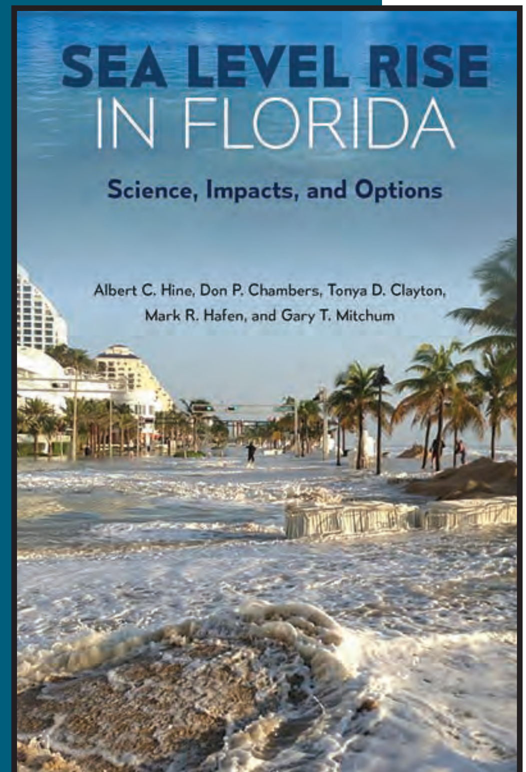
WHAT PEOPLE ARE SAYING

"A scientifically credible and highly readable account of what is likely the greatest threat to Florida's environment, economy, and culture over the coming decades."

—Reed F. Noss, author of *Forgotten Grasslands of the South*



"Every Floridian should read this book. It is the clearest and most readable description of how and why the sea level changes and what the future has in store for us."

—Orrin H. Pilkey, coauthor of *Global Climate Change: A Primer*

SEA LEVEL RISE IN FLORIDA

Science, Impacts, and Options

ALBERT C. HINE, DON P. CHAMBERS, TONYA D. CLAYTON, MARK R. HAFEN, AND GARY T. MITCHUM

978-0-8130-6289-1 • Hardcover $34.95 • 200 pages, 6 x 9, 76 color and 4 b/w illus.

UNIVERSITY PRESS OF FLORIDA • OCTOBER 2016

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The authors are available for interviews and appearances.

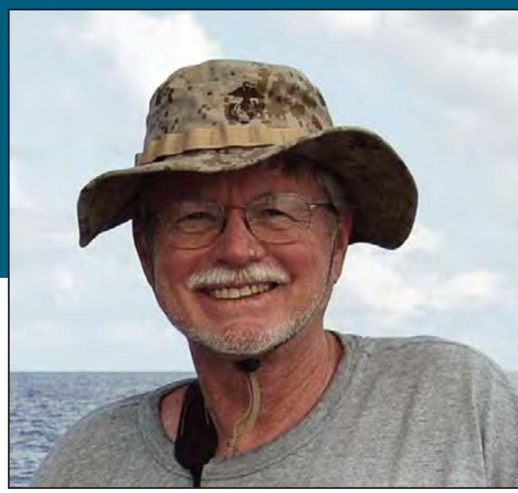
Q&A

with

ALBERT C. HINE

coauthor of

Sea Level Rise in Florida



Credit: Robert Halley

Sea level rise isn't a new environmental issue. Why do you think now is the right time for this book?

The general public is largely unaware of this issue. If they are aware, they might not understand why sea level is projected to rise in the coming decades. Some, due to their political persuasion, refuse to believe it. Yet, a growing group of concerned, motivated, and learned citizens is educating its members. This growing number is trying to understand the science, the potential impacts, and our options for coping with this predicted phenomenon.

The book discusses sea level rise in Florida. How does what you cover apply to the rest of the world?

Since approximately 40% of the world's population lives within 100 km of the global coastline (**http://sedac.ciesin.columbia.edu/es/papers/Coastal_Zone_Pop_Method.pdf**), sea level rise could affect roughly 4.4 billion humans by the year 2100. Historically, many if not most of the world's largest cities were established near natural harbors, estuaries, and embayments for economic (trade, fisheries, energy) and military necessity. With time, richer countries developed their coastlines for tourism, real-estate opportunities, and other economic drivers. Many of these population concentrations are in very low-lying areas topographically. The predicted rise of sea level by 2100 and beyond would fundamentally change and even destroy this enormous and essential human infrastructure.

