A PRIMER
ON SEA LEVEL & SEA-LEVEL RISE
FOR LONGBOAT KEY
AND THE
BARRIER ISLAND COMMUNITIES
OF
SOUTHWEST FLORIDA

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Preface

Across the world individuals, and families, communities, churches, businesses and governments of all sizes are trying to assimilate a virtual landslide of new information regarding climate change. We seek to understand as much as possible in order to evaluate risk from personal to national scales, and to decide what actions are necessary and sufficient to meet emerging challenges.

People have different concerns depending on their location. Populations in high latitudes are dealing with losses of ice and permafrost. People living in the middle of continents are concerned about desertification and others, dependent on mountain glaciers for water, are concerned about climate changes at high altitude. Billions of people live near the sea and for them the phenomenon of sea-level rise is of paramount concern. Some low-lying Pacific island nations are planning to abandon their homelands because they have no other options.

In some ways, sea-level rise is understood better than other components of climate change. Sea level has been measured by tide gages for decades and even centuries and new satellites monitor the level of the entire world's ocean on a daily basis. Ocean physics is a mature science and the "grand equation" explaining where sea level is or could be is essentially complete—all of the relevant variables have been identified and the contributions of many but not all of these have been measured. And because the tangible effects of sea-level rise coincide with centers of human population at the coast line, our understanding of the effects of sea-level rise on natural and cultural systems is fairly advanced compared to other expressions of climate change, such as ocean acidification, or "osteoporosis of the ocean."

It remains true and a challenge that what we know about the ocean and sea level has yet to be scaled down to localities of specific interest to individual coastal communities. In 2011 it is accurate to state that many processes and effects of sea level, even at Florida-scale, are inadequately understood. However, it is possible and meaningful to create narrative explanations at local levels, accounting for what is known, what is probable, what is possible, and what remains to be learned. Such a narrative can serve as a scaffold of knowledge upon which individuals can add new relevant information, thus improving our ability to discuss and debate the issues, perceive risks, and judge appropriate responses.

Elsewhere in Florida, technical narratives about sea-level rise have been written for the southeastern cities and counties, the Everglades and Florida Keys, and Charlotte Harbor. Others are being prepared for Tampa Bay and the St. Johns River and watershed. This essay is a narrative relating sea-level rise to the coastal areas of west central Florida including the mainland, rivers and bays, and natural resources. It will focus on barrier islands and the island chain including Longboat Key in particular, including information about natural systems with information on human values and interests.

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Dedicated to the memory of David K. Bulloch (1929-2011): Director of the southeast chapter of the American Littoral Society; chemist, inventor, author, diver, advocate for nature; friend.

WE ARE ALL familiar with changing sea levels. Waves and tides are sea-level changes we experience every day. Strong winds can fill or empty the bay and a storm surge is a sea-level change we prefer to avoid. Other important changes occur in southwest Florida but without much notice, such as the rise and fall of sea level from month to month. In February, all else being equal, average monthly sea level is about 8 inches lower than it is in September. The low tides of winter are due in part to tides and wind, but this monthly variation is one of the more important explanations of why mudflats, oyster reefs, and seagrass beds seem so exposed at this time of year.

Why should sea level vary from month to month? The answer lies in the temperature of the Gulf of Mexico. The west Florida shelf is the broad expanse of shallow rock and sand extending under the gulf far beyond the horizon. Gulf waters are not very deep across the shelf. In fact, one can motor out to sea about 75 miles and still be in waters less than 200 feet deep. The shallow gulf warms in summer and cools in winter, and the warm sea expands and the cool sea contracts in the same way that water, alcohol, or mercury does inside a thermometer. In this sense, the Gulf of Mexico behaves like a very large thermometer, expanding and contracting in harmony with the temperature of the atmosphere.

