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Riding the Rising Tide: Fathoming Our Changing Coast and Future

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"Change is the only constant"

noted Heraclitus of Ephesus sometime around 500 B.C.E.

I like that phrase for its paradoxical and brilliant insight into the nature of nature. But given our short attention spans and the radically longer time scales over which some types of change occur, many of us operate our daily lives under the comfortable assumption that we inhabit a space of static constancy. This notion of constancy seems to me related to John Steinbeck's insight in the *Grapes of Wrath*, as recounted by my son who just completed the novel, *that the good times made them forget the bad times and the bad times made them forget the good times.*

We go about our lives pretty much expecting a continuation of what went before. This approach usually works but occasionally needs reappraisal. Here along the Connecticut coast, we experience daily changes in the level of Long Island Sound; the tides come in and go out, the sea level rises and falls. We expect this and plan our swimming, boating and clamming activities accordingly. Twice a day we see this cycle play itself out in the Sound, varying as the earth, moon and sun dance their way across the heavens. The sun and especially the moon exert gravitational forces on planet earth causing bulges of water to form on the rotating earth, creating tidal currents and changing sea levels. Other planetary

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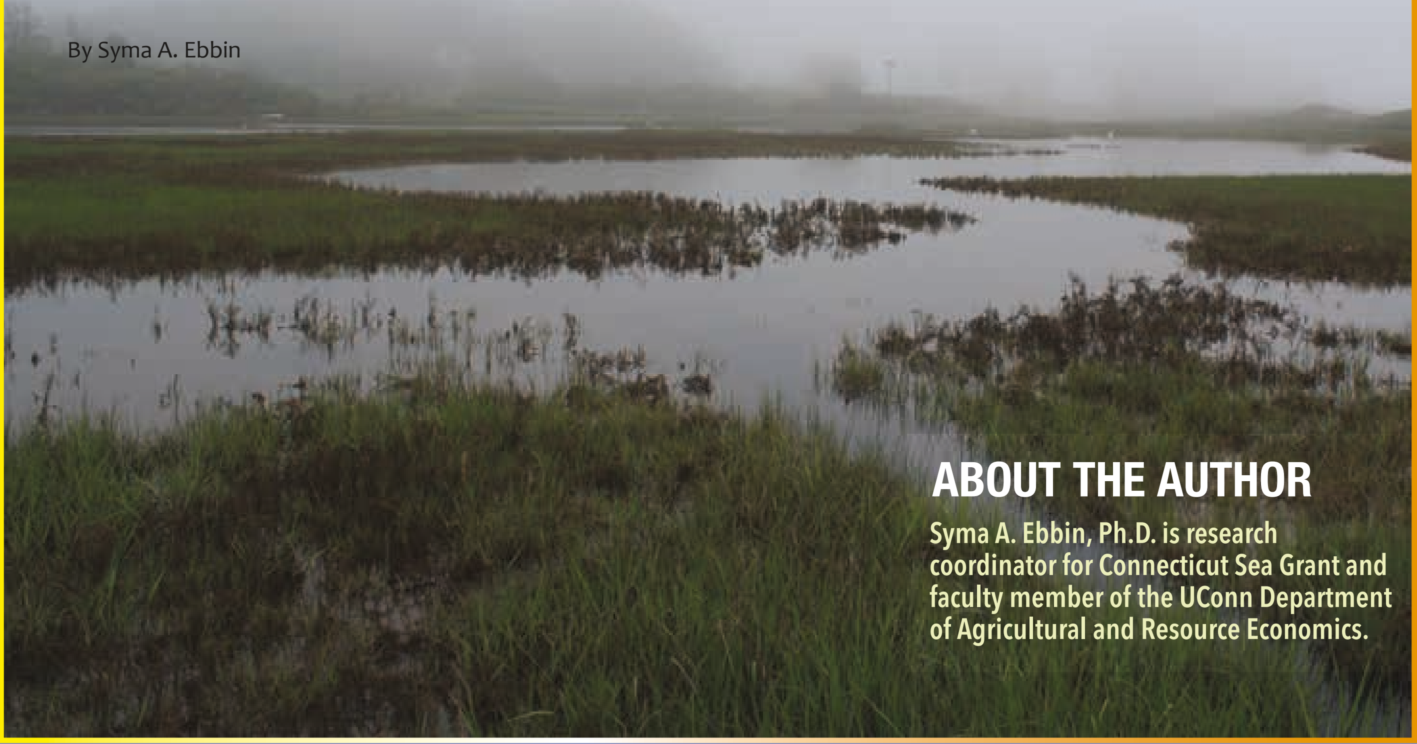

