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Sea-Level Rise in Florida—the Facts and Science

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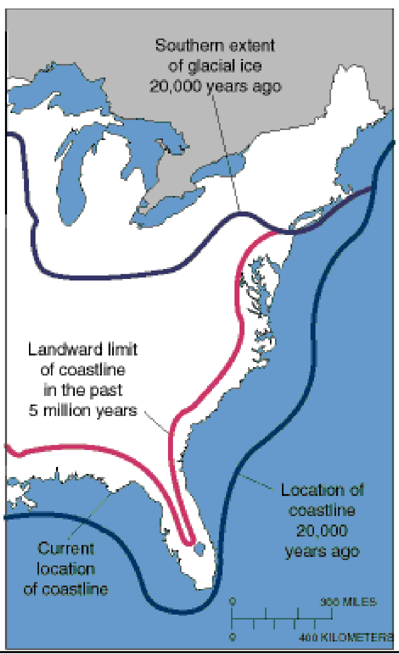
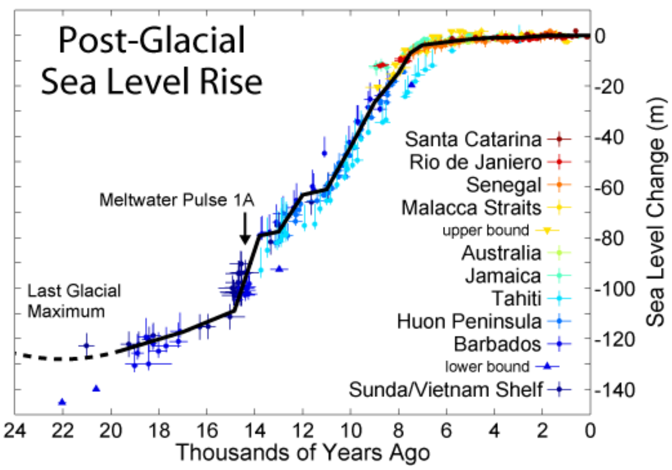
This primer on sea-level rise (SLR) offers information on its causes and what this may mean for Florida. While this document includes only limited discussion of estimated rates for future SLR, further information may be found in the report "Sea Level Changes in the Southeastern United States: Past, Present, and Future" as well as at "United States Army Corps of Engineers Sea-Level Rise Guidance Document."



Williams, S.J., K. Dodd, and K.K. Gohn. 1997. Coasts in Crisis, U.S. Geological Survey, Circular C-1075.

Has Sea Level Changed Before?

Yes. Sea levels around the globe have fallen and risen dramatically over millions of years, driven primarily by glacial advance and retreat. Sea-level changes in the distant past were often substantial and occurred faster than our current change. However, during these periods either humans did not yet exist or our settlements were simple enough that we easily moved them as the shoreline migrated landward or seaward.



Source and more information on this graph available at: http://en.wikipedia.org/wiki/File:Post-Glacial_Sea_Level.png

During the height of the last ice age, global sea level was about 400 feet lower than today.[1]

After the last ice age ended approximately 20,000 years ago, sea level rose rapidly,[2] but for the last few thousand years has been rising very slowly[3] and has been almost stable for the last 4-5 thousand years.[4] Importantly, this recent era of stability encompasses the history of human civilization, meaning significant global sea-level rise is truly unprecedented in human history.

How Has Sea-Level Changed During the Last Century?

While sea level was first recorded on tide gauges in some sites in Europe as early as the 17th century,[5] the most reliable tide gauge data used for measuring

1 Thanks to Dr. Nancy Gassman, Broward County; Dr. Gary Mitchum, University of South Florida; Whitney Gray, Florida Sea Grant and the Florida Fish & Wildlife Conservation Commission; and Dr. Joseph Donoghue, Oklahoma State University, for reviewing and improving this fact sheet.

recent SLR in Florida only goes back a little more than 100 years.[6] In Florida, sea level has increased by about 8 inches over this time, or about an average of 2 mm/yr. More recent data, based on satellite altimetry, indicates that the average rate of rise in this region since the early 1990s is about 3.0 mm/yr.

What causes sea levels to rise and fall?