Might not rainfall and river flows account for the seasonal differences in the gulf's level? After all, most rain falls in September and October and the flows of rivers on the peninsula are greatest then. In fact, some river discharges do elevate sea level. The gulf near the mouth of the Suwannee River, for example, stands about a foot higher than sea level at Cedar Key, only 12 miles south of the river. The large discharge of the river raises local sea level. In general, however, river flows do not explain seasonal highs of sea level because most peninsular rivers have rather meager flows, and the seasonal high stand of sea level is evident even during drought years. Water temperature primarily accounts for the month-to-month variation seen around Longboat Key.

Air and water temperature variations over geological time have caused sea-level variations of breathtaking magnitude. Ice ages are caused by astronomical forces, continental drift, and other factors. Fresh water evaporating from the sea surface freezes on land to form ice caps, ice sheets, and glaciers. As more ice forms, less water returns to the sea as rainfall or river-flow, and sea level falls as the world ocean diminishes. And because the ice-age world is colder, the sea naturally contracts with the added effect of lowering sea level even more. In periods between ice ages, when most ice is melted and the world is generally warmer, sea level is much higher.

Relative to modern-day Longboat Key, sea level during the last ice age (ending only 20,000 years ago) was about 400 feet lower than the present shoreline. Considering how flat and shallow the west Florida shelf is, it is not too surprising to learn that a depth of 400 feet today is about 110 miles west of us. During the last ice age, the gulf "beach" was as far west of Longboat Key as today's Atlantic seashore is east of the Key. The place occupied by Longboat Key was then in the middle of Florida rather than on its coast. The land to our west was covered by dry-lands and grassy prairies, sparse forests, ephemeral streams, and the occasional spring. Wildlife roamed the land in vast numbers. Even human beings lived there during the past few millennia. But as sea level rose, the shelf drowned. All of the plants and animals, habitats and communities, rivers and springs, and tentative human settlements—everything—was flooded out; was drowned. It all disappeared under the relentless action of grinding waves, scouring sands, and poisonous salt water.

Between far older and harsher ice ages, sea level rose far above its present stand. Pretending that modern-day Florida existed then, which it did not, Longboat Key would have been under almost 200 feet of ocean water. So for purely natural reasons, sea level has ranged from depths of 400 feet to elevations of 200 feet—a range of 600 feet. And sea level can rise or fall at precipitous rates, again for purely natural reasons. In a way, the only thing remarkable about sea level now is that it has changed so little for several thousand years.

Longboat Key, like all of Florida's barrier islands, owes its existence to the fact that the rate of sea-level rise began to slow some 6,000 to 4,000 years ago and has remained at its present level, more or less, for the past 3,000 years. The same may be said for all of Florida's prominent coastal features including salt marshes, mangrove forests, bays and estuaries, coastal springs and the rivers they form, the Florida Keys and reef tract, the Everglades, and even the shape of the state's peninsula. It has not always been so.

Some 3 miles below our feet rests the piece of earth's crust that forms our bedrock. Millions of years ago it was located about where today's Galapagos Islands lay. Continental drift caused this crustal bit to migrate northward into, across, and out of the tropics to its present location. On its journey the plate became covered by a thickening layer of limestone and other carbonate materials from clams, corals, algae, and plankton. The Florida Platform is basically a 3-mile thick Alka-Seltzer® tablet larger than the Bahama Bank, covered by a veneer of quartz sand.

The Florida Platform once stood apart from North America, in the way that Cuba is separated from Florida today. A wide, deep and powerful channel as large as the Florida Straits isolated the Florida Platform from North America, but with continental drift, and weathering of the Appalachian Mountains, quartz sand filled in the channel as the coastal plains developed. Then, a layer of continental quartz sands was spread across the platform aided by fluctuating sea levels, movement of sand along beaches, and other processes. The quartz sand layer is thickest in northern Florida but thins toward the south of the peninsula, eventually feathering out near Florida Bay.

Quartz sands cover the west Florida shelf in thin to thick deposits, commonly forming vast systems of underwater dunes that migrate across the sea floor in response to currents. The flat coastal uplands of southwest Florida contain the same quartz sands, which are often invested with fossil shark teeth, manatee bones, and other prehistoric materials of marine origin, deposited when sea level was higher than the land. All of the quartz sands on and around Florida have been in motion for millions of years.

