


Memorandum



Date: June 13, 2016

To: Honorable Chairman Jean Monestime
and Members, Board of County Commissioners

From: Carlos A. Gimenez
Mayor 

Subject: Southeast Florida Regional Climate Change Compact Update

The following report is an update to the Board of County Commissioners (Board) on the efforts of the Southeast Florida Climate Change Compact (Compact).

Under the authorization granted by Resolution No. R-1388-09, which was approved by the Board on December 1, 2009, Miami-Dade County joined Monroe, Broward, and Palm Beach counties to establish the Compact. More specifically, the Compact was created with the understanding that the collaborative efforts and resources of the four (4) Southeast Florida counties, which represent approximately 30 percent of the state's population, would result in a greater policy voice at the state and federal levels, as well as more effective implementation of climate change mitigation and adaptation efforts. Through this Compact, which was approved by all four (4) counties by February 2010, counties committed to work collaboratively on climate change issues and actions. In the six (6) years since the Compact was forged, the counties and their partners have successfully completed a 110-recommendation Regional Climate Action Plan, developed a unified sea level rise projection for Southeast Florida, completed a regional greenhouse gas emissions inventory and a regional vulnerability analysis to sea level rise, developed joint annual state and federal legislative programs, and planned and executed seven (7) Regional Climate Leadership Summits, as well as countless other joint activities. These efforts and accomplishments have resulted in significant national and international attention for the Compact, its member counties and partners, and the Southeast Florida region.

Below are a few of the more current Compact-related efforts that provide an important foundation for further progress in 2016.

1. Establishment of a Partnership between the Southeast Florida Regional Climate Change Compact and the Florida Climate Institute

The County and the Compact have been benefitting greatly from the expertise and research occurring at universities in southeast Florida and throughout the state. Since its inception in 2009, the activities of the Compact have provided a great number of opportunities for collaboration with academic partners. In addition to assisting the Compact with many of the projects and deliverables previously mentioned, our academic partners have also assisted with the South Florida Resilient Redesign workshops and the hydrologic and economic model development, as well as provided support for climate communications and the development of visualization tools.

In 2010, the University of Florida and Florida State University officially initiated the Florida Climate Institute (FCI), which is a "multi-disciplinary network of national and international research and public organizations, scientists, and individuals concerned with achieving a better understanding of climate variability and change." It is currently comprised of eight (8) member universities, including Florida A&M University, Florida Atlantic University, Florida International University, Florida State University, the University of Central Florida, the University of Florida, the University of Miami, and the University of South Florida, and over 200 individual affiliate members. The mission of the FCI is to foster interdisciplinary research, education, and extension to: 1) improve the region's collective understanding of the impact of climate variability, climate change, and sea

level rise on the economy, ecosystems, and human-built systems; 2) develop technologies and information for creating opportunities and policies that reduce economic and environmental risks; and 3) engage society in research, extension, and education programs for enhancing adaptive capacity and responses to associated climate risks.

Understanding the strong alignment of FCI's mission with the objectives of the Compact, the significant resources these universities provide and the potential to attract additional resources to the region, the Compact Staff Steering Committee initiated conversations with FCI representatives in 2014, which led to the development of an informal partnership. This informal partnership was ceremonially signed by representatives of the Staff Steering Committee at the 2014 Annual Climate Leadership Summit (Attachment A). It is aimed at improving coordination and alignment of research occurring at FCI member universities with the information and implementation needs of the Compact partners. This is anticipated to accelerate the dissemination of climate information and enhance climate resiliency planning in support of urban and natural systems, while also improving the competitiveness of the region for research funding and other support.

In addition to this enhanced coordination at the regional level, I have also directed staff to work closely with our local university partners, not only on climate change and sea level rise issues, but also on resiliency issues and strategies for Miami-Dade County. I look forward to the mutual benefits this collaboration will bring to the County, the universities, and the region overall.

2. 2015 Update of the Compact Unified Sea Level Rise Projection for Southeast Florida

One of the first important accomplishments of the Compact was the development of a Unified Sea Level Rise Projection for Southeast Florida, which was released in April of 2011. It was developed through extensive research of scientific literature and numerous facilitated discussions by a technical ad hoc workgroup, the Compact Sea Level Rise Work Group. The Compact Sea Level Rise Work Group was comprised of researchers, senior scientists, and lead engineers representing the U.S. Army Corps of Engineers, the National Oceanographic and Atmospheric Administration, the South Florida Water Management District, the University of Miami, Florida International University, and Florida Atlantic University. It was agreed that this initial unified projection, which was based on the U.S. Army Corps of Engineers' July 2009 Guidance Document, would be used for planning purposes by all Compact counties. In order to keep the projection relevant for planning purposes, it was also understood and agreed that it should be periodically reviewed and possibly updated to keep up with new data and scientific information.

In October of 2015, the Compact's Sea Level Rise Work Group released the 2015 update of the Unified Sea Level Rise Projection for Southeast Florida (2015 Update). This followed almost a full year of comprehensive review of recent scientific and technical information and data. Key components of the 2015 Update include the following:

- The projection baseline has been adjusted from 2010 to 1992, to be consistent with guidance provided by the U.S. Army Corps of Engineers and the National Oceanographic and Atmospheric Administration.
- The projection timeline has been extended from 2060 to 2100 and includes consideration of processes that affect the local rate of sea level rise.
- The 2015 Update estimates sea level rise of six (6) to ten (10) inches by 2030 from the 1992 baseline. Since approximately three (3) inches of the projected rise has already occurred since the 1992 base year, this amount is subtracted from these projections in estimating additional rise (relative to 2015) in the 2030 and 2060 timeframes.

A detailed explanation of how to use these projections is provided in the 2015 Update guidance document entitled, "Unified Sea Level Projection-Southeast Florida," published in October 2105, which is included as Attachment B and is also available on the Compact website at: <http://www.southeastfloridaclimatecompact.org/wp-content/uploads/2015/10/2015-Compact-Unified-Sea-Level-Rise-Projection.pdf>

The 2015 Update is an important deliverable as Miami-Dade County begins incorporating vulnerability to sea level rise into its capital planning process. For instance, the Miami-Dade Water and Sewer Department has already incorporated this updated projection in recent assessments of the impact of sea level rise, storm surge, flooding, and wind under the Ocean Outfall Legislation Contract. The 2015 Update and information from these recent analyses will be used to inform other County departments and local jurisdictions as they evaluate the resiliency of their existing and proposed capital assets, which will aide in preparing these assets for current and future projected impacts.

3. Reaffirmation of the Southeast Florida Regional Climate Change Compact

As mentioned above, the Compact has experienced success on numerous levels since its inception in 2009. In addition to the accomplishments listed above, the Compact Counties were named as a White House Climate Action Champion in 2014 in recognition of their past leadership on climate issues and the prospect of their continued leadership in the future. Furthermore, the Compact model has been cited in the federal government documents such as the Third National Climate Assessment, and the Recommendations of the President's State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience, as well as many other documents and media. In addition to the significant external funding and resources drawn in to the region, the Compact's efforts have also enhanced cooperation amongst many local, regional, state, and federal agencies and stakeholders. Due to the tremendous success and multiple benefits of the Compact, the Staff Steering Committee coordinated a reaffirmation of the original Compact commitment at the 7th Annual Climate Leadership Summit held December 1 through December 3, 2015, in Key West, Florida. This Reaffirmation of the Southeast Florida Regional Climate Change Compact (Reaffirmation), which is included as Attachment C, was ceremonially signed by Monroe County Mayor Pro Tem Heather Carruthers; Broward County Commissioner Beam Furr; Palm Beach County Commissioner Steven Abrams; and Miami-Dade County Chairman Jean Monestime.

With this Reaffirmation, each of the Compact counties commit to continue to support the following activities that comprised the original commitments outlined in the 2009 Compact:

- Development of and advocacy for joint positions on federal and state legislation, regulations, and administrative policies pertaining to climate and energy issues, including, but not limited to, agreement on annual Compact state and federal legislative programs.
- Creation of common regional baseline information, including a unified sea level rise projection, regional greenhouse gas emissions inventory, and regional vulnerability assessment, and periodic updates to this information.
- Convocation of an annual Regional Climate Leadership Summit.
- Development of a Regional Climate Action Plan, including strategies to reduce regional greenhouse gas emissions, adapt to climate impacts, and strengthen regional resilience, to be revised every five (5) years from the date of publication of the first Regional Climate Action Plan.

The Reaffirmation was signed with the understanding that the commitments contained within it would not become effective until approved through the required procedures of each respective County.

I voted in support of the Compact as a County Commissioner in 2009 and have seen and experienced the many benefits of this ground-breaking partnership as County Mayor since its inception. The County supports this reaffirmation, and we look forward to the continued collaboration and success with our Compact partners.

If you have questions concerning the above, please contact James F. Murley, Chief Resilience Officer, Department of Regulatory and Economic Resources, at (305) 375-5593 or murleyj@miamidade.gov.

Attachments

- c: Honorable Harvey Ruvlin, Clerk of Courts, Eleventh Judicial Circuit
 Abigail Price-Williams, County Attorney
 Office of the Mayor Senior Staff
 Department Directors
 Lourdes M. Gomez, Deputy Director, Department of Regulatory and Economic Resources
 James F. Murley, Chief Resilience Officer, Department of Regulatory and Economic
 Resources
 Mark R. Woerner, Assistant Director for Planning, Department of Regulatory and
 Economic Resources



**Partnership Agreement on Regional Coordination
between the Southeast Florida Regional Climate Compact and the
Florida Climate Institute**

Purpose

The following agreement establishes a partnership between the Southeast Florida Regional Climate Change Compact (Compact) and the Florida Climate Institute (FCI) to increase the effectiveness of current collaborations among Florida's institutions of higher learning and the local governments and regional agencies of Southeast Florida. The purpose of this Partnership Agreement is to seek better alignment between public sector information and management needs and ongoing research objectives, to improve coordination among the parties in pursuing competitive research funding opportunities, and to assure that the best and brightest ideas emerging from Florida's world-class institutions are well positioned for implementation in supporting Southeast Florida's efforts to transition to a resilient and low-carbon economy.

