidence suggests that SLR for the available period of record is best represented as a single, non-linear function, which has important implications for relating RSLR and GSLR estimates, and especially for assumptions of the differential representing local land surface change.

More important for CPRA planning purposes is the projection of future GSLR. Based on the available data, LACES recommends that any SLR modeling scenarios models for state restoration projects assume a 1-meter (3.3') MSL rise by 2100 compared to the late 1980s and should be bracketed by GSLR ranges of 0.5-1.5 meters (1.4'-4.9') by 2100. The specific recommendation for factoring in the range of GSLR into local calculations of RSLR is given below.

Recommendations for Calculating RSLR in Coastal Louisiana

Based on the information presented to this point, it is our recommendation that when participating in project planning and design activities, local RSLR be calculated using the following procedure to populate the variables of the generalized RSLR equation

$$E(t) = a*t + b*t^2 + S. \qquad \text{(Eqn. 7)}$$

1. Use local observations of historical sea-level rise from contemporary satellite altimetry (Figure 16) just offshore of coastal Louisiana, in order to account for the substantial east-west gradient in documented rates. Specifically, we recommend using an average of the three most proximate points shown in Figure S3. This is the rate of SLR (mm/yr.) and variable **(a)** from the generalized equation.

2. Calculate the acceleration constant that assumes a MSL increase of 1 meter (3.3') by 2100 as the most heavily-weighted project alternative, while also testing MSL increases of 0.5 meters (1.6') and 1.5 meters (4.9') to account for uncertainty in the literature.

This provides the change in water levels over time at a project location. To localize further,

3. Add in local subsidence values obtained from the most proximate local source, which is variable **(S)**in Equation 7.

In order to predict the persistence the coastal wetland, and specifically the persistence of the wetland surface or conversely marsh surface collapse and drowning, a fourth step is necessary.

4. Use the sum of #s 1-3 above to establish an inundation function, especially the rate of inundation for the period of analysis, in order to predict local responses of marsh vertical accretion as those models and data products become available. This can be inferred from scientific literature if no reliable data exist on site, or can be estimated from vegetation productivity models if available.

As discussed in Section 2.4.1., predicting future RSLR must account for the acceleration constants (variable **b**) being specific to NRC (1987) acceleration scenarios having a starting point of 1986. Appendix D of the report shows specifically how the variables discussed feed into a refined version of Equation 8 that accounts for that specific starting point.

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