When sea level rises rapidly, coastal sediments are especially mobile. Such was the case during the period from about 18,000 to 6,000 years ago. For centuries at a time sea level rose as fast as an inch per year (about 8 feet per century), drowning the uplands that occupied the low coastal areas of west Florida and putting all of those sediments into play as mobile beaches and submarine dune lines. The shoreline receded rapidly then, eroding perhaps as much as 1,000 feet horizontally for every foot of vertical sea-level rise. An 8 foot rise per century might correspond to a shoreline retreat of a mile and a half.

Early humans would have witnessed a coast far different than ours of today. They would have seen uplands literally falling into the Gulf, with mature forests toppling along mile after mile of shoreline. The nearshore waters would have been muddied as pockets of wetland, pond, lake, and swamp soil rich in organic matter were swept into the surf. Mangroves and salt marshes would have struggled to exist on submerging soils, clinging to an ever-changing shoreline as little more than green bathtub rings.

Durable uplands resisted erosion and became coastal headlands, only to finally surrender their sediments to the sea: the mainland beaches at Indian Rocks Beach, Venice, and Naples are weathered headlands. Sandy shoals and low islands formed as huge amounts of terrestrial sands entered the coastal sediment system but most were small or narrow, and short-lived because of terrific erosion pressure, overtopping by storm surges, and liquification from within and below as sea level rose. A few large islands actually drowned in place without destruction, to become fossilized by overgrowths of coral. Pulley Ridge, off southwest Florida in 200 feet of water, is a set of preserved barrier islands, home to one of America's deepest coral reef systems. Otherwise, the coast was too dynamic for islands made of loose sand to persist.

A remarkable event began about 3,000 years ago give or take a few centuries when sea level stabilized near its present location. Sea level of course varied from year and century to year and century, and for brief times probably stood higher than it does today, but compared to the preceding millennia of rapid change the stability would have profound effects. In fact, some historians attribute the advancement of human civilization to the formation of stable river deltas, and the agriculture such deltas support, made possible by this global slowing of oceanic inundation.

Florida, relatively isolated from other factors that cause land to sink while the sea rises, has had a rate of sea-level rise on the order of eight to nine inches per century for a very long time. This is known from historic records made by tide gages and from prehistoric times by finely-calibrated geological records. There is a singular reason why our coast has its shape, why estuaries are situated where they are, why coastal rivers bend and run deep or shallow where they do, why marshlands and mangrove forests cover immense reaches, why oyster reefs are nestled perfectly between tide lines, and why seagrass beds grow at the depths they do—and the reason is that sea-level rise has been uncharacteristically slow and stable for many, many centuries.

Such were the conditions at the birth of Longboat Key and Florida's other barrier islands. As the rate of sea level slowed, stable sediment accretions were able to form. Some became grounded on high points of limestone bedrock or reefs made of worm-tubes or small snails, creating anchor points for the accumulation of wider, deeper sand systems. Rain seeped into the low spots on these germinal islands, establishing lenses of fresh water just below ground. Seeds from grasses and later shrubs and trees were blown or floated from land and colonized dry areas, their fibrous roots transforming barren sands into simple soils. Though buffeted by winds and waves and storms, the islands endured, and grew.

Each island, including Longboat Key, exists as the geological expression of a process always tending toward but never reaching physical equilibrium. None is in true equilibrium. What one sees of an island is a single frame frozen in the continuous adding and subtracting of island length, width, height, and orientation. A long time-series of aerial photographs taken over a typical island in southwestern Florida would reveal its dynamism—growing fat at one end and narrow at the other; fusing with a neighbor island but then splitting into new ones; smoothing out over broad areas but then corrugating into straight or curving, parallel or intersecting dune and swale lines; and above all, migrating to the east, as if to rejoin the parent soils of its main land.

