

Western Carolina University Climate Change Report

Sea Level Rise: Science and Management

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Introduction

While Western Carolina University has numerous scientists engaged in research that will document the impacts of global climate change on local biodiversity, hydrology, and economies. The bulk of this research is in its early stages. The University has chosen to focus this report on an area where we have long-standing, direct expertise in both the science and management of the impacts of global warming. The Program for the Study of Developed Shorelines is a national leader in conducting scientific research in the coastal zone and translating that science into management and policy recommendations. This report will focus on the potential coastal management decisions that North Carolina will face during the next century as the state responds to a global warming-induced rise in sea level. The author of this report is currently co-authoring a book on sea level rise (SLR) to be published by Island Press in the spring of 2009. This report summarizes much of the research that went into that book. The report is written in a non-technical style in order to make it readable and useful to a lay audience.

Is the Earth Warming?

The northern hemisphere winter of 2007-2008 was the coldest since 2001 according to NOAA's National Climate Data Center. This has led many of those skeptical of the impact of global warming to call once again for a blanket repudiation of warming predictions. It is always difficult to argue for or against global warming based on temperature data.

Any team charged with measuring temperature trends over the last few years or decades has an unenviable task. Where do you begin? Daytime highs? Nighttime lows? Summer temperatures? Winter temperatures? What do you do about the significant portions of our planet where there is no data or data of poor quality? Trying to determine if the planet is warming in this fashion seems impossible and fraught with peril.

One doesn't need to measure "global average temperature change" to find evidence on whether or not the planet is warming. The Earth does the averaging for us. There are many physical and biological characteristics of our planet that have been responding to long-term changes in average temperatures. For example, studies from both hemispheres indicate that the world's alpine glaciers are retreating. Glacier National Park in Montana is down to 26 named glaciers from 150 in 1850, and is expected to be ice-free by 2030.

Mount Kilimanjaro's once massive Furtwängler Glacier, made famous by the Hemingway short story, will likely disappear in the next 15 years. Glaciers in the Himalayas are shrinking so rapidly that the flow of the major rivers (Ganges, Yellow, Yangtze) they feed may be impacted. Permafrost regions are thawing in high northern latitudes, causing a wide variety of troubles for human infrastructure like sinking

buildings and crumbling roads. And, much has been made of the recent thinning and disappearance of arctic sea ice. Open water has been reported at the North Pole for the first time since scientists have been able to monitor those conditions.

Then there is the focus of this report: global sea level is rising. This fact is clear from the examination of rising tide gauge data the world over, and from the increase in coastal erosion along many of the planet's shorelines.

So, one doesn't need to calculate average, global temperatures to look for evidence that the planet is warming. The Earth does the averaging for us. Clearly, it is.

Sea Level Rise

In broad terms there are two types of sea-level change, local (isostatic) and global (eustatic) sea level changes. Isostatic changes result from factors that are causing the local land surface to move up and down. This can be mountain building resulting from tectonic plate collisions, glaciation, sediment compaction in large deltas, or anything that adds or subtracts weight from the crust. For example, the rate of sea level rise in Louisiana is very different from the rate of sea level rise just down the coast in Alabama. The difference is due to local subsidence of the Mississippi River delta in southern Louisiana. There are many places in the Arctic where sea level is in fact currently falling. This is because the land is rising as glacial melting removes weight from the lithosphere. Isostatic or local, relative sea-level rise, then, can vary greatly from place to place.

Eustatic sea level rise is simply a measure of the increase in the volume of water in the oceans, expressed as a change in the height of the oceans. Currently, eustatic sea level is rising at a rate of approximately 2 mm/yr if averaged over the last 100 years and around 3 mm/yr over the last 15 years. The rate of eustatic sea-level rise is accelerating in response to global warming. This is the rate addressed by the Intergovernmental Panel for Climate Change. They have predicted that sea level will rise 18 to 59 cm by the end of this century. These IPCC estimates do not include significant contributions from melting of the large ice sheets (Greenland and Antarctica) due to a great deal of uncertainty over their future behavior.

There are two ways global, eustatic sea level can be changed: 1) change in the accommodation space in the ocean basins brought about by a change in the rate of tectonic plate movement; and, 2) change in the amount of water in the oceans. Modern sea-level rise is being driven by the latter, but in times past the former has generated much more dramatic excursions of the ocean onto land.

The volume of water in the oceans can be changed in two ways: by the addition of more water or by heating the water up. Both of these factors are fairly straightforward as concepts. Water expands as it warms. Heat 50 gallons of water up by 100° F and you will have roughly 51 gallons. As the planet warms, the ocean absorbs a tremendous amount of that heat. Thermal expansion of ocean water is expected to play an important role in rising sea level throughout the next century. The IPCC's most recent rise estimate results primarily from thermal expansion.

