

Climate Change and the North Carolina Coast

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One of the greatest challenges currently facing geographic education is developing instructional materials to inform students and communities of the geographical aspects of climate change. One approach is to teach the material as a 'stand alone' subject, or as a subtopic of physical geography or climate science. Such an approach is very effective in providing learners with an understanding of the scientific principles upon which climate change theory is based. However, too often, such efforts fall short of providing a local context for the impacts of global climate change (Bizikova et al., 2007; IPCC 2007; Shaw et al., 2009).

An effective and promising approach is to include climate change as a component of instruction about local landscape development or evolution. Geography programs frequently provide such material and instruction in many regional, historical and global change geography courses. Further, the academic discipline of geography has a rich history of advancing the concept of landscapes and landscape change. In North Carolina, perhaps the most pressing climate related planning issue (and thus one of the greatest education opportunities!) is the impact of sea level rise on coastal communities. Those communities face the dilemma of mitigating or adapting to sea level rise in order to avoid loss of property, habitat, and infrastructure. But how does one mitigate or adapt to a global scale prediction at a local level? Perhaps the best answer is to realize that we in North Carolina are already adapting to and mitigating risk in a highly variable system of perpetual coastal change. Ongoing efforts need to address a

future with great coastal transition induced by climate change.

Accordingly, this lesson plan provides three sections: a review of North Carolina coastal change; a review of climate change predictions and how they may impact the North Carolina coast; and exercises to engage students through problem or resource based learning. Instructors may want to incorporate the first two sections into lectures or readings, and then use the exercises in laboratory periods or as out of class assignments.

Review: Processes of Coastal Change in North Carolina

Residents of North Carolina, and other coastal regions, must remember that climate change induced sea level rise is just the latest layer of change to an already dynamic and variable coast. The coastal landscape has always represented a dynamic zone in which land and sea meet, and energy and matter are exchanged. Whether it is across the diurnal tidal cycle, seasonal storms cycles, or decades of human development, the North Carolina coast undergoes constant change. Water flows in all directions, beaches lengthen and shorten, dunes migrate back and forth, and land cover is in constant transition. Consequently, the issue of climate change and sea level rise are just two more variables that increase the dynamism of perpetual coastal change.

Valiela (2006) offers an excellent summary of eight global coastal change processes. The author is quick to point out that coastal change is driven by increases in human coastal populations and their

consequent increased use of coastal resources. Global population is increasing and many of those people live or are moving to coastal areas. In 1990, about 23% of the human population lived within 100km of the coast (Nicholls and Small, 2002). In North Carolina, the coastal counties of New Hanover and Brunswick have grown from populations of 103,471 and 35,777 in 1980, to populations of 192,538 and 103,160 in 2008 (USCB, 2010). Further, Frankenberg (1995) found the assessed value of Outer Banks real estate in Dare County increased from \$6 million to \$3.5 billion from 1950 to 1993.

The eight pathways of global coastal change outlined by Valierla (2006) include atmospheric-driven changes, sea level rise, alteration of freshwater discharges, alteration of sediment transport, loss of coastal habitats, introduction of exotic species, harvest of finfish and shellfish, and eutrophication. All of these types of coastal change can be found along the North Carolina coast but several types are particularly salient to the discussion of future climate change driven sea level rise. Since the majority of North Carolina's coast is comprised of barrier island complexes, it is important to understand the causes of variability in these dynamic coastal systems. Leatherman (1988) identifies the rate of sea level rise, sand supply, sea energy, and human intervention as the primary causes of coastal change in barrier island systems. Those causes correspond to Valierla's (2006) atmospheric-driven changes (sea level rise and sea power), alteration of sediment transport (sand supply), and loss of coastal habitats (human intervention) and must be discussed within the local context of the North Carolina coast.

In North Carolina, barrier island complexes dominate the coast. Barrier islands typically take the form of a series or complex of elongated (longer than wide) islands separated from each other by tidal inlets. The islands are separated from the mainland by a lagoonal body of water which itself can be a few hundred meters to 100s of km wide (the most well known in North Carolina being the Pamlico Sound) and have wind-blown dunes

and vegetation on the seaward side of the island. In these systems, atmospheric-driven coastal change and alteration of sediment transport are closely linked.

Atmospheric driven coastal change occurs across a broad array of scales. From daily shift in wind patterns, to 5-6 year El Nino Southern Oscillation patterns, to the occurrence of glacial and interglacial periods, the atmosphere can cause an increase or decrease in wave heights or water levels which represent the amount of energy transferred to a coast from the sea, causing erosion and other coastal alterations.

One of the most frequent, episodic atmospheric-driven coastal changes is the impact of storm surge upon a coast. Storm surge represents higher than normal high tide sea levels created by tropical and non-tropical storms. The higher than normal high tide sea levels and high wave heights are created by onshore winds which push water towards the shore. Such storm surge causes massive sediment transport as it moves across a barrier island and then back to the sea, loss of habitat due to deposition of sediment on a coast, and widespread damage to natural and man-made structures and objects. The end result can be wholesale change to a coastal area initiated by a single, relatively short event.