Background

Since its creation in 2009 by forward-thinking elected officials, the Compact has emerged as one of the preeminent regional metropolitan climate change governance models nationally and globally. The collaboration and coordination across cities and counties and among federal, state and local agencies has advanced the region rather quickly toward increased shared aspirations for greater climate resilience and reductions in regional emissions. Likewise, the Florida Climate Institute is a path breaking collaboration among eight of Florida's world class universities that serves as a multidisciplinary network for research and education aimed at helping Florida meet the many challenges of global climate change. Together, the Compact and FCI recognize that responsible action on global climate change will require the talents and insights of nearly every academic discipline from primary climate science to architecture and engineering, from the arts and humanities to ecology and finance. And the parties to this agreement further recognize that knowledge, to be effective, must be well integrated into the public policy of Southeast Florida.

Partnership Agenda

The Southeast Florida Regional Climate Change Compact and the Florida Climate Institute agree to the following partnership actions:

- I. We will improve communication and coordination between our respective networked organizations.
 - a. By mutual consent, we will each appoint representatives to serve as liaisons to the other's primary governance and coordination teams;
 - b. We will each promote and participate in the activities and events of our respective entities, recognizing the constraints sometimes provided by limited budgets and resources;
 - c. We will work together to ensure that research conferences and symposia focusing on our mutual interests will be located such that Compact participants are able to participate without incurring significant travel costs; and
 - d. We will establish a joint Southeast Florida Hub that will allow us to more specifically address regional issues in Southeast Florida, while maintaining communication and collaboration with the broader statewide FCI partners.

- II. We will engage in an annual process of identifying the highest priority research objectives based on the needs of Compact managers and the academic pursuits of FCI faculty affiliates.
 - a. We will work together to develop proposals from this annual process and assure transparency in the preparation of all presentations, grants, awards, abstracts or letters of support that formally reference our collective work together as a basis of award or recognition;
 - b. Each party will actively consider opportunities to include members and affiliates of the other in responses to unforeseen calls for proposals and/or notices of funding opportunities.

- III. We will work together to perfect this agreement for ratification by our respective Compact and University Principals at a later date.

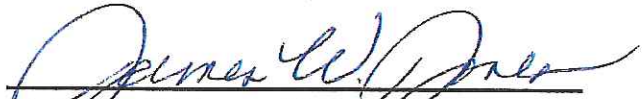
Agreed, this day, October 1, 2014, in Miami Beach, Florida.

For the Compact

For the Florida Climate Institute



Dr. Jennifer Jurado, Director, Broward
County Environmental Planning and
Community Resilience Division




Dr. James W. Jones, Director and Chair
Florida Climate Institute



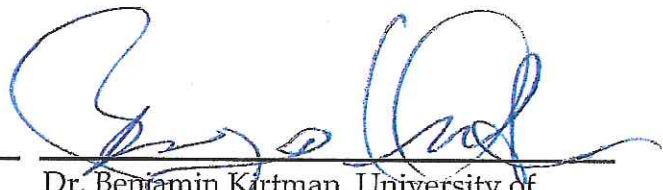
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UNIFIED SEA LEVEL RISE PROJECTION SOUTHEAST FLORIDA

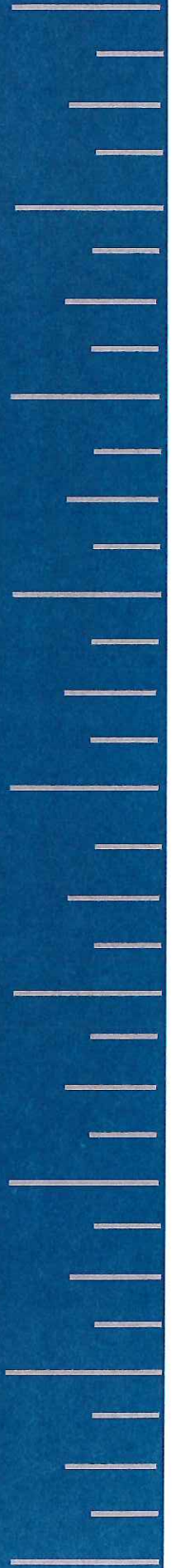
**SOUTHEAST FLORIDA
REGIONAL COMPACT
CLIMATE
CHANGE**



October 2015

Prepared by the

Sea Level Rise Work Group



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Recommended Citation

Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact).
October 2015. *Unified Sea Level Rise Projection for Southeast Florida*. A document prepared for
the Southeast Florida Regional Climate Change Compact Steering Committee. 35 p.

EXECUTIVE SUMMARY

The Southeast Florida Regional Climate Change Compact reconvened the Sea Level Rise Work Group for the purpose of updating the unified regional projection based on global projections, guidance documents and scientific literature released since the original regional projection in 2011 (Compact, 2011). The objective of the unified sea level rise projection for the Southeast Florida region remains consistent that the projection is for use by the Climate Compact Counties and partners for planning purposes to aid in understanding of potential vulnerabilities and to provide a basis for developing risk informed adaptation strategies for the region. For the 2015 update, the starting point for all sea level rise projections has been shifted from 2010 to 1992. This allows for direct use of local tide station information to convert projections into local water surface elevations for flood vulnerability studies, and is consistent with current guidance from the U.S. Army Corps of Engineers (USACE) and the National Oceanographic and Atmospheric Agency (NOAA). The Unified Sea Level Rise projection for Southeast Florida has also been extended to 2100 in recognition of the need for longer range guidance for major infrastructure and other long term investments now being planned.

In the short term, sea level rise is projected to be 6 to 10 inches by 2030 and 14 to 26 inches by 2060 (above the 1992 mean sea level). In the long term, sea level rise is projected to be 31 to 61 inches by 2100. For critical infrastructure projects with design lives in excess of 50 years, use of the upper curve is recommended with planning values of 34 inches in 2060 and 81 inches in 2100. The National Aeronautics and Space Administration Jet Propulsion Laboratory (2015) has reported the average global sea level has risen almost 3 inches between 1992 and 2015 based on satellite measurements. Sea level rise in South Florida has been of similar magnitude over the same period (NOAA, 2015) but is anticipated to outpace the global average due to ongoing variations in the Florida Currents and Gulf Stream.

Projected sea level rise, especially by 2060 and beyond, has a significant range of variation as a result of uncertainty in future greenhouse gas emissions and their geophysical effects, the incomplete quantitative understanding of all geophysical processes that might affect the rate of sea level rise in climate models and the limitations of current climate models to predict the future. As such, the Work Group recommends that the unified sea level rise projection include three curves, in descending order, the NOAA High Curve, the USACE High Curve and a curve corresponding to the median of the IPCC AR5 RCP8.5 scenario, with specific guidance as to how and when they should be used in planning. This guidance document describes the recommended application of the projection as it relates to both high and low risk projects and short and long-term planning efforts. Also, the Work Group recommends that this guidance be updated every

five to seven years because of the ongoing advances in scientific knowledge related to global climate change and potential impacts.

INTRODUCTION

WHO SHOULD USE THIS PROJECTION AND GUIDANCE DOCUMENT?

The Unified Sea Level Rise Projection for Southeast Florida is intended to be used for planning purposes by a variety of audiences and disciplines when considering sea level rise in reference to both short and long-term planning horizons and infrastructure design in the Southeast Florida area.

HOW SHOULD THE REGIONAL PROJECTION BE APPLIED?

The projection (*Unified Sea Level Rise Projection for Southeast Florida*) contains a graph and table describing the rise in sea level from 1992 through the turn of the current century. The projection can be used to estimate future sea level elevations in Southeast Florida and the relative change in sea level from today to a point in the future. *Guidance for Application* contains directions and specific examples of how the projection can be used by local governments, planners, designers and engineers and developers. This regional projection is offered to ensure that all major infrastructure projects throughout the Southeast Florida region have the same basis for design and construction relative to future sea level.

WHAT ARE THE IMPACTS ASSOCIATED WITH SEA LEVEL RISE?

The consequences associated with sea level rise include direct physical impacts such as coastal inundation of inland areas, increased frequency of flooding in vulnerable coastal areas, increased flooding in interior areas due to impairment of the region's stormwater infrastructure i.e. impacts to gravity drainage systems and features in the regional water management canal system, saltwater intrusion into the aquifer and local water supply wells, and contamination of the land and ocean with pollutants and debris and hazardous materials released by flooding. Consequences also include cascading socio-economic impacts such as displacement, decrease in property values and tax base, increases in insurance costs, loss of services and impaired access to infrastructure. The likelihood and extent to which these impacts will occur is dependent upon the factors influencing the rate of sea level rise such as the amount of greenhouse gases emitted globally, rate of melting of land-based ice sheets, the decisions and investments made by communities to increase their climate resilience and the many interconnected processes described in the *Appendix B: State of Science Update*. One of the values of this sea level rise projection is the ability to perform scenario testing to better understand the potential impacts and timeline of sea level rise within the Southeast Florida community.

WHO DEVELOPED THE UNIFIED SEA LEVEL RISE PROJECTION FOR SOUTHEAST FLORIDA?

In 2010, the Southeast Florida Regional Climate Change Compact Steering Committee organized the first Regional Climate Change Compact Technical Ad hoc Work Group (Work Group). Their objective was to develop a unified sea level rise projection for the Southeast Florida region for use by the Climate Compact Counties and partners. Its primary use was for planning purposes to aid in understanding of potential vulnerabilities and to provide a basis for outlining adaptation strategies for the region. The Work Group reviewed existing projections and scientific literature and developed a unified regional projection for the period from 2010 to 2060 (Compact, 2011). The projection highlighted two planning horizons: 1) by 2030, sea level rise was projected to be 3 to 7 inches above the 2010 mean sea level and 2) by 2060, sea level rise was projected to be 9 to 24 inches above the 2010 mean sea level. In anticipation of the release of the United Nations Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, 2013), the Sea Level Rise Work Group recommended a review of the projection four years after its release in 2011.