The two main factors affecting global sea levels are the temperature of the oceans and the amount of water in the ocean. At the local level, sea level may change due to the rising or falling of coastal land. This short summary does not address myriad other factors with smaller impacts on global or local sea levels.[7]

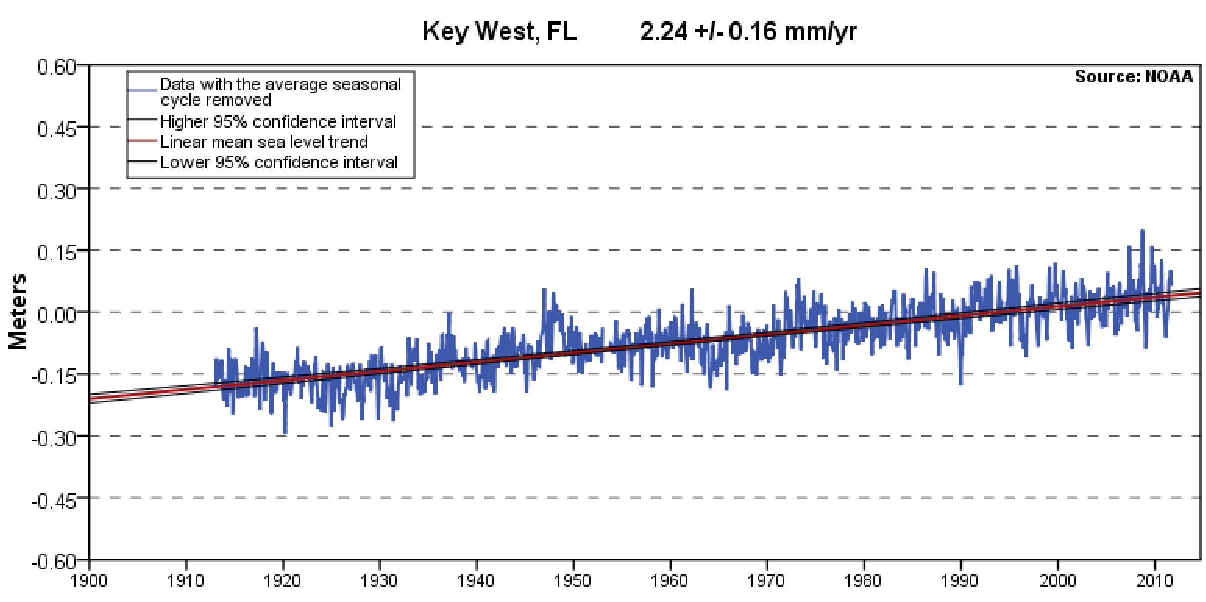
Tide Gauge Station	Data Years	Mean Sea Level Trend (mm/yr)
Fernandina Beach	1897-2006	2.02
Mayport	1928-2006	2.40
Key West	1913-2006	2.24
St. Petersburg	1947-2006	2.36
Cedar Key	1914-2006	1.80
Pensacola	1923-2006	2.10

Adapted from Table 4, NOAA Technical Report NOS CO-OPS 053: Sea Level Variations of the United States 1854-2006
http://tidesandcurrents.noaa.gov/publications/Tech_rpt_53.pdf

As water in the ocean warms, it expands. This means that even without adding any water, warmer ocean water increases in volume, causing sea level to rise. This effect has been an important driver of SLR during the last several decades, accounting for about a third of observed SLR.[8]

The quantity of water in the oceans of course also affects the level. Additional water can be added to the world's oceans by the melting of land-based glaciers and ice sheets or by the extracting of groundwater and adding it to the water cycle.[9] The melting of land-based ice masses, like those in Greenland, contributed about 60% of observed SLR from 2003 to 2009.[10]

SLR is also classified as global (eustatic) or relative (regional or local). Global SLR is the overall SLR trend on the planet. Still, things like long-term weather trends, ocean currents, winds, and other factors mean that SLR is not uniform across the oceans. Regional SLR is how much sea level is changing relative to the local coast line. These may differ for a number of reasons, but the most important one is usually whether the land itself is rising or falling.[11] Land may be falling—or subsiding—due to pumping of groundwater or oil; these are impacting areas of Texas' coast. In some areas, the land is rising as a



result of glacial isostatic rebound. This occurs when the land is still slowly rising after having been squashed down under the massive weight of ice during the last ice age. This is happening along some parts of the coastline in Alaska.[12] Barring significant other factors at play, local SLR is basically the global trend plus local subsidence or minus local uplift.

> SLR is not so much a completely new coastal hazard as one that exacerbates existing coastal hazards such as flooding from rain or tide, erosion, and storm surge. The easiest way for local governments to begin addressing SLR is to do a great job of addressing general coastal hazards. For example, Pinellas County has implemented a "coastal storm area" that limits particularly vulnerable uses, such as nursing homes, in the coastal storm area.