The transport of sand from the ocean across a barrier island is known as overwash. As overwash occurs, sediment is transported to the landward side of the barrier island, burying backbarrier environments or damaging and removing structures. The process is evident along the barrier islands of North Carolina in that relic and recent washover fans can be seen extending from a beach onto the backbarrier marsh. New overwash fans are easily identifiable after a storm; fresh sand deposited in a fan shape on top of marsh along with overwash debris and no vegetation growing through the sand. However, overtime the overwash fans become harder to identify as new marsh and vegetation re-colonizes the storm deposited sediment.

The constant overwash of sediment on barrier islands by storms causes a net transport

of sediment from the front of the barrier island to the back of the barrier island. If such overwash transport continues without sediment being supplied in the opposite direction from the land (in the form of fluvial deposits or tidal transport of sediment on the back side lagoon or bay), the entire barrier island complex will retreat, or transgress landward. If supply of sediment from a fluvial or lagoon system is greater than the overwash transport of sediment the barrier island complex will move seaward, or prograde. If transport of sediment by overwash and fluvial/lagoon systems is equal or the same magnitude, the system reaches equilibrium and the barrier island complex is stable, remaining in the same position relative to land and sea (Leatherman 1988).

Long-term changes in the atmosphere, or climate change, can have a large influence on whether barrier island complexes are stable, transgressive, or prograding. In a period of climate warming, glaciers melt and sea water expands, causing sea level to rise. With a rise in sea level, river valleys become flooded and sediment is trapped in these flooded valleys or estuaries, preventing the deposit of sediment on the back of barrier islands and progradation. Thus, during a period of sea level rise induced by a warm climate, barrier island complexes must retreat landward to maintain a constant elevation above mean sea level, or disappear under the sea. Such a retreat of barrier island complexes is currently occurring along North Carolina due to the current rise in sea level created by a warming climate. Evidence of this retreat is seen in several locations where peat and relic trees, established on backbarrier marshes before retreat, are currently exposed along a beach face. In addition, many manmade structures which were originally built back, away from the shore are currently positioned along the shore and in some instances are swallowed by the sea as the barrier island complex retreats (Figure 1).

Beyond the movement of sediment landward or seaward as barrier island complexes transgress or prograde, currents and tides also constantly move sediment along

and among the barrier islands, forming and reforming the islands, and carving and filling inlets. Frankenberg (1995) reports 18 historic and 3 current inlets along the Outer Banks the past 400 years. The result is that barrier islands complexes in North Carolina are dynamic features whose form is constantly changing. Residential development is vulnerable to flood damage, sand burial, coastal erosion or truncation or submergence due to inlet re-establishment (Figure 1).

In response to such vulnerability many coastal North Carolina communities have instituted programs of beach protection and shoreline stabilization. Those programs take many forms but most common are the building of jetties or groins to reduce erosion or stabilize inlets, beach renourishment that adds sediment to beaches to compensate for erosion, or the movement of structures away from the beach (Figure 2). In a few cases, the armoring of shorelines with objects such as boulder rip-rap or sand tubes is permitted (Figure 3).

Ultimately the projects alter the supply of sand or sediment to the barrier island complex. The alteration may be successful in regard to its intent, protecting a beach or stabilizing a shoreline, however, they also impact other areas of the barrier island complex by decreasing or increasing sediment transport. Because barrier island sediment transport systems are so complex, it can be very difficult to predict the end result of a protection or stabilization project. Projects usually create mixed results; protection of one area and erosion of another, the result being coastal change caused by humans imprinted upon an already high degree of natural variability or coastal change.

Beyond alteration of sediment transport, human settlement and development of barrier islands along the North Carolina coast results in loss of coastal habitats. Typically the habitat loss takes two forms. The first is the loss of barrier marshes as they are infilled with sediment to create a stable surface for construction. This construction may take the