In September 2014, the Sea Level Rise Work Group was reconvened for the purpose of updating the unified regional projection based on projections and scientific literature released since 2011. This report released in October 2015 contains a summary of the projections and publications reviewed and discussed, the methodology for deriving the projection, the recommended unified regional projection and additional recommendations from the Sea Level Rise Work Group.

UNIFIED SEA LEVEL RISE PROJECTION FOR SOUTHEAST FLORIDA

PROJECTION AND SUMMARY

This Unified Sea Level Rise projection for Southeast Florida updated in 2015 projects the anticipated range of sea level rise for the region from 1992 to 2100 (Figure 1). The projection highlights three planning horizons:

- 1) short term, by 2030, sea level is projected to rise 6 to 10 inches above 1992 mean sea level,
- 2) medium term, by 2060, sea level is projected to rise 14 to 34 inches above 1992 mean sea level,
- 3) long term, by 2100, sea level is projected to rise 31 to 81 inches above 1992 mean sea level.

Projected sea level rise in the medium and long term has a significant range of variation as a result of uncertainty in future greenhouse gas emissions and their geophysical effects, the incomplete quantitative understanding of all geophysical processes affecting the rate of sea level rise in climate models and current limitations of climate models to predict the future. As such, the Work Group recommends that the unified sea level rise projection include three global mean sea level rise curves regionally adapted to account for the acceleration of sea level change observed in South Florida. The titles of the global mean sea level rise curves were retained for simplicity of referencing source but the curves have been adjusted from the global projections to reflect observed local change. The projection consists of the NOAA High Curve, the USACE High Curve (also known as the NOAA Intermediate- High) and the median of the IPCC AR5 RCP8.5 scenario, with specific guidance as to how and when they should be used in planning.

- The lower boundary of the projection (blue dashed line) can be applied in designing low risk projects that are easily replaceable with short design lives, are adaptable and have limited interdependencies with other infrastructure or services.
- The shaded zone between the IPCC AR5 RCP8.5 median curve and the USACE High is recommended to be generally applied to most projects within a short -term planning horizon. It reflects what the Work Group projects will be the most likely range of sea level rise for the remainder of the 21st Century.
- The upper curve of the projection should be utilized for planning of high risk projects to be constructed after 2060 or projects which are not easily replaceable or removable, have a long design life (more than 50 years) or are critically interdependent with other infrastructure or services.

Unified Sea Level Rise Projection (Southeast Florida Regional Climate Change Compact, 2015)			
Year	IPCC AR5 Median (inches)	USACE High (inches)	NOAA High (inches)
2030	6	10	12
2060	14	26	34
2100	31	61	81

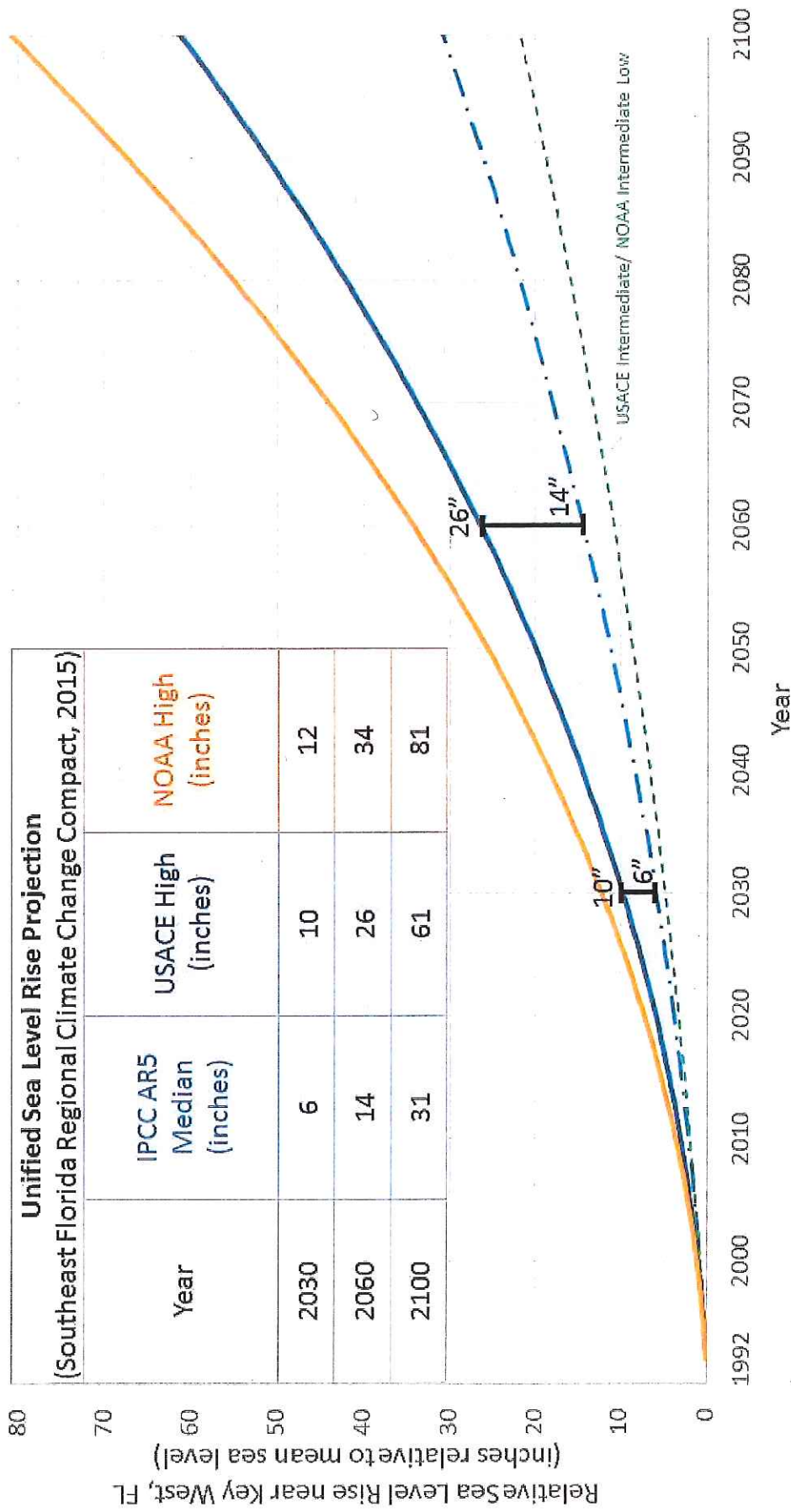


Figure 1: Unified Sea Level Rise Projection. These projections are referenced to mean sea level at the Key West tide gauge. The projection includes three global curves adapted for regional application: the median of the IPCC AR5 RCP8.5 scenario as the lowest boundary (blue dashed curve), the USACE High curve as the upper boundary for the short term for use until 2060 (solid blue line), and the NOAA High curve as the uppermost boundary for medium and long term use (orange solid curve). The incorporated table lists the projection values at years 2030, 2060 and 2100. The USACE Intermediate or NOAA Intermediate Low curve is displayed on the figure for reference (green dashed curve). This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect current emissions trends.

PROJECTION UPDATE

The key components of the methodology used to develop the unified sea level rise projection are as follows:



Planning Horizon of 2100: In response to the release of climate scenarios extending to year 2100 from the Intergovernmental Panel on Climate Change (IPCC), projections through year 2100 by federal agencies including the US Army Corps of Engineers (USACE) and the National Oceanographic and Atmospheric Administration (NOAA) and the need for planning for infrastructure with design lives greater than 50 years, the unified sea level rise projection time scale has been extended to 2100.



Starting in 1992: The year 1992 has been selected as the initial year of the projection because it is the center of the current mean sea level National Tidal Datum Epoch of 1983-2001. A tidal datum epoch is a 19 year period adopted by the National Ocean Service as the official time segment over which tide observations are used to establish tidal datums such as mean sea level, mean high water etc. The National Tidal Datum Epoch is revised every 20-25 years to account for changing sea levels and land elevations.



Tide gauge selection: The Key West gauge ([NOAA Station ID 8724580](#)) was maintained as the reference gauge for calculation of the regional projection as was used in the original projection. In addition, appropriate conversion calculations are provided in Section 4: Guidance for Application in order to reference the projection to the Miami Beach gauge ([NOAA Station ID 8723170](#)) or the Lake Worth Pier gauge ([NOAA Station ID 8722670](#)). The Key West gauge has recorded tidal elevations since 1913. Tidal records from Miami Beach and Lake Worth Pier are available since 2003 and 1996, respectively.



Review of existing projections: Global projections released since 2011 were reviewed and considered for interpretation for the unified sea level rise projection including those developed by USACE (2011; 2013), NOAA (Parris et al., 2012), IPCC (IPCC, 2013), Bamber and Aspinall (2013), Horton et al. (2014), Jevrejeva et al. (2014), and Kopp et al. (2014). Review criteria included comprehensiveness of datasets and models used to develop the projections, standing in the scientific community, and applicability to the Southeast Florida region.