Natural barrier islands indeed migrate toward land. The entire island may slip, bit-by-bit, into its bay, or the island might rotate as if one end was nailed to bedrock while the other end whip-saws its inlet with ribbons of moving sand. The motive forces behind this migration are winds, waves, storms, and ultimately, sea level. Every-day waves move sand up or down a beach. At inlets, tidal currents push sands into shoals that form just outside and just inside of the islands' ends. Storm surges take large amounts of beach sand and push it across the island, sometimes adding to or subtracting from the island's height, and other times creating fans of sediment that extend from the island's lee shore into the bay. The island migrates into the bay as beach loss is repeatedly coupled with bayside expansion. The process is accelerated when marshes or mangroves colonize the sediment fans, starting a process of ecological succession that will eventually lead to terrestrial soils and plant communities.

The role of sea-level rise tends to be under-appreciated in barrier island evolution. We tend to visit an island after a hurricane and remark upon the large changes the great storm has wrought. However, in areas also experiencing sea-level rise, the hurricane's punch has been fortified by a general weakening of the island system. Rising seas can steepen beaches and shore-faces, make beaches narrower, raise soil water content and soil erosion potential, or kill vegetation that anchors soils (by raising soil salinity). These effects amplify the effects of a hurricane, and of course, a storm surge of a given height will reach father up and into an island when sea level is rising, then when it is falling: this is why the timing of astronomical high tides are critical to assessing the threat of an approaching storm. That sea-level rise amplifies the effects of a hurricane can be appreciated by imagining how a barrier island would be affected by the same storm but at a time when sea level was falling rather than rising.

Longboat Key is a naturally formed barrier island. Like nearby islands it is about 3,000 years old, but today it is quite different than an undeveloped island owing to 7 decades of settlement. Conspicuous changes include Gulf of Mexico Drive, streets and buildings, dredged canals and filled mangrove forests, landscaping, and nourished beaches. But there are still numerous indications that today's Key is still a barrier island in form and function. There once was an inlet where Buttonwood Harbor and Cranes Bayou sit today, near 3100-3200 Gulf of Mexico Drive. North of this site one former barrier island is clearly discernable in its drumstick shape: narrow in the south and wide in the north. Another drumstick island extends south from its tenuous connection to its neighbor. Longboat Key may thus be considered a pair of island twins joined head-to-foot.

Other tips to the Key's wild side exist. Land on the gulf side of Gulf of Mexico Drive is higher than land on the bay side. Its existing inlet systems change continuously (New Pass was created by a hurricane as recently as 1848). And remnants of original coastal forest peek out from undeveloped lots and park lands. Taken as a whole, though, Longboat Key is a highly-modified barrier island. It is not at all clear how beach nourishment or armoring, inlet maintenance, extensive canal systems, or the hardening effect of buildings, roads, and parking lots will affect Longboat Key's reaction to future sea-level rise.

It is universally accepted that sea level will continue to rise. There are no scientific reasons to expect that sea level will fall in this or the next century. There will be months and years when average sea level falls but the overall trend will be upward. If sea level continues to rise at its historic rate, about eight to nine inches per century, the maintenance of beaches and stormwater systems will become increasingly difficult and expensive. More widespread effects of 8-9 inch per century sea-level rise probably will be masked until a significant storm. As previously noted, even a slow rise in sea level will aggravate the effects of tropical storms and hurricanes.

What, then, of future sea levels? From an historical perspective, the news is good. Since projections of sea level were first made in the 1970s, subsequent projections have decreased from alarming to threatening to problematic. In other words, as knowledge about the factors controlling sea level has increased, and data on earth's atmosphere and oceans have improved, the amount of projected sea-level rise has steadily decreased! The 2007 report of the United Nation's Intergovernmental Panel on Climate Change, or IPCC, predicted that sea level will probably stand between 7 to 23 inches higher than it does today, by 2100.

Note that a sea-level rise of 7 inches by 2100 is on the order of historic trends measured around Florida. A rise of 23 inches works out to a rate about two to three times greater than Florida's measured rate.