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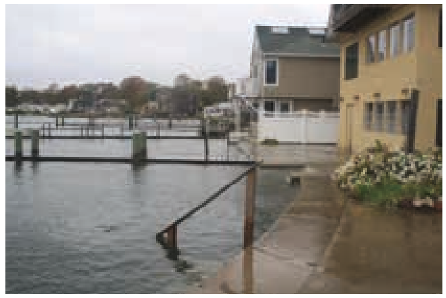
alignments and cycles, which we may be more or less aware of, overlay this diurnal one. Some like those that create spring and neap tides occur several times a year, others occur on longer time scales, such as the lunar nodal cycle which occurs on an 18.6 year rotation. Other factors too, such as storms and winds, and the shape of the land and seabed influence the rising and ebbing tides.

Here on the coast of Long Island Sound, to grasp the dynamics of our rising sea, we should consider also our recent geological history. Connecticut was covered by glaciers during the last ice age, reaching our state around 26,000 years ago. The south fork of Long Island was the southernmost extent of this glacial advance, which is marked as a terminal moraine, and the shoreline at this time was approximately 90 miles offshore from where it is today. Recessional moraines composed of rock and sediment marked the retreat and created a dam at the mouth of the nascent Sound, blocking the runoff of glacial melt-water that flowed from the disappearing glacier. Long Island Sound was first born a lake. Lake Connecticut formed when sea level was about 300 feet lower than it is today. The glacial milk flowing in deposited clay sediments creating a shallow-basined lake which ultimately broke through the sediment dam and drained to the Atlantic through the break at the Race between Fishers and Long Island Sounds. Once the heavy burden of ice was removed, the land began to rebound while at the same time, the sea level began to rise from the input of melting glacial waters. Eventually, both rebound and sea level rise slowed, fringing salt marshes formed, and about 3000 years ago the Sound we know today came into being.

According to the New London tide gauge, sea level has been rising at an average of 0.09 inches a year from 1938 to 2006, which represents an increase of about nine inches per century. Some scientists believe the slope of recent year increases in this area is significantly higher than this long term average, ranging from 0.16 to 0.20 inches a year. These local area increases are greater than the global average of 0.07 inches a year calculated by the Intergovernmental Panel on Climate Change (IPCC).

The science needed to understand the dynamics driving rising sea levels and to predict where they may ultimately end up is complex and still emerging. Are you ready to dive into the (sea) weeds of the rising sea? First we need a bit of background on the dynamics of sea level fluctuations. There is a complex interplay among different factors affecting both land and sea involving changes in tectonic, hydrologic and atmospheric systems. On the land side we have forces which cause land to rise or sink such as the uplift that occurred after the retreat of glaciers. This is countered by subsidence or sinking of the land caused by the removal of minerals and groundwater and the compaction of soils. Tectonic forces change not only the land but the contours of ocean basins as well. The ocean is linked to the atmosphere, absorbing and storing much of the solar radiation which reaches earth as well as half of the carbon dioxide and methane. Our atmosphere is warming and that in turn has warmed the ocean and ultimately, increased the volume of ocean water, a phenomenon called thermal expansion. This warming has also increased the rate of melting and discharge of water from continental glaciers and ice sheets.