Summaries of the existing global projections are included below:

- ❖ *USACE Guidance: There was no update to the projections since 2011 (USACE, 2011). The range of global mean sea level change projected by USACE was approximately 0.2 to 0.6 meters (9 to 25 inches) by 2060 and 0.5 to 1.5 meters (20 to 59 inches) by 2100. Existing guidance and the online USACE Sea Level Change Calculator were used to adapt the global mean sea level change curves for the unified South Florida projection.*
- ❖ *IPCC AR5 Projections: The 5th Assessment Report (AR5) included four scenarios based on predicted greenhouse gas concentration trajectories (Regional Concentration Pathways, RCPs). The global mean sea level change projected in these scenarios ranged from 0.17 to 0.38 meters (7 to 15 inches) by years 2046 to 2065 and 0.26 to 0.82 meters (10 to 32 inches) by 2081 to 2100.*
- ❖ *NOAA Projections produced for the National Climate Assessment (NCA): For the 2014 NCA, four global mean sea level rise scenarios were defined in a manner allowing the user to select the appropriate curve based on risk of concern, uncertainty tolerance and type of application. The global mean sea level rise projected in these scenarios ranges from 0.2 meters to 2 meters (8 to 80 inches) by 2100.*
- ❖ *Recent Probabilistic Projections: Recently, several authors have quantitatively and qualitatively approached determining the likelihood or percent chance that the global mean sea level rise projections will occur by 2100. For example, based on a probability density function, Jevrejeva et al. (2014) concluded that there is only a 5% chance global mean sea level rise will be larger than 1.8 meters (71 inches) by 2100. Using an alternate method, Kopp et al. (2014) concluded there is only a 5% chance global mean sea level rise will be larger than 1.76 meters (69 inches). These studies represent examples of possible methods of further explaining applicability of projections for future use.*
- ❖ *Science Community Polling: Several polls have been conducted amongst groups within the scientific community to understand the experts' opinions on the level of uncertainty associated with existing global mean sea level rise projections. These surveys have yielded reported likely ranges of global mean sea level rise of 0.4 to 1.2 m (16 to 42 inches) depending on warming scenarios (Horton et al., 2014) and 0.29 m to 0.84 m (11 to 33 inches) (Bamber and Aspinall, 2013) by 2100.*



Projection confidence: The understanding of past sea level changes has improved since the Work Group's last review due to additional observations and analyses of processes driving thermal expansion, loss of ice from ice sheets and glaciers and terrestrial water storage by the scientific community. Despite this improved understanding, the development of complex climate models is evolutionary and many processes and responses are yet to be incorporated. The numerous ice melt accelerating feedbacks not in the models are especially of concern as they are speeding up ice melt and sea level rise well beyond model projections. Models do continue to offer useful approximations of trends and order of magnitude of rates of change and acceleration based on climate data input and are suitable for determining projected future ranges for planning and design efforts. Additionally, as noted in Parris et al. (2012), the quadratic curves comprising the projection were selected by the some of the scientific community for simplicity. Sea level will not rise in the smooth manner illustrated by the quadratic curves but, may be punctuated by faster and slower rates (Parris et al., 2013).

GUIDANCE FOR APPLICATION

INCREASE IN RECURRENT FLOODING AND REDUCED DRAINAGE CAPACITY

Recent analyses of tide gauge records acquired along the US Atlantic coast indicate a rapid acceleration in the rate of sea level rise since 2000, which was attributed to possible slowing down of the Atlantic Meridional Overturning Circulation (AMOC) (Ezer et al., 2013; Sallenger et al., 2012; Yin et al., 2009). The higher sea level resulted in increasing flooding frequency in several coastal communities, e.g., Boston, Norfolk, and Miami Beach (Ezer et al., 2013; Kirshen et al., 2008; Kleinosky et al., 2007; Wdowinski et al., 2015). These frequent flood events, often termed “nuisance flooding”, occur mainly due to heavy rain during high tide conditions but sometimes occur due to high tide alone and are termed “King tides”, “lunar flooding” or “sunny sky flooding”. Recently, Ezer and Atkinson (2014) used tide gauge data to calculate accumulated flooding time in twelve locations along the Atlantic coast and showed a significant increase in flooding duration over the past twenty years. They suggested that flood duration is a reliable indicator for the accelerating rate of sea level rise, which is often difficult to estimate on a regional-scale.

On the national scale, NOAA (2014) published an assessment of nuisance flooding finding that the duration and frequency of these events are intensifying around the United States. Subsequently, Sweet and Park (2014) demonstrated that coastal areas are experiencing an increased frequency of flood events (an acceleration) over the last few decades, and that this acceleration in flood occurrence will continue regardless of the specific rate of sea level rise.

A detailed analysis of nuisance flooding occurrence in Miami Beach was conducted by Wdowinski et al. (2015), who used a variety of data sources (tide gauge, rain gauge, media reports, insurance claims, and photo records) from the past 16 years (1998-2013). They found that most flooding events occur after heavy rain (> 80 mm, 3 inches) during high tide conditions, but also after the fall equinox tides regardless of rain events. An analysis of flooding frequency over the past 16 years revealed that since 2006, rain-induced events increased by 33% and tide-induced events quadrupled, from 2 events during 1998-2005 to 8-16 events in 2006-2013. Wdowinski et al. (2015) also analyzed the nearby Virginia Key tide gauge record and found a significant acceleration in the rate of sea level rise since 2006. The average rate of regional sea level rise since 2006 is 9 ± 4 mm/yr, significantly higher than the global average rate of 2.8 ± 0.4 mm/yr estimated from in-situ data (Church and White, 2011). Although the Work Group notes that continued analysis of changes in trends over time is necessary to determine long-term significance of this recently observed uptrend, studies have already begun to correlate the regional sea level rise to the slowing down of the Gulfstream. A comparison between sea level variations near Miami with high-resolution global climate model simulations (Kirtman et al., 2012) revealed a strong correlation between increasing sea level rise in the Miami area and a

weakening of the Florida Current-Gulf Stream system. This finding confirmed concurs with other studies that relate sea level rise acceleration along the US Atlantic coast with weakening of the Gulf Stream (e.g., Ezer et al., 2013; Park and Sweet, 2015).

STORM SURGE AND SEA LEVEL RISE

Storm surge and sea level rise are independent coastal processes that when occurring simultaneously lead to compounded impacts. Sea level rise will increase the inland areal extent inundated by surges, the depth of flooding and power of the surge and the extent and intensity of damage associated with storm surge and waves. As a result, severe storms of the future will cause more damage than storms of equal intensity occurring at today's sea level. Tebaldi et al. (2012) estimate a 100-year magnitude surge flooding (by today's standards) will begin to occur every 20 years at the projected mean sea level in 2050. Regional hazard mapping does not yet include the combined effects of sea level rise and surge but the impacts are anticipated to be significant.

Historically, the sea level extremes have increased along with the increase in mean sea level at locations along the coasts. Using this as the basis, one can relate the sea level extremes to mean sea level which allows the determination of future extremes and return periods (Obeysekera and Park, 2013). Another approach is to use the non-tidal residuals (component of storm surge and waves above the tidal variations), NTR, and determine their probabilistic characteristics. Assuming future sea level rise scenarios and the tidal variations, one can then superimpose extreme storm surge of NTR for a given return period to determine total sea level extreme for a given time epoch in the future. Return period for a given scenario can be determined using methods outlined in Salas and Obeysekera (2014). Both approaches assume there is no change in future "storminess" although with higher sea levels, magnitude of storm surge may change at some locations along the coasts.

NATURAL RESOURCE DEGRADATION

As sea level rise increasingly inundates coastal areas, there is the potential for degradation of natural resources and loss of their services to the surrounding environment. Ecosystems will transition either by retreat and migration, adaptation, or elimination of functions and certain species. Shallow water habitats may transition to open water, forcing ecological changes in coastal wetlands and estuaries affecting nesting, spawning and feeding locations and behavior. Intrusion of saltwater inland, into inland water bodies and within the aquifer is negatively impacting freshwater resources, and these impacts will worsen or accelerate with further sea level rise. Inundation of shorelines will increase the extent and severity of beach erosion and

previously stable coastal areas. In combination, these impacts will cascade throughout the region's ecosystems even if they are not immediately adjacent to open water areas.

Natural infrastructure is critical to the resilience of the urban environment, in that it provides many benefits related to storm protection, water and air purification, moderating urban heat effects, and socio-economics. South Florida's tourist economy is heavily dependent on these natural resources. The region must prioritize providing space for habitat transitions and focus on reducing anthropogenic pressures that would compound the degrading effects of sea level rise.

GUIDANCE IN APPLYING THE PROJECTIONS

AUDIENCES

The Unified Sea Level Rise Projection for Southeast Florida is intended to be used for planning purposes by a variety of audiences and disciplines when considering sea level rise in reference to both short and long-term planning horizons as well as infrastructure siting and design in the Southeast Florida area. Potential audiences for the projections include, but are not limited to, elected officials, urban planners, architects, engineers, developers, resource managers and public works professionals.

One of the key values of the projection is the ability to associate specific sea level rise scenarios with timelines. When used in conjunction with vulnerability assessments, these projections inform the user of the potential magnitude and extent of sea level rise impact at a general timeframe in the future. The blue shaded portion of the projection provides a likely range for sea level rise values at specific planning horizons. Providing a range instead of a single value may present a challenge to users such as engineers who are looking to provide a design with precise specifications. Public works professionals and urban planners need to work with the engineers and with policy makers to apply the projection to each project based on the nature, value, interconnectedness, and life cycle of the infrastructure proposed.

Finally, elected officials should use the projections to inform decision making related to issues such as adaptation policies, budget impacts associated with design features which address planning for future sea level rise, capital improvement project needs especially those associated with drainage and shoreline protection, and land use decisions.

APPLYING PROJECTION CURVES TO INFRASTRUCTURE SITING AND DESIGN

When determining how to apply the projection curves, the user needs to consider the nature, value, interconnectedness, and life cycle of the existing or proposed infrastructure. The blue

shaded portion of the projection can be applied to most infrastructure projects, especially those with a design life expectancy of less than 50 years. The designer of a type of infrastructure that is easily replaced, has a short lifespan, is adaptable, and has limited interdependencies with other infrastructure or services must weigh the potential benefit of designing for the upper blue line with the additional costs. Should the designer opt for specifying the lower curve, she/he must consider the consequences of under-designing for the potential likely sea level condition. Such consequences may include premature infrastructure failure. Additionally, planning for adaptation should be initiated in the conceptual phase. A determination must be made on whether or not threats can be addressed mid-life cycle via incremental adaptation measures, such as raising the height of a sluice gate on a drainage canal..