To understand how to add water to the oceans, it helps to think back to grade school and the first, simple description given in science class of the Earth's water cycle. Water evaporates from the oceans, falls back to Earth as rain, and flows back into the oceans through rivers (more or less). But, your grade school teacher probably forgot to

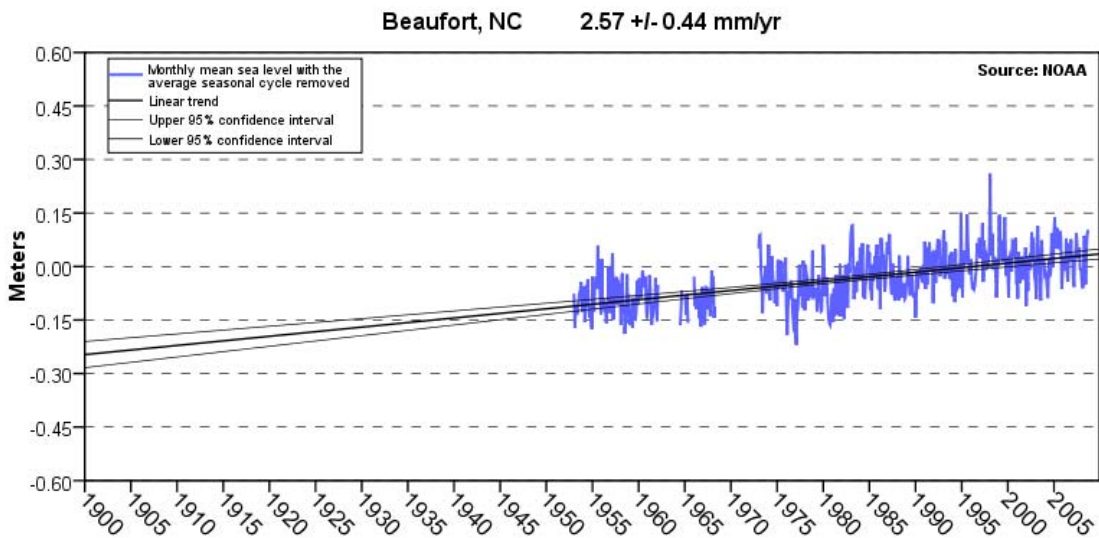
tell you about a wrinkle in this scenario— glaciers. If climate is getting colder, more of that precipitation will fall as snow and get stored in glaciers. If climate is getting warmer, the glaciers begin to melt and return water to the sea. So, fluctuations in global temperature will change the balance between water stored on land and water stored in the oceans.

At present, nearly all of the world’s glacial ice is retreating and thinning, adding water to the oceans. The collapse of the Antarctic ice sheet or melting of the Greenland ice sheet could create a catastrophic rise in sea level of as much as 65 to 70 m. Regardless, the health of the world’s glaciers will be closely monitored by scientists monitoring the future of rising sea levels.

Measuring modern sea-level rise

The fact that sea level is rising is not debated to the same extent that global warming deniers debate the warming of our planet. The evidence for sea level rise is clear. The United States spends hundreds of millions of dollars each year managing eroding beaches, in most cases a direct result of rising sea level. Venice is flooding. The Netherlands is walled off from the sea.

Even more convincing, sea level rise can be directly measured in a far more straightforward way than something like global temperature. The longest record of direct measurement of sea level comes from tide gauges. A tide gauge is a device built to measure water-level variations due to tides and weather, and to eliminate effects due to waves. Tide gauges were not built with the intention of measuring a rise in sea level, but they have proven very useful for doing so. A glance at a simple tide gauge record like the one from Beaufort, NC reveals a complex history of water level change with a clear upward trend of 2.57 mm/yr. This places the North Carolina coast somewhere around the average for sea level rise globally. This is because our coast is tectonically, relatively stable. Some areas of the US are experiencing very high rates of local sea level rise because the land is sinking (e.g. the Louisiana delta).



Sea level can also be measured from space, and the data derived from doing so closely parallels that from tide gauge measures. The TOPEX/Poseidon satellite, launched in 1992, measured sea level and was also used to map the ocean floor. As TOPEX/Poseidon orbited Earth, an altimeter bounced radar signals off the ocean's surface. The altimeter recorded the time it took for the radar signal to return to the satellite and that gave a precise measurement of the distance between the satellite and the sea surface. Measurement from orbit is the only way to assess sea level independently of land-level changes. TOPEX/Poseidon served as the primary means for monitoring the oceans until it was supplanted by the more accurate sea level monitoring satellite Jason-1, launched in 2001.