There are two general methods for forecasting sea level rise. One involves empirical methods, based on the relationships among measured attributes such as temperature and sea level. The other employs process-based models developed through understanding the physical dynamics of the climate system. The most influential sea level rise forecasts are of the latter type: model-based scenarios produced by the IPCC. The 4th IPCC Assessment estimates took into account only the thermal



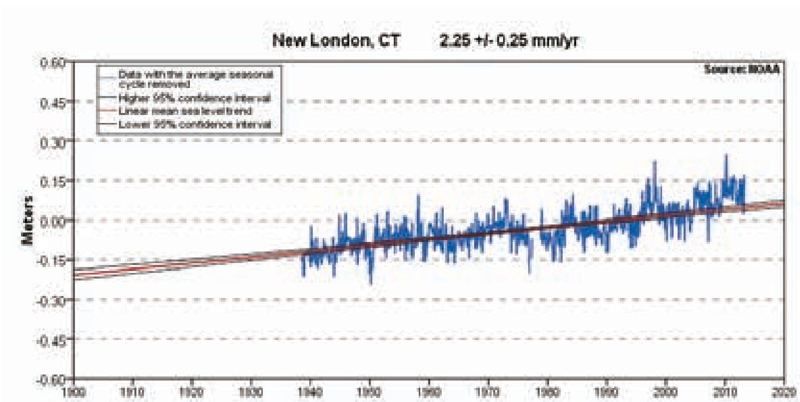
expansion of the ocean and did not consider the melting of glaciers and the Antarctic and Greenlandic ice sheets. The 5th Assessment includes these components. In either case, the melting of these ice sheets is the real "wild card" in estimating sea level rise since such a great volume of water is stored within them and little is known about the dynamics of this process.

With greenhouse gas emissions at 2000 levels (substantially lower than exist today), the IPCC's 4th Assessment projected a sea level rise between seven and 23 inches by the end of the 21st century. However, the draft 5th Assessment released in August 2013 reworked the estimates to include projected changes in glacial melting. The new estimates range from 10 inches to slightly over three feet by the end of the century under a scenario in which greenhouse gas emissions continue to increase as they have in recent years. A recent IPCC press release from September 27th quoted Co-Chair Qin Dahe as saying, "As the ocean warms, and glaciers and ice sheets reduce, global mean sea level will continue to rise, but at a faster rate than we have experienced over the past 40 years." While the IPCC assessments provide the official best scientific estimate, alternate estimates of sea level rise by other researchers far exceed the upper ends of this range; others corroborate the lower estimates. On the higher end of sea level rise estimates is Stefan Rahmstorf of the Potsdam Institute for Climate Impact Research who has estimated increases in the range of six to ten feet in the next century. Another recently published study based on geological evidence from Australia indicates that sea levels may have risen 30 feet above the current height near the end of the Eemian epoch which preceded the most recent ice age, and most unsettlingly, that approximately 17 feet of this increase occurred in a geological instant — less than one thousand years.

So what do we know about what may happen in Connecticut? Estimation becomes even less reliable and more variable the closer to home we get. The more geographical and temporal specificity we demand, the less reliable the resulting estimates. Complicating this forecast is the fact that Connecticut's phase of glacial rebound is ending and the state is now sinking slightly at about 0.03 - 0.035 inches per year. Sea level does not rise at the same rate everywhere, and local projections of sea level rise in Connecticut have forecast increases on the high end of IPCC projections. A 2004 projection made by Environmental Defense researchers put increases in the range of nine to 35 inches by 2080. More recent research from the U.S. Geological Service has identified a "hotspot" of accelerated sea level rise, potentially three to four times higher than the global rate of increase, extending from Cape Hatteras north over 600 miles along the Atlantic coast of the U.S. and encompassing this region. These spatial variations result from dynamic processes driven by circulation and variations in temperature and salinity (which determine seawater density and therefore its volume) as well as forces associated with Earth's rotation, shape and changing gravity.

However, even these more regionalized estimates of sea level rise won't tell us much about the on-the-shore dynamics we may experience in Long Island Sound. The Sound is not just a big enamel bathtub filling up with seawater. We need to consider the relationship between that rising sea and the shoreline, the shape and composition of the shore, its susceptibility to erosion, local differences in land elevation, the quantity and rate of sediment inputs (accretion) and outputs (erosion). On shorelines composed of loose sediments such as sand, changes in the shape of the coast will be determined not just by higher high tides, but also by the powerful impacts of waves and storms shifting those sediments into new shapes. Although models exist to predict shoreline retreat, the complexity of processes and interactions on the shore make these predictions quite unreliable.