While some debate whether Florida, or parts of Florida, are rising, falling, or essentially stable,[13] any rise or fall of land in Florida is not nearly so large as either current or predicted rates of global SLR. In other words, communities in Florida can more or less use the global/eustatic SLR estimates for their local planning purposes.

How Much Sea-Level Rise Can We Expect in Florida?

Most of the scientific estimates of SLR currently range from about a 1.5 to 4.5 feet increase in sea level by 2100.[14] The United States Defense Department's Army Corps of Engineers (USACE) in 2009 and in 2011 issued guidance on how to take SLR into account for projects USACE is required by Congress to construct.[15] This guidance utilizes a 3-scenario evaluation process to incorporate SLR into projects: 1. A "low" scenario that uses historic changes in sea level to predict SLR of 20 inches by 2100; 2. an "intermediate" scenario that predicts about 39 inches of SLR; and 3. a "high" scenario that seeks to incorporate the possibility of significant SLR due to dramatic ice melt, resulting in a prediction of about 59 inches by 2100.

In addition, numerous other entities have developed their own predictions for SLR based on the evolving science, and incorporating new understanding of the melting of the ice sheets, including many instances of creating possible SLR scenarios for use in planning for shorter timeframes.[16]

What Will Rising Sea Levels Mean for Florida?

Past SLR has already shown its face in Florida. The evidence from tide gauge data is reinforced by the increased tidal flooding problems plaguing many areas in Florida. The South Florida Water Management District is already replacing gravity-flow drainage infrastructure with pump stations because higher sea levels only allow gravity-drainage during low tides. SLR impacts sometimes occur in very unexpected ways for local governments: Monroe County has noticed that they now incur increased fleet maintenance costs for their vehicles because they are being damaged by more frequent driving through saltwater on tidally flooded roads.

Over longer time periods, SLR of only one half foot to one foot may present dramatic challenges to coastal communities in Florida because of our very flat coastal topography. In addition to impacting drainage and groundwater levels, it will exacerbate saltwater intrusion, limiting Florida's already decreasing freshwater supply. Increased sea levels will also exacerbate storm surges and flooding.[17]

> The Southeast Florida Regional Climate Compact is composed of Miami-Dade, Broward, Palm Beach, and Monroe counties. Collectively, these counties represent about one-third of Florida's population. The Climate Compact has already distinguished itself as a national leader in addressing climate change and SLR.

Assessing the impact of SLR through erosion in coastal areas is very difficult. Extensive current research seeks to understand how SLR will affect coastal ecosystems based on the ability of the different habitats to adapt. For example, it is estimated that at a SLR of more than about 0.13 inches per year (or 1.3 inches per decade), coastal marshes will drown and turn into open water. The impact on beaches is less well understood. While it is generally accepted that SLR causes landward migration of the beach, how much is hard to calculate. In most instances, so many factors determine complex beach dynamics that it remains impossible to reliably determine exactly how much SLR is a contributing factor to current erosion rates.[18]

How is Florida Responding to Rising Seas?

At the state level, the response to rising seas has not been very high profile. This contrasts with the federal response. In 2009, President Obama signed Executive Order 13514, which requires all federal agencies to account for climate change in their planning. NOAA, EPA and the Department of Defense are especially active in planning for future sea level rise. Florida's Department of Environmental Protection continues to evaluate permits for coastal construction without accounting for SLR. While regulatory reform is needed to incorporate sea level into Florida laws, planning understand potential impacts is occurring. The Florida Department of Economic Opportunity has a project evaluating methods for improving coastal resilience and supporting local government integration of SLR into local planning. In addition, the Florida Fish and Wildlife Conservation Commission has begun to integrate SLR into management for imperiled species. The Florida Department of Transportation is investigating the likely impact of SLR on transportation infrastructure, and the Florida Department of Health has a grant from the Centers for Disease Control to evaluate climate impact, including SLR, on public health.

Many local governments in Florida have begun to take action to address the impacts of SLR in their communities. Communities can address SLR in one of two general ways: either directly through adaptation planning and implementation or, more indirectly, through good coastal planning that will tend to make their community more resilient to coastal hazards generally. This second approach emphasizes "no-regrets strategies" that, even were SLR not to accelerate from its current rate, would still serve to better protect people and property from coastal hazards such as storm surge, flooding, and erosion.