A rise in sea level of 23 inches is easy to visualize around the edges of Longboat Key. As it happens, the natural range between each month's highest tide and lowest tide around the key is about 25 inches. When sea level is two feet higher than today, the lowest tides will be approximately where the highest tides are, now. Find a high tide line on the beach or on a seawall: add two feet to find an approximate location of high tides in 2100, according to the IPCC upper estimate. (The careful reader will notice a possible mistake in assuming that the future range of tides will be the same as today's. There is no basis for this assumption. In fact, the tidal characteristics of Sarasota Bay could be different after sea level has risen substantially, especially if inlets are significantly changed. Research on this issue is beginning.)

Until now, this essay, like the 2007 IPCC report, has focused on one essential cause of sea-level rise, namely, the thermometer effect. Past forecasts including the IPCC's relied largely on estimates of thermal expansion to account for sea level. Other factors were considered such as the rebounding of continental edges relieved of ice-sheet burdens, but these factors were not as important as thermal expansion. Expansion accounts for about a third of sea-level rise.

While the IPCC was working to conclude its last report it became increasingly clear that another significant sea-level factor was in play, namely the addition of "new" water being added to the world ocean from the melting of land-based ice. Glaciers at sea do not add to the ocean's volume upon melting, but when glaciers, ice sheets and ice caps sitting on land melt, the ocean's volume is increased incrementally. Because ocean basins are like bathtubs a larger ocean can only expand a lot in an upward direction. New water contributes to sea-level rise. The IPCC acknowledged that its 2007 forecast of sea-level rise was incomplete: "Dynamical processes related to ice flow not included in current models but suggested by recent observations could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude.[1]"

The IPCC will release its Fifth Assessment Report during the 2013-14 period, with the influential "Summary for Policy Makers" appearing last in 2014. For the first time in the report series the fifth report is probably going to reverse the IPCC's successive downward adjustments to sea-level predictions in 2100. As of this writing, sea-level projections will probably be increased significantly relative to the 2007 report because of recent reports on melting ice. Because new water accounts for about a third of sea-level rise, new projections of sea level in 2100 will be of considerable consequence for the State of Florida.

Some empirical evidence supports the potential for higher sea levels than predicted by the IPCC. Satellites are now able to monitor sea level continuously for all of the world's oceans. The most recent satellite observations confirm global average sea-level rise to be about 80% faster than the best estimate of the IPCC 2007 report. To put it another way, global sea level is rising at a rate equal to the IPCC's uppermost prediction based primarily on the thermometer effect. The rates derived from satellite data are consistent with the effect of new water from melting ice being added to ocean expansion.

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[1] IPCC, 2007: Summary for Policymakers. In: *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. Avery, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., page 17.

Using a variety of data sources and analytical tools, scientists around the world have been working to estimate the contribution that melting ice may make to sea level. One approach is to assume that the ice-ocean system responds to temperatures of today as it did in the past. Past temperatures can be inferred from geological records such as deep deposits of fossilized plankton buried in the sea floor. Matching past sea level records to past temperature records is one way to estimate future sea levels under future temperatures. Other methods are also being used.

Last year, the U.S. National Research Council estimated the rise in sea level by 2100 to be on the order of 20 to 39 inches, and the council "cannot rule out" a rise of 38 to 61 inches calculated by other scientists in 2009. Let us investigate a rise on the high end of the first estimate and the low end of the second– say, 38 inches. We have already accounted for a rise of 2 feet; 38 inches or a bit more than 3 feet is about half again the estimate that did not account for ice-melt. We have seen that a 2 foot rise moves today's low tide line to today's high tide line. A 3 foot rise would put low tide at or above many seawalls in this part of Florida.