What changes have already been made to cope with the rising seas, and why isn't it enough?

Countries such as The Netherlands have been challenged with living at or even below sea level for decades. Cities such as Venice are challenged as well. Both have built various types of engineering structures to cope. Small countries such as Kiribati, located on a coral atoll in the Pacific, have already decided to move, en mass, and have reached an agreement with the New Zealand government to relocate there once Kiribati submerges and becomes inhabitable. But, for the most part, few plans have been created to deal with sea level rise in topographically low areas due the overall lack of understanding in the U.S., particularly Florida. The issue simply has not attracted the widespread attention necessary, partially due to our tendency as a country—and as a species—to avoid multi-decadal planning and to instead think in much shorter time spans. We need to learn 50-100 year planning for issues like sea level rise and its effects on transportation, food, water, health, climate, living space, etc.

Do you believe our coastal cities and towns still have hope, or are the rising seas something we're helpless to stop?

If the worst case predictions turn out to be true, there is little hope for mitigation and little hope for continued living close to the water's edge.

What have been and what will be the most dramatic consequences of sea level rise in Florida?

Right now, we are beginning to see low neighborhoods routinely flooding at very high tides, which did not happen decades ago. We are seeing "nuisance rainfall," which causes street flooding, because higher water levels prevent adequate runoff into street drains and culverts. Eventually, wholesale evacuation and abandonment of property and infrastructure over multiple decades will be unavoidable.

Is there a consequence of sea level rise that you believe most people don't know about or fully appreciate the significance of?

The greatest consequence will be the rising cost of mortgages (or simply the unavailability of mortgages) and flood insurance, preventing people from selling their low-lying property. Banks will not provide mortgages for property that will be submerged within the lifetime of the mortgage. Coastal property values will fall and will no longer be the investment they once were. We have to realize that sea level rise can continue centuries beyond the year 2100, which is an arbitrary target. Finally, another great unknown is the instability of ice sheets possibly causing much more rapid pulses of sea level rise than we have currently predicted.

What is something we could do every day that would help alleviate this issue in some way?

The problems will be addressed be future generations—not ours. So, we need to include the science of climate change and all of its ramifications in school science curricula. The next generations will have to provide solutions. We will be long gone.

What actions do you hope readers take after learning the information covered in the book?

Keep learning more. You can never learn enough. Start to talk to local political leaders and other people in planning positions to see if they have a clue. Get climate science into the primary and secondary school curricula.

Projections of Sea Level Rise

Projections of sea level rise over the next hundred years are difficult to make. This is because many factors affect sea level rise, and these factors are not steady. Thus, one cannot simply project the current mean rate of sea level rise for the next 100 years or longer. Doing so would very likely severely underestimate the amount of future sea level rise.

The ocean responds very slowly to a warming climate, much more slowly than the atmosphere and the ice sheets. Even if the amount of carbon dioxide and methane in the atmosphere could be magically stabilized over the next 100 years, the ocean will continue to take up heat for a much longer time because of the slowness of the processes that transfer heat from the upper ocean to the deep ocean.

Unfortunately, there is no reason to expect atmospheric carbon dioxide and methane to diminish or even stabilize over the next century, based on realistic estimates of population growth and energy usage and on the fact that there is no foreseeable alternative energy source. Thus, as scientists, we have to expect the earth's atmosphere to continue to hold more and more heat, which will lead to increasing warming of the oceans and increasing melting of ice.

However, we also have to make these projections of sea level rise based on physics: the atmosphere can only warm so fast, the ocean can respond only so quickly, and ice can melt only so rapidly. Unfortunately, there are still limitations to physical models. Contrary to some public perceptions, scientists understand how increasing levels of carbon dioxide and methane affect the earth's heat imbalance very well. Because these gases mix globally in the atmosphere very quickly (in less than a year), we can easily estimate the amount of excess heat that will be trapped by the earth's atmosphere from these so-called well-mixed greenhouse gases.

Other factors that affect the global heat budget of the planet include changes in solar radiation, in levels of natural and anthropogenic aerosols and particulates in the atmosphere (for example, volcanic eruptions), and clouds. These factors can either increase the warming or decrease it somewhat, and all of them are more uncertain than the well-mixed greenhouse gases. Except for the aerosols and particulates, they also have a much smaller effect on the climate than greenhouse gases do. In particular, changes in solar radiation are very small. Cooling from volcanic eruptions can cause significant cooling for several years after a major volcanic eruption; this has been observed and modeled. However, the particulates and gases from such eruptions do not stay in the atmosphere, so the cooling effect is temporary.