Forward thinking risk management is critical to avoiding loss of service, loss of asset value and most importantly loss of life or irrecoverable resources. An understanding of the risks that critical infrastructure will be exposed to throughout its life cycle such as sea level rise inundation, storm surge and nuisance flooding must be established early on in the conceptual phase. If incremental adaptation is not possible for the infrastructure proposed and inundation is likely, designing to accommodate the projected sea level rise at conception or selection of an alternate site should be considered. Projects in need of a greater factor of safety related to potential inundation should consider designing for the upper limit of the blue-shaded zone. Examples of such projects may include evacuation routes planned for reconstruction, communications and energy infrastructure and critical government and financial facilities.

Due to the community's fundamental reliance on major infrastructure, existing and proposed critical infrastructure should be evaluated using the upper curve of the projection, the orange curve (Figure 1, NOAA High). Critical projects include those or projects which are not easily replaceable or removable, have a long design life (more than 50 years), or are interdependent with other infrastructure or services. If failure of the critical infrastructure would have catastrophic impacts, it is considered to be high risk. Due of the community's critical reliance on major infrastructure, existing and proposed high risk infrastructure should be evaluated using the upper curve of the projection, the orange curve (Figure 1, NOAA High). Examples of high risk critical infrastructure include nuclear power plants, wastewater treatment facilities, levees or impoundments, bridges along major evacuation routes, airports, seaports, railroads, and major highways.

For low risk infrastructure projects, the lowermost curve of the projection (Figure 1, IPCC AR5 RCP8.5 curve) may be applied. Low risk projects include infrastructure expected to be constructed and then replaced within the next 10 years, projects that are easily replaceable and

adaptable or projects with limited interdependencies and limited impacts when failure occurs. An example of such a project may be a small culvert in an isolated area.

Additionally, planning for adaptation should be initiated in the conceptual phase. A determination must be made on whether or not risk can be addressed mid-life cycle via incremental. If incremental adaptation is not possible for the type of high risk infrastructure proposed and inundation is likely, designing to accommodate the projected sea level rise at conception or selection of an alternate site should be considered. To ensure an appropriately conservative design approach is used, the upper limit of the projection (Figure 1, NOAA High) should be used for projects with design lives of more than 50 years.

AVAILABLE VULNERABILITY ASSESSMENTS

The Southeast Florida Regional Climate Change Compact and the individual Compact Counties have developed region-wide and county-wide sea level rise inundation vulnerability assessments available for public use ([Compact, 2012](#)). These assessments spatially delineate areas of inundation correlating to 1 foot, 2 feet and 3 feet of sea level rise. In addition, the [Compact website](#) hosts a multitude of sources of information, tools and links in support of adaptation and mitigation planning for use by the Compact communities.

SUMMARY

The Work Group recommends the use of the NOAA High Curve, the USACE High Curve (USACE, 2015) and the median of the IPCC AR5 RCP8.5 scenario (IPCC, 2013) as the basis for a Southeast Florida sea level rise projection for the 2030, 2060 and 2100 planning horizons. In the short term, sea level rise is projected to be 6 to 10 inches by 2030 and 14 to 26 inches by 2060 (above the 1992 mean sea level). Sea level has risen 3 inches from 1992 to 2015. In the long term, sea level rise is projected to be 31 to 61 inches by 2100. For critical infrastructure projects with design lives in excess of 50 years, use of the upper curve is recommended with planning values of 34 inches in 2060 and 81 inches in 2100. Sea level will continue to rise even if global mitigation efforts to reduce greenhouse gas emissions are successful at stabilizing or reducing atmospheric CO₂ concentrations; however, emissions mitigation is essential to moderate the severity of potential impacts in the future. A substantial increase in sea level rise within this century is likely and may occur in rapid pulses rather than gradually.

The recommended projection provides guidance for the Compact Counties and their partners to initiate planning to address the potential impacts of sea level rise on the region. The shorter term planning horizons (through 2060) are critical to implementation of the Southeast Florida Regional

Climate Change Action Plan, to optimize the remaining economic life of existing infrastructure and to begin to consider adaptation strategies. As scientists develop a better understanding of the factors and reinforcing feedback mechanisms impacting sea level rise, the Southeast Florida community will need to adjust the projections accordingly and adapt to the changing conditions. To ensure public safety and economic viability in the long run, strategic policy decisions will be needed to develop guidelines to direct future public and private investments to areas less vulnerable to future sea level rise impacts.

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SOUTHEAST FLORIDA
REGIONAL COMPACT
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CHANGE



APPENDIX A: STAND ALONE GUIDANCE DOCUMENT AND PROJECTION

The Southeast Florida Regional Climate Change Compact's 2015 Unified Sea Level Rise Projection is presented below showing the anticipated range of sea level rise for the region from 1992 to 2100 (Figure 1). The projection highlights three planning horizons:

- 1) Short term, by 2030, sea level rise is projected to be 6 to 10 inches above 1992 mean sea level;
- 2) Medium term, by 2060, sea level rise is projected to be 14 to 26 inches above 1992 mean sea level with the less likely possibility of extending to 34 inches;
- 3) Long term, by 2100, sea level rise is projected to be 31 to 61 inches above 1992 mean sea level with the less likely possibility of extending to 81 inches.

The Unified Sea Level Rise Projection for Southeast Florida include three curves, named after the global sea level rise curves from which they were derived: the NOAA High Curve (orange solid), the USACE High Curve (blue solid) and the median of the IPCC AR5 scenario (blue dashed). The blue shaded area represents the *likely* range of sea level rise for our region. The orange curve represents a condition that is possible but less likely. The USACE Intermediate or NOAA Intermediate Low curve is displayed on the figure for reference (green dashed curve). This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect the impact on sea level from the current emissions trends.

When determining how to apply the projection curves, the user needs to consider the nature, value, interconnectedness, and life cycle of the infrastructure in question. The following guidance is provided for using the projection.

- The shaded zone between the IPCC AR5 median curve and the USACE High is recommended to be generally applied to most projects within a short to long-term planning horizon, especially those with a design life expectancy of less than 50 years. The designer of a type of infrastructure that is easily replaced, has a short lifespan, is adaptable, and has limited interdependencies with other infrastructure or services must weigh the potential benefit of designing for the upper blue line with the additional costs. Should the designer opt for specifying the lower curve, he must consider the consequences of under designing for the potential likely condition.
- The uppermost boundary of the projection (orange curve) should be utilized for planning of critical infrastructure to be constructed after 2060 or projects with a long design life (more than 50 years) as a conservative estimate of potential sea level rise. Critical projects include those which are not easily replaceable or removable, have a long design life (more than 50 years), or are interdependent with other infrastructure or services. If failure of the infrastructure would have catastrophic impacts on the economy, community or environment, it should be considered critical.

To reference the projection to the current year i.e. 2015, simply subtract the values listed in the table below from the projected sea level rise. For example, based on the projection, sea level rise in 2030 will be 6 to 10 inches above 1992 mean sea level. In order to determine how much rise will occur relative to the current year, 2015, the values listed in the table below for the IPCC AR5 median and USACE High curves can be subtracted from the projected range i.e. $6-3=3$ inches for the lower end of the range and $10-4.3=5.6$ inches for the upper end of the range, respectively. The projection can be restated as such: sea level will rise 3 to 5.6 inches from this year (2015) to 2030.

Current Year	IPCC AR5 Median (Blue Dashed Line)	USACE High (Blue Solid Line)	NOAA High (Orange Line)
2015	3	4.3	5.3
2016	3.1	4.7	5.6
2017	3.4	4.9	6
2018	3.5	5.3	6.4
2019	3.7	5.5	6.8

To convert local relative sea level rise datum from mean sea level to a topographic reference point used in surveying land elevations (NAVD 88), add the number listed in the table below to projected sea level rise:

	To convert relative sea level rise datum from mean sea level to feet NAVD 88*, add the number below to value from projection	To convert relative sea level rise datum from mean sea level to inches NAVD 88, add the number below to value from projection	Mean High Water (MHW)	Mean Low Water (MLW)
	Mean Sea Level in feet NAVD 88	Mean Sea Level in inches NAVD 88	Inches NAVD 88	Inches NAVD 88
Key West	-0.87	-10.4	-5.6	-14.2
Vaca Key	-0.83	-10	-5.6	-14.2
Miami Beach	-0.96	-11.5	3.0	-26.5
Lake Worth Pier	-0.95	-11.4	4.9	-27.8

*North American Vertical Datum of 1988 (NAVD 88) is the topographic reference point used in surveying land elevations. By definition it is the vertical control datum of orthometric height established for vertical control surveying in the United States of America based upon the General Adjustment of the North American Datum of 1988.

Alternatively, the USACE Sea Level Change Curve Calculator (Version 2018.88) (USACE, 2015) found at this website <http://www.corpsclimate.us/ccaceslcurves.cfm> can be used to change datums, reference years and tide gauge locations. The projection curves were generated using this tool.

The equations used for the curves comprising the unified sea level rise projection are as follows:

- ❖ NOAA High Curve (Parris, 2012) and USACE High Curve (USACE, 2013):

$$E(t_2) - E(t_1) = a(t_2 - t_1) + b(t_2^2 - t_1^2)$$

where $E(t_2) - E(t_1)$ = Eustatic sea level change (m) with reference year of 1992;

t_1 = difference in time between current year or construction date and 1992 e.g. 2015-1992 = 23 years;

t_2 = difference in time between future date of interest and 1992 i.e. 2060-1992 = 68 years;

where a is a constant equal to 0.0017 mm/yr, representing the rate of global mean sea level change,

and b is a variable equal to 1.56×10^{-4} for the NOAA High Curve; 1.13×10^{-4} for the USACE high curve, representing the acceleration of sea level change.