> *To see firsthand where a 38-inch rise in sea level might place high tide in September, visit the Joan M. Durante Community Park, 5550 Gulf of Mexico Drive, Longboat Key, and look for a one-inch, green plastic disk nailed to a post on the dock overlooking Sarasota Bay.*

A 38 inch rise in sea level by 2100 implies that each year going forward, on average, sea level would be 7/16$^{\text{ths}}$ of an inch (roughly, a half-inch) higher than the previous year. This assumes that the rise of 38 inches is distributed evenly across the coming years. An annual rise of a half inch, more or less, would be easy to recognize in the records of tide gages in southwest Florida. Global sea-level rise has accelerated, to about a third of 38 inches per century, but the acceleration is not yet evident in Florida tide gage records. In fact, the long-term averages of sea-level rise measured at gages around Florida are the equivalent of about 8 inches per century. What accounts for this disparity?

Several factors are involved. First, measurements of globe-wide sea level are made by satellites, but the record only began in 1993. Tide gage measurements at the nearest long-term station, St. Petersburg, began in 1947. A person's average growth rate since 1947 is understandably different than one calculated since 1993 and the same is the case with sea-level rise. Second, satellite measurements are less precise at the land-sea boundary where most tide gages work, than they are over the open ocean. Third, predictions of global sea level are predictions of average levels and there are parts of the world ocean where rates are naturally higher and lower: oceanographic factors have been suggested to explain why Florida rates are lower than average global rates.

However, the Florida Oceans and Coastal Council[2] finds, "Florida sea-level rise can for most practical societal purposes be considered to be essentially similar to global sea-level rise throughout the state's coastal areas," especially where predictions are concerned.

Predictions of global sea level are not linear. In other words, the expected rise is not distributed evenly across the coming years, as we earlier assumed. As it happens, all available predictions are relatively straight and gently rising for a few decades but then accelerate in subsequent decades. A graph of assets increased by compounding interest is an apt analogy. We do not expect to see half-inch per year increases in local sea level now because the acceleration of global, and hence Florida, sea-level rise, is not expected for a few decades.

The fact that sea level will rise slowly at first, and then with increasing rapidity, suggests that the *effects* of sea-level rise will unfold smoothly. This is unsupported by experience. It is reasonable to expect that the impacts of sea-level rise in the near future will look more-or-less like the impacts we see today, as in beach erosion and imperfect drainage. If predictions are correct these effects will worsen with time but it is entirely possible that a threshold or tipping point will come when accelerating sea-level rise brings new, unfamiliar, and challenging processes into play.

For example, when the rate of sea-level rise has increased ten-fold, mangrove forests on the bayside of the key may perish. Note that the level of the sea is not important here—what matters will be the rate. Mangrove forests keep pace with sea-level rise by forming and trapping sediments. The forest floor accretes and elevates the forest, in large part by contributions of mangrove roots. But mangroves lacking ample supplies of freshwater and sediment, as our bayside forests do, cannot keep pace with too rapid a rise in sea level: they drown in place, and the forests perish. In nature the forests can "migrate" onto low uplands as seaward mangroves are lost and seedlings colonize new up-slope areas, but on Longboat Key, seawalls, buildings, and roads will prevent forest migration.

These same developments, and others, will make it difficult to anticipate the specific effects of accelerated sea-level rise on Longboat Key. It is reasonable, though, to expect other kinds of thresholds to appear, probably at different rates for different island features. The Florida Oceans and Coastal Council observes, "Large storms may lead to a 'change-in-state' causing island breaching. The possibility of a correlation between an increased frequency of larger storms and increased sea level will exacerbate the erosion impacts. Furthermore, human development may prevent some of the natural process of island migration and may lead to increased vulnerability or catastrophic failure."

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[2] Florida Oceans and Coastal Council. 2010. Climate Change and Sea-Level Rise in Florida: an update of "*The Effects of Climate Change on Florida's Ocean and Coastal Resources.*" Tallahassee, FL. vi + 26 pages. http://www.floridaoceanscouncil.org/reports/.