The global average rate of sea level rise measured via satellite altimetry for the period 1993-2003 is 3.1 mm/yr according to the IPCC. Interestingly, the eustatic sea level rise signal is not uniform in the global ocean. Variability in ocean temperatures, ocean currents, and events like El Nino can locally mask the global signal. Sea level in the Atlantic and the eastern Indian oceans is rising, while sea level in eastern Pacific has been falling in that period.

The recent IPCC report estimates that for the period from 1961-2003, approximately 60% of the sea level rise was due to an addition of fresh water to the oceans from melting glaciers, while 40% was due to thermal expansion. For the period from 1993-2003, the ratio is reversed with thermal expansion accounting for 60% of the rise. These data may indicate why coastal erosion seems to have reached crisis levels along many of the world's shorelines over the last two decades. Even communities that have been around for a while, like Happisburgh in England, are seeing dramatic losses in land and property.

Clearly, sea level has been rising at an accelerating rate through the 20th century and into the 21st. The real trick, of course, is projecting such observations into the future with some accuracy.

Predicting Sea Level Rise

The United Nations Intergovernmental Panel on Climate Change (the IPCC) produced their fourth assessment (the AR4 report) on global change in 2007. It is one of the most important documents of our time, and for their work in developing the report the scientists that produced it received the 2007 Nobel Peace Prize. The report was published in three volumes: 1) The Physical Science Basis; 2) Impacts, Adaptation and Vulnerability; and 3) Mitigation of Climate Change. Much of the predictive modeling of sea level rise is reported in Volume 1.

The reports are thick, dense in exposition, and without indexes. A real effort is required to understand and interpret them. Even the brief summary document the IPCC produced for policymakers and non-scientists is complex. Probably what makes the reports difficult is that the writing is done or approved by a wide array of scientists with their characteristic reserve, reticence, and insistence on highly qualified statements.

The following conclusions concerning sea level rise are paraphrased from the Summary of AR4 for Policymakers.

I. The level of the sea will rise between 7 to 23 inches by the end of the 21st century mostly due to ocean warming and consequent expansion of its waters plus melting of mountain glaciers.. Thermal expansion of the oceans will continue for many

centuries, even after greenhouse gasses are stabilized (i.e., reach a peak and begin to go down). Sea level will rise 0.2 to 0.6m due to thermal expansion per degree Celsius of global average warming

II. An additional amount of sea level rise will result from "melting ice sheets, glaciers and ice caps" of the Greenland and the West Antarctic Ice Sheets. Recent field observations have indicated that the contribution to sea level rise from both of these ice sheets may be much larger than previously assumed. Most likely such melting will produce a rise in sea level larger than that due to ocean expansion. "Rapid sea level rise on a century scale cannot be excluded."

Fuzzy and complicated wording of IPCC documents has created large misunderstandings and created much fodder for global warming opponents. The media now widely accept that the predicted sea level rise will be between 7 and 23 inches by century's end, but as just noted, this range doesn't include critical, perhaps catastrophic increases due to ice sheet melting.

Another widespread but flawed interpretation is that the 2007 report predicts a lower maximum sea level rise than the previous, 2001 IPCC report did—down from 88cm to 59 cm. This is misleading. The earlier, higher estimate includes the expected contribution from the melting of Greenland ice but the 59 cm maximum of the 2007 report does not, thus making the comparison one of apples and oranges.

These confusions are a result of the IPCC's decision for its 4th report to provide actual predictions for only some of the causes of sea level rise (those that they could predict with mathematical models). They produced predictions based on sea-level rise from thermal expansion and land ice melting while refusing to assign numbers to what is likely to be the most important source of sea level rise in the 21st century: ice sheet melting. They said, in essence, that too little was understood for a mathematical model to be constructed on which to base even a rough number.

In the absence of sufficient guidance from the IPCC regarding ice sheet contributions to sea level rise, a number of national, state and local organizations in the United States and elsewhere have begun to make their own predictions. One of these is the Science and Technology committee of Florida's Miami-Dade County Climate Change Task Force. They argue in their January 2008 report that the *minimal* figures for sea level rise over the course of the 21st century are as follows:

Thermal Expansion of ocean water	30 cm
Mountain Glaciers	10 to 25 cm
Greenland ice sheet melting	48 to 84 cm
Antarctica ice sheet melting	10 to 15 cm
Minimal total	98 to 151 cm (3.3 to 5 ft)

Rhode Island's Coastal Resource Management Council independently came up with the same numbers as the Miami committee— a minimal rise of 3 to 5 feet by the year 2100. The UK Climate Change Impacts Program suggests that a minimum sea level rise of a little less than 3 feet should be expected or at least assumed by 2080 and an 8-foot rise should be considered a possible extreme. In a 2008 paper in the journal *Science*,

Tad Pfeffer, University of Colorado scientist and 8 colleagues argue that sea level rise could range from slightly less than 3 feet to a maximum of 6.5 feet by 2100.