- ❖ IPCC AR5 RCP8.5 Median Curve (IPCC, 2013):

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + (4.684499 \times 10^{-5})(t_2^2 - t_1^2)$$

- ❖ The NOAA Intermediate Low/ USACE Low curve that is not part of the projection but included on the graph for reference (green dashed line) can be derived as follows:

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + (2.71262 \times 10^{-5})(t_2^2 - t_1^2)$$

The equations above are global mean sea level rise projections. In order to adapt the curves for regional use, the average rate of mean sea level rise or “ a ” value is adjusted. For example, to reference the above equations to the Key West tide gauge, a equals 0.0022 mm/yr.

Unified Sea Level Rise Projection (Southeast Florida Regional Climate Change Compact, 2015)			
Year	IPCC AR5 Median (inches)	USACE High (inches)	NOAA High (inches)
2030	6	10	12
2060	14	26	34
2100	31	61	81

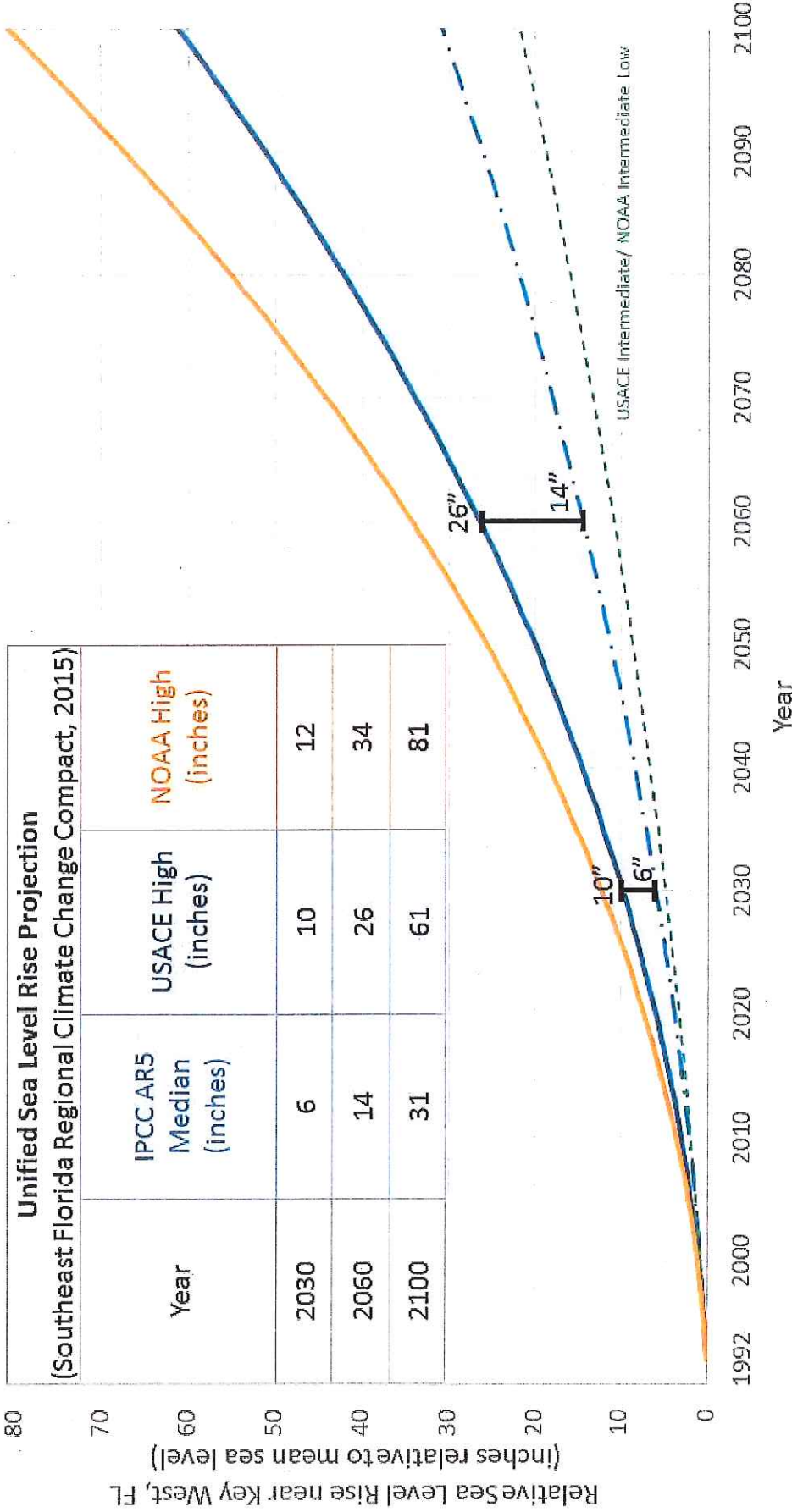


Figure A-1: Unified Sea Level Rise Projection. These projections are referenced to mean sea level at the Key West tide gauge. The projection includes three global curves adapted for regional application: the median of the IPCC AR5 scenario as the lowest boundary (blue dashed curve), the USACE High curve as the upper boundary for the short term for use until 2060 (solid blue line), and the NOAA High curve as the uppermost boundary for medium and long term use (orange solid curve). The incorporated table lists the projection values at years 2030, 2060 and 2100. The USACE Intermediate or NOAA Intermediate Low curve is displayed on the figure for reference (green dashed curve). This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect current emissions trends.

APPENDIX B: STATE OF SCIENCE UPDATE

ACCELERATION OF SEA LEVEL RISE

A statistically significant acceleration of sea level rise has been documented in the latter half of the 20th century continuing through recent years (Church and White, 2011; Calafat and Chambers, 2013; Hay et al. 2015; IPCC, 2013; Watson et al., 2015). Hay et al. (2015) reported the global sea level rise rate from 1901 to 1990 to be 1.2 +/- 0.2 mm/yr (a value which had been overestimated in previous studies). Since 1993, an increase in the average global mean sea level rise rate has been observed (Hay et al., 2015; Watson et al., 2015). Watson et al. (2015) has most recently reported the average global mean sea level rise rate to be more than double the rate of the previous century, indicating an acceleration; the observed rate was 2.6+0.4 mm/yr from 1993 to 2015 with an acceleration of 0.04 mm/yr². This acceleration indicates sea level will rise more rapidly in the future than it has historically. The global and regional processes driving sea level rise and its acceleration are discussed in the following sections.

FACTORS INFLUENCING SEA LEVEL RISE

GLOBAL PROCESSES

In 2011, the Work Group noted studies describing a variety of reinforcing (positive) feedbacks that are accelerating ice sheet melt in Greenland and Antarctica and also accelerating Arctic pack ice melt, permafrost thaw and organic decay, and methane hydrate release from the warming Siberian Shelf, in addition to other global processes affecting sea level rise i.e. increasing greenhouse gas concentrations, changes in volcanic forcing and tropospheric aerosol loading (Compact, 2011). Since then, numerous additional reinforcing feedbacks have been documented and previously recognized feedbacks have intensified.

ACCELERATION OF ICE MELT

Accelerated melting of the ice sheets on Greenland and Antarctica (Rignot et al., 2011; Talpe et al., 2014) is expected to be the predominant factor affecting sea level rise acceleration during the 21st Century. Melting is caused by increasing temperatures and warming of the atmosphere, warm currents moving along the coast of Greenland, and warm ocean water moving under and up into ice sheets through deep outlet glacial fjords in Antarctica. Recent observations have indicated ice sheets are more vulnerable to melting than previously realized due to the extent of deep valleys within the ice sheets connecting warmer ocean water to the internal areas of the ice sheets thus causing rapid melting and peripheral thinning (Jenkins et al., 2010; Jacobs et al., 2011; Morlighem et al., 2014; Rignot et al., 2014; Greenbaum et al., 2015). Accelerated melting results in large discharges of fresh water which raises the local sea level near the ice sheets (8

inches around Antarctica over past 20 years) (Rye et al., 2014). This release of freshwater has resulted in a seasonal increase in the amount of sea ice in the Antarctic (Bintanja et al., 2013; Rye et al., 2014) and slower circulation of North Atlantic surface water, also known as Atlantic Meridional Overturning Circulation (Rahmstorf et al., 2015). The slowdown in circulation may contribute to increased local sea level rise along the Florida coast, as discussed in the *Regional/Local Processes* section. The IPCC projections do not include the factors related to acceleration of ice melting processes described above, and as a result are likely an underestimate of future sea level rise (Rignot et al., 2011).

ICE SHEET DISINTEGRATION

Indicators of ice sheet disintegration include retreat of the ice sheet's outer boundary and rapid thinning. Lateral flow of the Greenland Ice Sheet margin, the outer boundary, has dramatically accelerated in the past two decades in response to surface melt waters penetrating fractures in the ice and warming and softening the ice (Bell et al., 2014). In addition to retreat, the ice sheets have initiated a rapid thinning process due to basal melt (Pritchard et al., 2012), signaling the initiation of prolonged ice sheet degradation based on historic analysis (Johnson et al., 2014). Joughin et al. (2011) have used numerical models to look at the sensitivity of the outlet glaciers of the West Antarctic Ice Sheet to ocean water melt and have concluded that the West Antarctic Ice Sheet collapse is already underway; the extent of the collapse in the future is not yet known. As part of the Gravity Recovery and Climate Experiment (GRACE) satellite monitoring program, ice sheet mass loss has been quantified as 280 ± 58 gigatons per year (Gt/yr) from Greenland and up to 180 ± 10 Gt/yr in Antarctica (Velicogna et al., 2014). As a reference for the magnitude of a gigaton, one could estimate one gigaton to equal the mass of over one hundred million elephants. In addition, significant recent work was completed to verify the estimated contribution of ice sheet disintegration to sea level rise using satellite data (Jacob et al., 2012; King et al., 2012; Gardner et al., 2013) with the conclusion that ice sheet melt accounted for $29 \pm 13\%$ of sea level rise from 2003 to 2009 (Gardner, 2013). In order to further refine the estimates and projections of the magnitude of ice sheet degradation and their contribution to sea level rise, the complex dynamics driving ice sheet melt need to be better understood, in particular the mechanisms driving interactions between ice sheets and warm currents.