Thus, for projections of sea level rise, scientists assume a scenario of future greenhouse gas emissions leading to increasing warming. This is then used to drive a large number of climate models. Most projections allow for small changes in solar radiation due to changes in earth's position relative to the sun, which is easily predictable, but assume that the solar output will be steady. This is reasonable, since the observed output has been found to vary by less than 0.1 percent, and this is mainly over the eleven-year solar cycle. Clouds and natural aerosols may or may not be included, as is the case for some anthropogenic aerosols. Volcanic eruptions are generally not included in projection runs, as it is impossible to forecast the strength, location, or number of volcanic eruptions in the future. Philosophically, it is better to not use unpredictable natural forcings that may or not happen in the future.

Projections are not based on a single climate model or a single run. Numerous studies have shown that by averaging results from many different climate models and different runs, scientists are better able to reduce random errors and reproduce observed climate signals such as the rise in sea level and changes in the heat content and surface temperature of the ocean. Examining the range of estimates from the model runs also provides an assessment of the certainty level of the projection.

There are limitations to climate models, especially for sea level projections. In order to conduct the calculations within a reasonable period of time for multiple climate scenarios, the models can only represent the broadest-scale ocean circulation and cannot account for some important processes in the ocean. One of these processes is oceanic eddies. These are spinning vortices a few hundred kilometers across that can transport large amounts of heat within the ocean both horizontally and vertically. Thus, climate models are best at representing the large-scale climate changes in the ocean that occur for periods longer than several decades and over very large spatial scales. They are still not capable of accounting for very localized changes in sea level rise that occur over a few years to a few decades, such as those that we have observed over the last two decades (figure 2.10). They can however, reproduce the observed global mean changes caused by thermal expansion (figure 2.9).

As we have explained previously, however, the majority of sea level rise presently comes from melting ice on land, either from glaciers or from the two large ice sheets. Over the next 100 years, this percentage is likely to increase further. Thus, for projections of sea level rise, we need to know how the ice sheets and glaciers will respond in a warming climate. This is difficult, as physically based models of ice sheet still lag behind models of the atmosphere and the ocean. In the IPCC report published in 2007, the ice models were not considered sufficiently reliable to include in projections of sea level rise.

Since then, significant efforts have been made to improve models of changes in ice mass based on the prescribed climate scenarios. The IPCC did include these results in the 2013 report for projections of sea level, but they chose to include the models that predicted ice mass contributions on the lower limit of all models. Several quite plausible models predict significantly higher contributions from the ice sheets.

The 2013 IPCC report synthesized multiple studies to assess projections for global mean sea level rise by 2013 based on four climate projections, determined by the rate at which greenhouse gases will increase by 2100. The climate scenario that leads to the lowest projection of sea level rise in the 2013 IPCC report assumes an ongoing reduction in carbon dioxide emissions such that the amount in the atmosphere in 2100 will be 70 percent lower than it is today. The only way to do this would be a dramatic and costly change from hydrocarbon-based energy to other sources that currently do not exist at the necessary scales.

The scenario that leads to the highest projected sea level rise in the 2013 IPCC report assumes continued reliance on hydrocarbon-based energy for the next 100 years with only modest switches to alternative energy and population increases at the current rates. Two intermediate scenarios were also considered based on reductions in greenhouse gases starting in the middle of the twenty-first century.