In a 2007 *Science* article Stefan Rahmstorf and 6 colleagues compared past IPCC model projections with actual sea level rise both from tide gauges and satellite measurements from 1990 to 2006. When they took the difference between predicted and actual sea level rise during that period, they projected that the actual sea level rise between 1990 and 2100 will likely be higher than the IPCC estimated. Their calculations suggested that sea levels in 2100 could be 0.5 to 1.4 m above 1990 levels.

Recommendations for the North Carolina Coast

Responding to rising sea level may be the greatest challenge that the State of North Carolina will face in this century. North Carolina's coastal communities will be on the frontline of the battle against global warming. An increase in ocean level will cause a dramatic increase in the rate of shoreline erosion, an increase in storm impacts (especially if storm frequency and intensity also grows), an increase in coastal flooding, salinization of coastal aquifers, and the backing up of storm drains in coastal cities.

Our response to these changes will be driven by many factors including politics, fiscal realities, and events (large storms). The surest approach to providing the best long-term management of our coastal economies during this transition will be wise, science-based planning at the state level. A detailed economic analysis of the potential impacts is beyond the scope of this report, but we make the following recommendations based on the discussion above.

- 1) North Carolina coastal managers should assume a minimum sea level rise of 1 m for the next century. This is not to say that we are predicting a sea level rise of 1 m. Obviously, prediction is still difficult and the upper limit on the rate of rise will depend largely on the behavior of the great ice sheets that do not figure into the IPCC estimate. We are suggesting that a minimum 1 m rise be used as a conservative estimate for long-term planning purposes and the siting of major infrastructure.
- 2) North Carolina has long-standing prohibitions against the use of coastal hard structures (seawalls, groins, and jetties) for the protection of private property. As coastal erosion continues, and worsens, there will be tremendous political pressures to rescind these bans. To do so would signal the demise of North Carolina's recreational beaches. The state should look to other alternatives for preserving coastal economies including beach nourishment and relocation of infrastructure.
- 3) Relocation of property and infrastructure away from eroding shorelines and high hazard areas should become the official state policy. North Carolina has a relatively low density of oceanfront development compared to states like Florida. Relocation of property is a viable (if not popular) alternative to the building of seawalls. Holding the line against coastal erosion will become increasingly difficult and costly as sea level rise accelerates. There is understandable concern within local coastal communities regarding the loss of tax base if oceanfront homes are moved or if oceanfront lots are lost. Yet, few, if any, studies have been conducted examining the potential benefits of relocating critical infrastructure away from an eroding shoreline. The benefits may outweigh the losses in many cases. These

- benefits can include: substantial savings for taxpayers, preservation of the recreational beach (the main economic resource for many tourist towns), an increase in the value of remaining properties, reduced future risk from storm damage and a lighter load for emergency managers. These benefits are rarely considered by local communities in planning for their future. The state should immediately begin a pilot study examining how the footprint of some representative coastal communities might be shifted in a well-planned retreat as the oceanfront becomes threatened. Relocation of some properties could be implemented after severe storms or with financial incentives. Relocation of the Cape Hatteras Lighthouse was a resounding success. The structure is now safe and its protection no longer costs taxpayers money. Beach nourishment, the currently preferred method of fighting coastal erosion, is becoming increasingly expensive. In the future, beaches will need more sand, more frequently. The sand resources are simply not available to fight this battle into the 22nd Century. In light of this, relocation may begin to seem like a more reasonable option.
- 4) Given the inevitability of increasing shoreline retreat, the state should consider a ban on increasing coastal development in vulnerable areas and a ban on any large buildings or non-critical, major infrastructure within the potential impact area. The greater the density of development, the less flexibility coastal managers will have in managing this important resource.

The science tells us that the coast of North Carolina will look different 100 years from now. These changes need not end the coastal economy as we know it. But, preserving our recreational beaches, and the businesses that depend on them will require insightful and long-term planning. Beginning an honest assessment of how we may deal with future sea level rise can help ensure that our coastal communities remain the beautiful, vibrant places that they are today. There is no doubt that change is coming and difficult decisions will need to be made. But, North Carolina has led the nation in progressive coastal management for decades. It is time for us to continue that tradition of forward-looking, science-based management.