WARM CURRENTS

In 2011, the Work Group acknowledged the effects of warm ocean water currents accelerating summer pack ice melt and causing melting beneath the outlet glaciers. Recent work has further clarified the compounding mechanisms driving the flow and temperature changes of warm currents. Spence et al. (2014) analyzed the poleward shift in direction of the southern hemisphere westerly winds since the 1950's and simulated the intense warming of coastal waters

associated with such a shift in order to explain and forecast the significant temperature increase in ocean waters interacting with the base of ice sheets and floating ice shelves. This study serves to validate the projection of the persistence of this wind trend and the resulting melting due to warm current interaction. Separate from wind forcing, an increase in ocean surface stress due to thinning of the formerly consolidated sea-ice cover near Antarctica is proposed to result in a redirection of warm ocean currents into submarine glacial troughs and further expediting melting of the deep ice-shelf base based on ocean-ice modeling (Hellmer et al., 2012). Ice sheet melt as a result of interaction with warm currents is one of the dominant factors contributing to recent global sea level rise (IPCC, 2013); however, as discussed in the next section, land based contributions to global warming may further exacerbate sea level rise in the future.

THAWING PERMAFROST

The potential for significant additional emissions of carbon dioxide and methane from thawing permafrost and the rate of occurrence continues to be investigated. The intricate feedback mechanisms associated with permafrost are not well understood; as such, the IPCC did not include permafrost thaw in its projections (Collins et al., 2013). This deficiency was criticized publicly due to the theorized potential for permafrost carbon emissions to exceed emissions from fossil fuel use. Schuur et al. 2013 conducted a survey of experts to quantify permafrost change in response to four global warming scenarios and found despite risk for significant contributions of emissions from thawing, fossil fuel combustion was likely to remain the main source of emissions and climate forcing until 2100 based on the proposed warming scenarios.

Following the release of the IPCC (2013) report, demand for research to understand the dynamics of the physical and chemical permafrost processes has increased in order to confirm the estimates of emissions from thawing. As an initial step, the occurrence of significant submarine permafrost thawing was confirmed by Overduin et al. (2014) when 8 to 10°C of warming within the permafrost layer was observed in less than 1,000 years, resulting in a degradation of ice-bearing permafrost at the rate of 3 cm/yr. In addition, seawater seeping through soil pores was identified as the source of sulfate necessary to oxidize methane in the upper layer of the thawing permafrost. Although site specific, studies such as Overduin et al. (2014) will begin to provide the information necessary to incorporate permafrost thawing into models and projections in the near future.

REGIONAL/ LOCAL PROCESSES

VERTICAL LAND MOVEMENT

Vertical earth movements, which regionally and locally modify the globally averaged rate of sea level change, result in a relative rate of change that varies from one location to another. These

land motions have been inferred from historical tide data and geodesic measurements. When added to projected rates of global mean sea level rise, they result in a perceived change ranging from increased rise in regions of subsidence (e.g., New Orleans) to falling sea levels where the land is being uplifted (e.g., along the northern border of the Gulf of Alaska). Other regions are geologically stable and have only small differences with respect to the global rate of change. In South Florida, in general, coastal land elevations are considered to be relatively stable meaning that the land is not experiencing significant uplift nor subsidence. It is also important to note, the vertical land movement that is occurring is non-uniform across South Florida and movement measured at specific monitoring stations sites may not reflect vertical land movement in adjacent areas.

The Continuously Operating Reference (COR) network of permanent Global Positioning System (GPS) receivers provides precise measurements of vertical land movement in four locations throughout Southeast Florida (Key West, Virginia Key, Pompano Beach, and Palm Beach) over periods of nine to eleven years. Additional continuous GPS measurements have been acquired in eight other sites in the region over various time periods (two to eleven years). Precise analysis of these data reveals negligible vertical movements at most stations (less than 1 mm/yr) (Snay et al., 2007; Santamaría-Gómez et al., 2012; NGL, 2015). However, some stations show 1 to 6 mm/yr of subsidence, reflecting mostly local unstable conditions of the GPS antenna monument (e.g., local building movements) (e.g., Bock et al., 2012).

National Geodetic Survey has operated continuous GPS stations at Key West, Fort Lauderdale, Miami and Palm Beach Gardens. The GPS data of these sites were processed by the Nevada Geodetic Laboratory, who presents the results at GPS time series (<http://geodesy.unr.edu/index.php>). The rates of vertical land movement at these stations are shown in Table 1 (Blewitt et al., 2015). It should be noted vertical land movement is non-uniform across South Florida as a result of geology variations and the non-uniform compaction of fill placed during development of the region. Subsidence at tide stations is closely monitored to ensure the accuracy of sea level rise measurements. The regional rate of sea level rise is affected by such localized subsidence and is accounted for in the regional sea level rise acceleration variable incorporated in the projections adapted for the region.

Table 1: Continuous GPS Operation in Southeast Florida (Blewitt et al., 2015)

Site	Location	Duration	Vertical rate (mm/yr)
KYW1	Boca Chica Key	1997-2008	-0.5 ± 0.1
KYW5	Boca Chica Key	2007-present	0.1 ± 0.1
KYW6	Boca Chica Key	2007-present	1.0 ± 0.1 (uplift)
KWST	Key West airport	2003-present	-1.5 ± 0.1
CHIN	Key West, 500 m south of tide gauge	2008-present	-1.6 ± 0.5
LAUD	Fort Lauderdale Executive Airport	2005-2014; 2014-2015	-0.5 ± 1.1
ZMA1	Miami Airport	2004-2008; 2008-present	0.2 ± 0.9
FLC6	Florida City	2009-present	-1.8 ± 1.2
PBCH	North Palm Beach County Airport	2005-present	1.0 ± 1.0 (uplift)

Additionally, in some regions, the effects of changing ocean currents can further modify the relative local rate of sea level rise. Such is the case of the east coast of Florida, as is discussed in the next section, **Ocean Dynamics, Gulfstream/ Circulation**

OCEAN DYNAMICS, GULFSTREAM/ CIRCULATION

Ocean circulation has changed little during the current period of scientific observation, but in the future it can considerably alter the relative rate of sea level rise in some regions, including Southeast Florida. A slowing of the Florida Current and Gulf Stream will result in a more rapid sea level rise along the east coast of North America. By 2100, these circulation changes could contribute an extra 8 inches of sea level rise in New York and 3 inches in Miami according to Yin et al. (2009). Most of the global climate models used by the IPCC (IPCC, 2007; 2013) project a 20-30% weakening of the Atlantic Meridional Overturning Circulation (AMOC), of which the Gulf Stream and Florida Current are a part. Measurements of the AMOC have yet to conclusively detect the beginning of this change, however there has been a report of a recent decline in AMOC strength by Smeed et al. (2014) that coincides with the mid-Atlantic hotspot of sea level rise reported by Ezer et al. (2013) and Rahmstorf et al. (2015). Recent analysis of the Florida Current transport has detected a decrease in circulation over the last decade, which appears to account

for 60% of South Florida sea level rise over the decade and contribute to a positive acceleration (Park and Sweet, 2015). If a long-term slowdown of the AMOC and Florida Current. Rahmstorf et al. (2015) use a proxy method also suggesting that a slowdown of the AMOC has begun. If a long-term slowdown of the AMOC does occur, sea level rise along the Florida east coast could conceivably be as much as 20 cm (8 inches) greater than the global value by 2100.

According to the most recent estimates by the IPCC (IPCC 2013, FigureB-1), the combined differential due to regional ocean heating and circulation change along the Southeast Florida coast would be in the range of 10%-20% greater than the globally averaged rise by 2090. For a median (50% probability) sea level rise of one meter by 2100, this would give about 10-20 cm (4-8 inches) of additional rise along the Southeast Florida coast, which is within the range of estimates by Yin et al. (2009). However, the IPCC models do not have the horizontal resolution required to effectively estimate these changes at the scale of the Florida Current and more research with higher resolution ocean models will be required. As such, it is prudent to add ~15% to the global mean sea level rise values projected by the IPCC in order to use them for Southeast Florida planning. This adjustment is accounted for in the regional sea level rise coefficients incorporated in the projections adapted for the region.

Percentage Deviation from Global Mean: Figure 3.21 of Ch.13, AR5

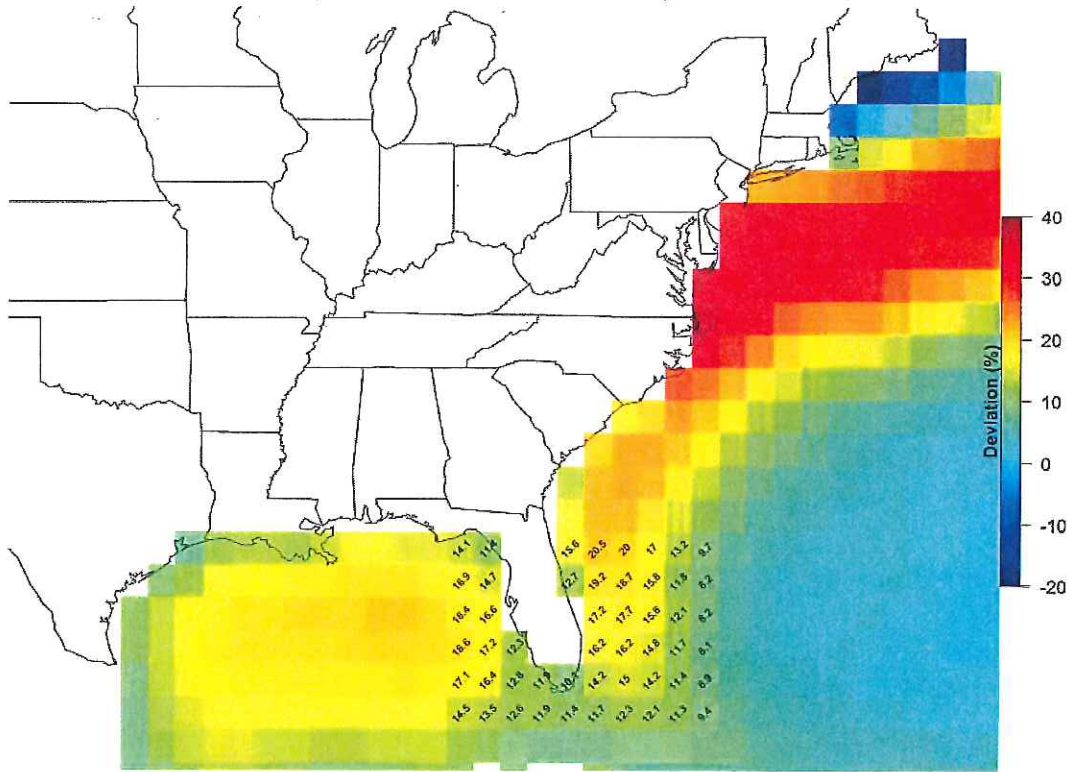


Figure B-1. Percentage of the deviation of the ensemble mean regional relative sea level change between 1986-2005 and 2081-2100 from the global mean value, based on Figure 13.21, IPCC (2013). The figure was computed for RCP4.5, but to first order is representative for all Representative Concentration Pathways (RCP). RCPs are the four greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5).