New London Tide Gauge



The upward trend in sea level rise is 0.09 inches/year based on monthly mean data from 1938 to 2006; however, the rate is higher in most recent years. Source: NOAA

To really understand what the interface between the marine and terrestrial spheres will look like, we also need to understand the nature of human development in the coastal zone. Connecticut is the fourth most densely settled state in the nation. Forty percent of the state's population lives in 36 coastal municipalities and over 95% live within 50 miles of Long Island Sound. Beaches, dunes and tidal marshes may be able to migrate inland if topography permits, but in areas we have developed, where we have built retaining walls, houses, restaurants and roads, this migration may be unable to occur. We have already compromised or destroyed many of these naturally buffering systems and more may be lost as sea levels rise, eliminating their capacity to buffer storm surges, mitigate coastal flooding and provide essential habitat to a suite of coastal species, some of which, like the piping plover which nests on Bluff Point, are already endangered. Coastal wetlands act as "horizontal levees" and, according to ecological economist Bob Costanza and his colleagues, 2.5 acres of this habitat in Connecticut prevents approximately $28,500 in storm damage on an annual basis, allowing us to avoid $23 billion in damages each year on the northeast and gulf coasts combined.

Finally, the role of high energy events must also be considered in this equation. Warm water is the "fuel" that drives hurricanes, and with warming waters it is predicted that there may be an increase in intense tropical hurricane activity in the North Atlantic, including Connecticut. Certainly, we have experienced a wave of extreme weather events in the past few years: an extreme 100 (+) year flooding event in March 2010, Tropical Storm Irene in August 2011, followed closely by the freakishly early Winter Storm Alfred in October 2011 and more recently, Superstorm Sandy last October, which entered some areas with a storm surge of 13 feet above mean sea level. Researchers have predicted that a 100-year storm event will occur more frequently in the future, recurring every three to 50 years by 2100 in the

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New London area, depending on the emission scenario used in the model. Intense hurricanes lead to impressive beach erosion, but even lower intensity, but more frequent, winter storms can have significant impacts; both types of events may cause substantial property damage in coastal areas.

For folks who are charged with planning for the future in our coastal communities, such as Groton, this range of forecasts and lack of consensus on how high the tide will ultimately rise is a problem. However, using plausible future scenarios can be a useful aid to planning and making decisions regarding the development and protection of coastal areas. There are two programs that have been developed to visualize potential impacts on local areas. The Nature Conservancy's Coastal Resilience Tool is one such program and can be accessed at: http://coastalresilience.org/. The CT DEEP and University of Connecticut Coastal Hazards Portal and Visualization Tool (http://coastalhazards.uconn.edu/visualizationtool/) is another means of visualizing potential impacts associated with different sea level rise scenarios.

This summer, my family and I went to see Shakespeare's "As you Like It" at the Connecticut College Arboretum. This play abounds in clever aphorisms; many highlight the paradoxical and interwoven nature of seemingly opposite concepts. One of my favorites was "The fool doth think he is wise, but the wise man knows himself to be a fool." I think Shakespeare was commenting on the foolishness of believing in the certainty and breadth of knowledge and the wisdom of recognizing its tenuousness and imperfection. Thus, it is with humility and an open mind that we should move forward into our changing world. We may not know exactly how high our seas will rise as a result of a warming climate and we may know even less about how our shorelines will retreat, but because many areas of our coast are already experiencing erosion and repeated damage to homes and infrastructure from storms, we must plan for the future, no matter how uncertain, and adapt to a present that seems now to be diverging from the past. It may be that in order to live in the good times (à la Steinbeck) we may need to remember the bad and indeed, act upon the knowledge embedded within experience and the lessons learned during those times. We might take heed of Lao Tzu's admonition "If you do not change direction, you may end up where you are heading" and decide to change course. We may not be able to stop the rising tide given the changes we've set in motion, but by planning for a range of conceivable futures and taking steps to meet the challenges ahead, we may be able to ride the crest of that tide and land our boat on a different shore.