The Council refers to another threshold for structures. “Shoreline retreat and coastal erosion will continue to increase as sea-level rise accelerates, and combined with higher water tables …will undermine sea walls and other protective structures. Higher sea level and water tables will create higher hydrostatic pressure of ground floor slabs and foundations of buildings and infrastructure, resulting in increased risk of structural damage especially during hurricanes and coastal flooding events.”

It is hopefully evident that sea-level rise actually represents two agents of change. The first, inundation, has been the focus of this essay but implicit in its treatment is the equally important fact that the energy environment of the gulf, bay, and key will also change as sea-level rises. Even on calm days tides and normal wave action deliver considerable energy to shorelines, with tides causing horizontal water motion and waves causing horizontal and vertical motions. Together these motions sculpt beaches, determine where wetlands, oysters, and other natural resources can and cannot live, and challenge shoreline structures on a 24/7 basis. Storms intensify and prolong this energy and give it larger reach. Sea-level rise has the effect of raising the energy upward and onto dry land. There will undoubtedly be thresholds and tipping points not only in the force exerted by such shifting energy, but in the effects it causes, as well.

For example, if the rate of sea-level rise exceeds the ability of Longboat Key’s mangrove forests to track sea level by accumulating sediments, they will drown in place. Forest mortality occurs rapidly, within a year or two. We know this from the effects observed when mangroves have been over-flooded because of inadvertent diking and filling projects. Waves that were normally dissipated within the forests become agents of erosion, removing wood and soil from the forest. In time the forest is eliminated. The buffering effect of the fringing forest is lost, and everyday waves convert uplands that were once screened from the bay into openly exposed waterfront. In this case, inundation and energy interacted to create a threshold or tipping-point effect.

Thresholds and tipping-points exist not only for responses to sea-level rise: as discussed earlier, there is ample geological evidence that sea level itself has abruptly risen or fallen. Rapid changes in glaciers and ice sheets, ocean warming and cooling, major ocean currents, and other factors are capable of causing the smooth curves of future projections to take the form of saw-teeth or stair-steps. Such abrupt changes of sea level will be relatively easy to detect but any abrupt rise of consequence will pose difficulties never before experienced in coastal communities.

What are coastal communities in Florida doing in response to rising sea-level? Many are beginning with the prospect of increased flooding. In Sarasota County, the University Of Pennsylvania Department of Geography used computerized mapping tools to depict the effect of sea-level rise on the inland reach of hurricanes of increasing magnitude. Communities elsewhere are also focusing on storm-related problems that will be aggravated by sea-level rise.

Another issue many areas are or soon will address is water supply. According to the Florida Oceans and Coastal Council, “The Pensacola Bay and St. Johns River watersheds and southern Florida from Palm Beach to Miami, the Florida Keys, Naples, and Fort Myers are especially vulnerable to saltwater intrusion into municipal freshwater supplies as sea levels rise,” and “The South Florida Water Management District already spends millions of dollars per year to prevent Miami’s Biscayne Aquifer from becoming brackish.”

The Council also reports, “A Southeast Florida Regional Climate Leadership Summit was held October 23, 2009, in Broward County. This partnership of Broward, Palm Beach, Miami-Dade, and Monroe counties formed a regional Climate Change/Green Task Force. The purpose of this summit was to develop a regional collaboration to support a coordinated climate change strategy. The Florida counties signed the Southeast Florida Regional Climate Change Compact to coordinate positions on state and national legislation on climate change and to coordinate activities on mitigation and adaptation. They also committed to preparing an action plan that will include adaptation strategies.” Sea-level rise is a prominent part of the Compact.

The Southwest Florida Regional Planning Council produced a detailed analysis of climate-related risks, including sea-level rise, facing the region. The Council worked closely with the City of Punta Gorda to develop priority concerns and potential actions relative to sea-level rise, resulting in the city adopting comprehensive plan language to address the impacts of sea level rise and to seek strategies to combat its effects on the shoreline of the City. Punta Gorda’s efforts have distinguished the city as one of the most progressive municipalities in the United States with regard to planning for climate change.