Several Florida communities have begun to lead the way in adaptation to SLR. For example Miami-Dade, Broward, Palm Beach, and Monroe counties joined together to form the Southeast Florida Climate Compact. Addressing SLR is part of the Compact's Regional Climate Action Plan. The City of Punta Gorda developed a climate change adaptation plan that includes SLR and incorporated SLR adaptation policies into their comprehensive plan. Likewise, Pinellas County addresses SLR in its comprehensive plan as does Sarasota County. Flagler County considered SLR when assessing hurricane and storm damage reduction feasibility. Still, many of these efforts remain limited to commitments to consider and evaluate SLR rather than implementing significant changes to actual regulations and practices in land development, infrastructure design and placement, and financial considerations.

In communities most vulnerable to SLR, this has begun to change. For example, Miami-Beach, which suffers from serious tidal flooding in some neighborhoods, is calculating projected SLR into current planning for a major stormwater drainage project. This includes the possible use of pump stations and backflow preventers in new stormwater infrastructure.

For more information on SLR and the built environment in Florida, please visit Florida Sea Grant's Coastal Planning website at www.flseagrant.org/coastalplanning

References

[1] Interdepartmental Climate Change Group, South Florida Water Management District, Climate Change and Water Management in South Florida 6 (2009). FAQ 5.1, IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] Sea level appears to have risen as rapidly as 45 mm. (1.8 inches) per year during a period about 14,000 to 11,000 years ago. Joseph F. Donoghue and Randall W. Parkinson. Discussion of: Houston, J.R. and Dean, R.G., 2011. Sea-Level Acceleration Based on U.S. Tide Gauges and Extensions of Previous Global-Gauge Analyses. Journal of Coastal Research, 27(3), 409–417. Figure 1, page 995. Journal of Coastal Research, 27(5), 994–996. DOI: 10.2112/JCOASTRES-D-11-00098.1

[3] State of Florida Department of Environmental Protection, James H. Balsillie and Joseph F. Donoghue, Report of Investigations No. 103: High Resolution Sea-Level History for the Gulf of Mexico Since the Last Glacial Maximum. Figure 8, p. 17. (2007); Interdepartmental Climate Change Group, South Florida Water Management District, Climate Change and Water Management in South Florida 6 (2009).

[4] FAQ 5.1, IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[5] State of Florida Department of Environmental Protection, James H. Balsillie and Joseph F. Donoghue, Report of Investigations No. 103: High Resolution Sea-Level History for the Gulf of Mexico Since the Last Glacial Maximum. P. 1. (2007)

[6] *Cf., e.g.* Jevrejeva, S., A. Grinsted, J. C. Moore, and S. Holgate (2006), Nonlinear trends and multiyear cycles in sea level records, J. Geophys. Res., 111, C09012,

doi:10.1029/2005JC003229 (noting on page 2 that while the Permanent Service for Mean Sea Level contains records from a total of 1,023 tide gauge stations, there were only 70 in 1900); *id. at* p.5 (noting that only five tide gauge stations were operating in 1850 and all were in the North Atlantic or Baltic).

[7] What makes sea level rise and fall is a surprisingly complex scientific question as many different factors can impact sea levels, especially at the regional level. Some examples: volcanic activity (see, e.g. Church, J. A., N. J. White, and J. M. Arblaster (2005), Significant decadal scale impact of volcanic eruptions on sea level and ocean heat content, Nature, 438, 74–77.); changes in gravitational pull due to ice melt (see, e.g. M. E. Tamisiea, J. X. Mitrovica, G. A. Milne, and J. L. Davis. Global geoid and sea level changes due to present-day ice mass fluctuations. Journal of Geophysical Research: Solid Earth. Volume 106, Issue B12, pages 30849–30863, January 2001; regional weather oscillations (see, e.g. News release: NASA Satellites Detect Pothole on Road to Higher Seas [noting that the switch from El Niño to La Niña in the Pacific has so affected rainfall and evaporation patterns that sea level rise has decreased], available at http://www.jpl.nasa.gov/news/news.cfm?release=2011-262); ocean currents (see, e.g. Department of Commerce, Center for Operational Oceanographic Products and Services, *Elevated East Coast Sea Level Anomaly: June-July 2009.* NOAA Technical Report NOS CO-OPS 051 *(2009), available at* http://tidesandcurrents.noaa.gov/publications/EastCoastSeaLevelAnomaly_2009.pdf. Despite all these complexities and regional variations, the overall trend that sea level is rising and the rate of the rise is accelerating is almost unanimously accepted by scientists who specialize in studying sea level change.

To make matters even more complex: just as today's trends may not accurately predict the future, the past may also not be a good predictor of the future. Andrey Ganopolski & Alexander Robinson. Palaeoclimate: The past is not the future. Nature Geoscience 4,661–663(2011)doi:10.1038/ngeo1268 (noting that estimated amount of melting of the Greenland ice sheet during the last interglacial may not be a good analogue for future melting because the amount of melting may have had more to do with the earth's orbit at the time than with the temperature).