The following are recommendations made by the Work Group for consideration by the Southeast Florida Regional Climate Compact Steering Committee to be used by the Compact Counties as part of the implementation of the Regional Climate Change Action Plan.

- a. The unified SE FL sea level rise projection will need to be reviewed as the scientific understanding of ice melt dynamics improves. The projection should be revised within five years of final approval of this document by the Southeast Regional Climate Change Compact Steering Committee. This timing is consistent with the release of Intergovernmental Panel on Climate Change Sixth Assessment Report which will provide a synthesis of the major findings in climate science to date.
- b. Users of the projection should be aware that at any point of time, sea level rise is a continuing trend and not an endpoint.
- c. The planet is currently on a high emissions trajectory for which committed sea level rise is probably near the high end of the ranges. It should also be noted that the attenuation of impacts through mitigation will not likely be sufficient to overcome the inertia of the climate system prior to 2060.
- d. Full and complete transparency of the projection and its implications should be promoted across the communities in order to encourage and guide effective and realistic planning, obtain realistic economic realities for maintaining functional infrastructure, insuring social and economically sound further development, and necessary adaptation.
- e. Further work to develop projections for the occurrence of extreme events in tandem with sea level rise may be necessary to assist communities in planning for storm drainage adaptation.

APPENDIX D: ACKNOWLEDGEMENT OF PARTICIPANTS

The Southeast Florida Regional Climate Change Compact Counties (Monroe, Miami-Dade, Broward and Palm Beach Counties) and their partners wish to acknowledge the Work Group participants and members of the SE FL Regional Climate Change Compact Steering Committee for participating in meetings to support the development of the Unified Sea Level Rise Projection and the guidance document. The following members contributed to the development and refinement of the projection:

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Gassman, Nancy, Ph.D.

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Jurado, Jennifer, Ph.D.

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Murley, Jim

Obeysekera, Jayantha, Ph.D., P.E.

Park, Joseph, Ph.D., P.E.

Steelman, Marcia, C.F.M

Van Leer, John, Ph.D.

Wanless, Hal, Ph.D.

Wdowinski, Shimon, Ph.D.

APPENDIX E: DEVIATION FROM 2011 PROJECTION

The updated unified sea level rise projection includes the range projected by the 2011 unified sea level rise projection with three enhancements. As described in previous paragraphs, the year the projection begins was shifted from 2010 to 1992. Since the projection now references the sea level rise that has occurred since 1992 instead of 2010, the values in the projection are larger as a result of the sea having 8 more years to rise. For example, at the lower boundary of the projection, by 2030, sea level rise is projected to be 5 inches above the where mean sea level was in 1992. This is the exact same projected elevation as 3 inches above where the mean sea level was in 2010, just a different elevation datum. Table 1 shows the adjustment of values from the 2011 Unified Projection with a reference (starting) year of 1992. Please note the lower boundary is the same in both the 2011 and 2015 projections. The second enhancement to the projection was the extension of the projection past 2060 continuing to 2100. The third enhancement to the projection was the addition of the NOAA High Curve as the upper boundary after Year 2060. For critical infrastructure projects with design lives in excess of 50 years, use of the upper curve is recommended with planning values of up to 34 inches in 2060 and up to 81 inches in 2100.

Table 2: Comparison of Unified Projection in 2011 and 2015 at Key West

Year	2011 Unified Projection (referenced to Year 2010) (inches above msl)		2011 Unified Projection (adjusted to reference Year 1992) (inches above msl)		2015 Proposed Unified Projection (referenced to Year 1992) (inches above msl)			
	NRC Curve I (1987)	NRC Curve III (1987)	NRC Curve I (1987)	NRC Curve III (1987)	NOAA Int.- Low	IPCC AR5 Median	USACE High	NOAA High
1992			0	0	0	0	0	-
2030	3	7	5	10	5	6	10	-
2035					6	7	12	-
2060	9	24	11	26	11	14	26	34
2075					15	20	38	49
2100					22	31	61	81

ATTACHMENT C

REAFFIRMATION OF THE SOUTHEAST FLORIDA REGIONAL CLIMATE CHANGE COMPACT

WHEREAS, Southeast Florida is one of the most vulnerable areas in the country to the impacts of climate change, especially sea level rise; and

WHEREAS, the County Commissions of Broward, Miami-Dade, Palm Beach and Monroe Counties (the "Compact Counties") adopted the Southeast Florida Regional Climate Change Compact ("Compact") in 2009-2010; and

WHEREAS, the Compact Counties have worked since then in common cause with one another and numerous stakeholders to address climate change at the regional scale; and

WHEREAS, in the six years since the Compact was forged, the Compact Counties and their partners have successfully completed a 110-recommendation Regional Climate Action Plan, a unified sea level rise projection for Southeast Florida (and an update thereto), a regional greenhouse gas emissions inventory, a regional vulnerability analysis, joint annual state and federal legislative programs, planning and execution of seven Regional Climate Leadership Summits, and countless other joint activities, earning significant national and international attention; and

WHEREAS, the President of the United States lauded the Compact and its collective efforts as "a model not just for the country, but for the world"; and

WHEREAS, the Compact model has been cited in the federal government's Third National Climate Assessment, the Recommendations of the President's State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience, and many other documents and media; and

WHEREAS, the Compact Counties were named as a White House Climate Action Champion in 2014 in recognition of their past leadership on climate issues and the prospect of their continued leadership in the future; and

WHEREAS, Compact activities yielded significant external funding and resources to support the climate-related work in Southeast Florida; and

WHEREAS, the Compact has galvanized cooperation among many local, regional, state, and federal agencies and stakeholders; and

WHEREAS, the benefits of regional coordination to the Compact Counties, partner municipalities, and other Compact partners have been demonstrated many times over,

NOW, THEREFORE, BE IT RESOLVED BY THE BOARDS OF COUNTY COMMISSIONERS OF THE COMPACT COUNTIES OF SOUTHEAST FLORIDA:

SECTION 1: "The Compact" shall refer to the 2009 Southeast Florida Regional Climate Change Compact, this document, and the collective efforts undertaken in furtherance of the aims of both documents.

SECTION 2: The counties of Broward, Miami-Dade, Monroe, and Palm Beach ("the Compact Counties") commit to continue to support the following activities, which comprise the original commitments outlined in the 2009 Compact:

- Development of and advocacy for joint positions on federal and state legislation, regulations, and administrative policies pertaining to climate and energy issues, including, but not limited to, agreement on annual Compact state and federal legislative programs.
- Creation of common regional baseline information, including a unified sea level rise projection, regional greenhouse gas emissions inventory, and regional vulnerability assessment, and periodic updates to this information.
- Convocation of an annual Regional Climate Leadership Summit.
- Development of a Regional Climate Action Plan, including strategies to reduce regional greenhouse gas emissions, adapt to climate impacts, and strengthen regional resilience, to be revised every five years from the date of publication of the first Action Plan.

SECTION 3: The Compact Counties commit to support the following activities representing a natural evolution of the original four commitments described in Section 2:

- Regional collaboration to advance Regional Climate Action Plan recommendations and track the progress thereof.
- Consideration of the full spectrum of economic, social, and environmental factors in Compact initiatives, including, but not limited to, disadvantaged communities, public health, natural systems, and the built environment.
- Continuation of a Compact Staff Steering Committee and any standing committees or ad hoc working groups deemed necessary by the Compact Staff Steering Committee to further the purposes of the Compact.
- Provision of appropriate staff resources and expertise to participate in the Compact Staff Steering Committee and Compact activities in general.
- Solicitation of external funding and resources to support Compact initiatives.
- Establishment of an enduring organizational structure for the Compact, subject to the approval of each County Commission, to facilitate Compact work, enhance the strong relationships among the Compact Counties and stakeholders, and improve the Compact's competitiveness in seeking external funding and resources.

SECTION 4. The Compact Counties, recognizing the need for close cooperation with their municipalities, will continue to include one municipality from each county on the Compact Staff Steering Committee and to seek the broad participation of municipalities throughout the region in Compact initiatives generally.

SECTION 5. The Compact Counties will continue to support and foster expanded public, private, and nonprofit engagement in Compact initiatives at the local, regional, state, national, and international levels, with an emphasis on communications, partnerships, and capacity building.

SECTION 6. In pursuit of the common aims of the Compact Counties under the Compact, each county pledges not to work at cross-purposes with the other counties. However, nothing in this Reaffirmation document shall be deemed to limit the power of each County Commission to govern its respective county.

SECTION 7. The commitments contained herein shall not be effective until approved through the required procedures of each respective County.