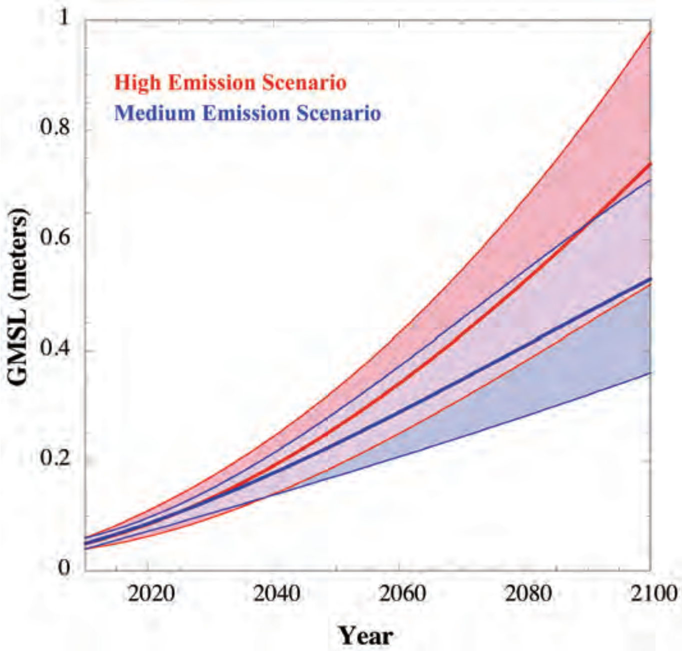


Figure 2.13. Projected global mean sea level rise over the next century from the IPCC's report, assuming scenarios of high emissions of greenhouse gases (i.e., "business as usual") and medium emissions. Source: IPCC (2013).

For our discussion of future sea level projections, we will not consider the lower projection from the IPCC 2013 report. Frankly, we don't consider the underlying scenario to be realistic, given the current attitudes toward conservation of energy and the levels of capital that would be required to convert to alternative (and generally more expensive) energy sources. Moreover, while developed nations have the capability to make some of these transitions if the citizens decide to do so, developing nations (including China) will likely rely on coal for significant portions of their energy for decades to come. Thus, we believe only the intermediate scenarios represent a likely lower bound of future climate change.

This gives a likely range of global mean sea level in 2100 of 0.5 meters at the low end (assuming still quite significant reductions in the burning of fossil fuels) to 1.0 meter at the high end (based on primarily using hydrocarbons for energy throughout the next century) (figure 2.13).

Recall, however, that these projections do not use the highest modeled contributions from Greenland and Antarctica. One process was not included in the projections that is still possible, and that is the collapse of an ice shelf in Antarctica. Several ice shelves have already collapsed or partially collapsed over the last twenty years. These massive tongues of floating ice currently are preventing glaciers from the main ice sheet from discharging ice into the ocean. When they collapse, there could be a dramatic increase in the discharge of ice into the ocean, and hence an increase in sea level.

Although the 2013 IPCC report did not include this possibility in the projections, it did assess the potential magnitude of sea level rise over the next 100 years: "There is *medium confidence* that it would not exceed several tenths of a meter of sea level rise during the 21st century" (IPCC 2013, 23). However, this could mean the potential for additional sea level rise that is anywhere from 0.1 to 0.5 meters.

Finally, it is important to point out that sea level rise will not magically stop in 2100. Thermal expansion of the ocean will continue for centuries longer, even if carbon dioxide emissions are curtailed. Ice sheets will also continue to melt and increase the sea level, although the contributions from mountain glaciers will diminish as their volume diminishes. Thus, although we may not quite reach 1.0 meter of sea level rise by 2100, we will get there eventually, and it is likely to go even higher.

The 2013 IPCC report did include scenarios that ran past 2100. For the high greenhouse gas scenario, the sea level is projected to be between 1.5 and 4.0 meters higher in 2300 and as much as 5.0 meters higher in 2400.

Essential Points to Know

1. The sea level has been rising at a faster rate over the twentieth century than it did over the nineteenth century and likely more rapidly than it had done for well over the 3,000 previous years.
2. Sea level rise at the coastline is a combination of change in the global volume of the oceans, local land motion, and dynamic effects.

3. For many regions of the world, such as Florida, local sea level rise closely follows the global mean for periods longer than several decades, with small differences due to land motion. For periods shorter than twenty years or so, dynamic effects from natural climate variability can cause much larger or smaller rates of rise for a limited time.
4. More than 70 percent of the current sea level rise is driven by glacial melting and ice discharge from Greenland and Antarctica. This is happening at an ever-increasing rate.
5. Changes in storm tracks, frequencies, and intensities should not be ignored. These will most likely have the largest impact over the next twenty years or so, even at the current rate of sea level rise. Humans will feel the effect of sea level rise incrementally, meaning through changes in what we usually call weather. In other words, someone with property near Tampa Bay will not have water lapping their front door in the next twenty years. However, they may find that they have more frequent flooding from smaller storms than they did twenty years earlier, as the mean level of Tampa Bay has risen.
6. The sea level will continue to rise over the next 100 years and longer, likely at an increasing rate.

Keywords

Sea level rise, sea level projections, tide gauges, satellite altimetry, satellite gravity, ocean warming, ice sheets, ice mass loss

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