In 2009 the Marine Policy Institute at Mote Marine Laboratory conducted an assessment of policy tools for local adaptation to sea-level rise. Funded by the Gulf Coast Community Foundation of Venice, the project assessed policy tools and leadership opportunities that already exist at state and local levels to help Florida local governments begin to act now to prepare for climate-associated sea level rise.   The assessment addressed five policy areas: comprehensive planning; local authority over coastal management and development; policies and programs for ecosystem conservation through land acquisition and conservation easements; public facility and infrastructure planning, and post-disaster redevelopment planning. Recommendations included organizing local governments into a climate change advisory task force; broadening local planning horizons (to 50 to 75 years) and incorporating sea-level rise in all planning elements; and expanding outreach and partnerships with scientists, community and conservation groups, and the private sector, to begin to educate the public about risks and options for sea level rise adaptation.

In southwest Florida, the national estuary programs for Tampa and Sarasota bays, and Charlotte Harbor, have undertaken climate and especially sea-level programs and projects. Mote Marine Laboratory and Sarasota Bay Estuary Program are presently working on a new project funded by the EPA Climate Estuary Project to describe sea level rise in the Sarasota Bay region. The project involves developing a web-based sea level visualization tool using the latest digitized elevation data for the two counties in the estuary, along with community workshops using the web-based tools to engage local communities on local sea-level rise scenarios, vulnerabilities, and tools for adaptation. The project is expected to be completed by the end of 2011 and will include recommendations that draw upon workshop results and other inputs from the community.

Conclusions

In terms of sea-level rise, a best-case future for Longboat Key has sea level rising at low historical rates for a few decades before the rate accelerates. Under that scenario sea-level rise will challenge sea walls, drainage systems, and beaches. Existing strategies for beach management are sophisticated and effective, albeit costly, but the beaches can be sustained using existing and improving engineering and technology. The same may be said of drainage systems, with newer systems employing underground tanks to temporarily store rain waters until they can be pumped to the bay during low tides. Sea walls and other fixed structures can be modified as they are replaced through time. New buildings will be elevated and hardened against storms with the prospect of sea-level rise in mind. Island communities will benefit from the experience of others, and there will be time to plan and adapt.

A worst-case scenario involves the early acceleration of sea-level rise, or abrupt increases of sea level that persist. It is difficult to foresee what will happen under such circumstances, or what should be done, for two reasons. First, specific effects will depend on the details of sea-level rise not presently known. Second, the particulars of Longboat Key's response to sea-level rise will depend on site-specific conditions on the ground, and these have not been inventoried with respect to their individual vulnerabilities.

Either future commends the establishment of partnerships among island communities, mainland cities and counties, and state and federal agencies for the purposes of learning more about sea level, what other communities are doing, and reasonable courses for local planning and analysis. Many resources are already available in Florida including practical experience in coastal science and engineering, planning, communications, economics, law, and policy; more are being developed at a quickening pace. Planning, like investment, yields the greatest return when begun early.

About the Author

Dr. Ernie Estevez has been engaged with tides and sea level since the mid 1970s through ecological research and applications for coastal resource management and policy. Motivated by the implications of future sea-level rise, he conducted a survey of 76 Florida cities and counties in 1990, to identify their experience with past sea level and concerns for the future. He has also assisted local, regional and state by explaining the essentials of sea-level science.

Estevez has served on the Florida Oceans and Coastal Council since 2005 and participated in the production of Council reports on climate change and sea-level rise. A past president of the Florida Academy of Sciences and the Myakka Conservancy, with whom he received a Governor's Council for Sustainable Florida Award, Estevez is also the recipient of a Distinguished Alumni Award from the University of South Florida, and the Eugenie Clark Scientific Explorers Award.

Dr. Estevez sincerely hopes that sea level does not rise as predicted. Unproductively, he has sought to identify errors of evidence and argument in future projections. Based on an objective assessment of the best scientific information available at present, and a deep understanding of the risks Florida faces, he has worked to explain the technical content of sea-level rise and risk, and precautionary principles, to the widest possible audience.