[8] Gardner, A.S. et al. 2013. A reconciled estimate of glacier contributions to sea level rise: 2003-2009. Science 440: 852-853 (indicating that about 29% of SLR from 2003-2009 was due to melting glaciers and even more was due to melting ice sheets). Southeast Florida Regional Climate Change Compact Technical Ad hoc Work Group. April 2011. A Unified Sea Level Rise Projection for Southeast Florida. A document prepared for the Southeast Florida Regional Climate Change Compact Steering Committee. P. 3. This paper indicates that about 30% of recent sea-level rise is due to thermal expansion (based on Cazenave, A. and Llovel, W. Contemporary sea level rise. Annual Review of Marine Science 2: 145-173, 2010.).

[9] Southeast Florida Regional Climate Change Compact Technical Ad hoc Work Group. April 2011. A Unified Sea Level Rise Projection for Southeast Florida. This indicates about 55% of recent sea-level rise is from the melting of land-based ice.

[10] Gardner, A.S. et al. 2013. A reconciled estimate of glacier contributions to sea level rise: 2003-2009. Science 440: 852-853 (indicating that about 29% of SLR from 2003-2009 was due to melting glaciers and even more was due to melting ice sheets).

[11] Other factors besides land movement that may have lesser impacts on regional SLR include factors such as prevailing winds and ocean currents.

[12] See, e.g. "Sea Levels Online" from the National Oceanic and Atmospheric Administration, available at http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml.

[13] Some recent scientific papers have asserted that Florida is stable (Sella GF, Stein S, Dixon TH, Craymer M, James TS, Mazzotti S, Dokka RK (2007) Observation of glacial isostatic adjustment in "stable" North America with GPS. Geophys Res Lett 34:L02306–L02307; Department of the Army, U.S. Army Corps of Engineers Circular No. 1165-2-212, Figure C-2 (1 October 2012)).

Others assert that Florida is rising (Peter N. Adams, Neil D. Opdyke and John M. Jaeger. Isostatic uplift driven by karstification and sea-level oscillation: Modeling landscape evolution in north Florida. *Geology* 2010;38;531-534); and Florida is sinking (George A. Maul, Ph.D., Florida's Changing Sea Level, in Shoreline, May 2008 (published by the Florida Beach and Shore

Preservation Society, May 2008, available at http://www.fsbpa.com/documents/0508Shoreline.pdf).

[14] See, e.g. S. Jevrejeva , J.C. Moore , A. Grinsted. Sea level projections to AD2500 with a new generation of climate change scenarios (estimating SLR by 2100 of 0.57 meters to 1.10 meters [22 inches to 43 inches]). Mitchum, G. Sea Level Changes in the Southeastern United States: Past, Present, and Future (Aug. 2011). Louisiana Applied Coastal Engineering and Science Division. Recommendations for Anticipating Sea-Level Rise Impacts on Louisiana Coastal Resources During Project Planning and Design, Summary of the Technical Report for Coastal Managers (2012) (recommending that restoration project planners and designers utilize an estimate of 1 meter of SLR [3.3 feet] compared to late 1980's levels and that this be bounded by a range of 0.5-1.5 meters [1.4'-4.9'] by 2100).

[15] Department of the Army, U.S. Army Corps of Engineers Circular No. 1165-2-212 (1 October 2011).

[16] *See, e.g.* Southeast Florida Regional Climate Change Compact Technical Ad hoc Work Group. April 2011. A Unified Sea Level Rise Projection for Southeast Florida. A document prepared for the Southeast Florida Regional

Climate Change Compact Steering Committee. 27 p. (April 2011) (establishing a likely rise of 3-7 inches by 2030 and 9-24 inches by 2060).

[17] In Florida, it is estimated that a coastal flooding event currently calculated to have a 1% chance of occurring each year (i.e.—a "100-year" flood) will, with SLR, have a 25% chance of occurring each year. See, e.g. Climate Central, Facts and findings: Sea level rise and storm surge threats for Florida, available at http://www.flseagrant.org/coastalplanning/policy-tools-and-resources/.

[18] Indeed, while SLR will impact erosion of beaches, the more urgent concern will often be flooding of property along low-lying protected coastlines such as along estuaries. *See, e.g.* Coastal Science & Engineering, Coastal Erosion and Solutions: A Primer, 2nd Edition, page 35 (2011).