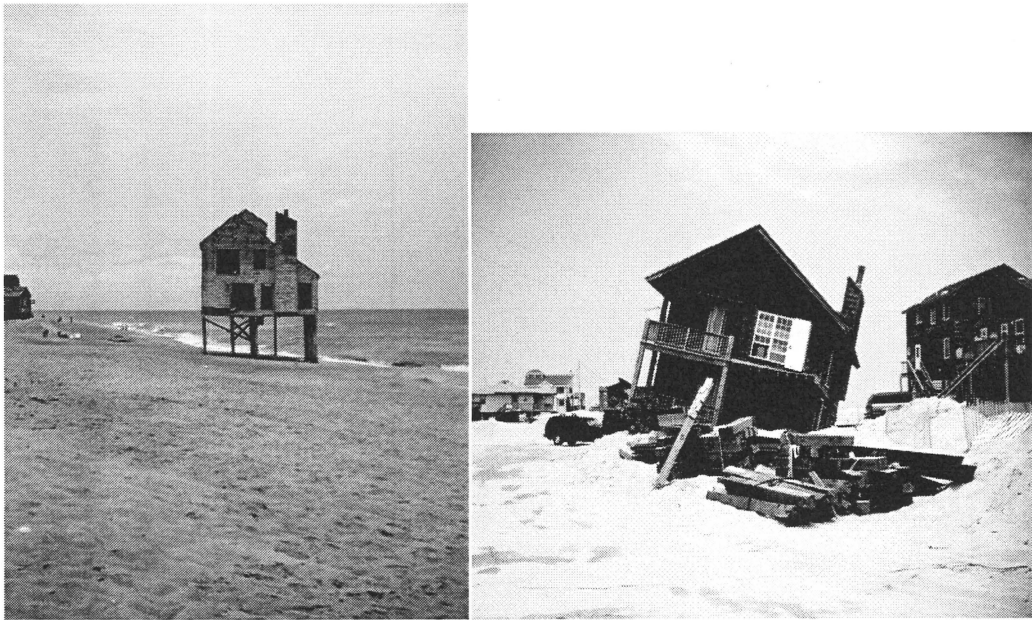


Figure 1. Left: Summer 2004. An abandoned house located in the swash zone behind the Chicamacomico Lifesaving Station. The house was originally built back from the beach, but erosion and island retreat have caused the swash zone to overtake it. The next summer, only the houses pylons remained. Right: House damaged by storm surge from Hurricane Isabel, Rodanthe, North Carolina (Photos: D.W. Gamble).



Figure 2. The movement of a house away from the ocean side of a barrier island to protect it from erosion and storm surge damage, Nags Head, North Carolina.



Figure 3. Left: Groin used to protect the Cape Hatteras Lighthouse before it was moved. Such hard structures are usually only permitted in North Carolina to preserve sites of historical significance or navigational importance. Right: Sand bags or tubes used to protect a house in Rodanthe, North Carolina. Soft structures are occasionally permitted to protect residential property (Photos: D.W. Gamble).

form of residences, commercial districts, or right of way for bridges and roads. Secondly, as ocean front residences and businesses are built, fore dunes at the back of the beach are usually lost and unable to reestablish in front of the newly built structures.

Wrightsville Beach, offers an excellent example of habitat loss to development. The settlement first consisted of a barrier island reachable by trolley on a bridge across backbarrier marshes. Then in 1925, in response to increased use of automobiles and desire for residency on the coast, the salt marsh landward of the beach, called Harbor Island, was infilled to allow for construction of residences and a road network. In 1965, Moores Inlet was infilled, connecting Wrightsville Beach and Shell Island, also allowing for development of nearby marshes. The result is a complete transformation of the local barrier island and its habitats over the past 90+ years (Figure 4).

Review: Future Climate Change and the North Carolina Coast

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) indicates global warming (a positive linear increase in mean global temperature) of 0.74°C since 1906 (IPCC, 2007). Further, 11 of the last 12 years in the instrumental record of global surface temperatures (since 1850) rank among the 12 warmest years on record, and the linear warming trend over the last 50 years is nearly twice that of the last 100 years. In short, global warming is unequivocal and warming is expected at 0.6 to 4.0°C over the next 100 years. Warming air causes ocean water to warm and expand, which in turn causes sea level to rise. Current IPCC predictions of sea level rise range from the current rate of approximately 18 cm/century to 60 cm/century by 2100. However, these predictions do not include the effects of

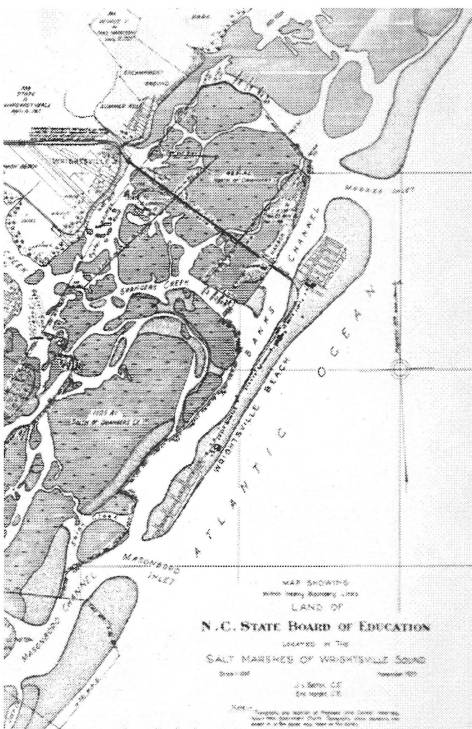
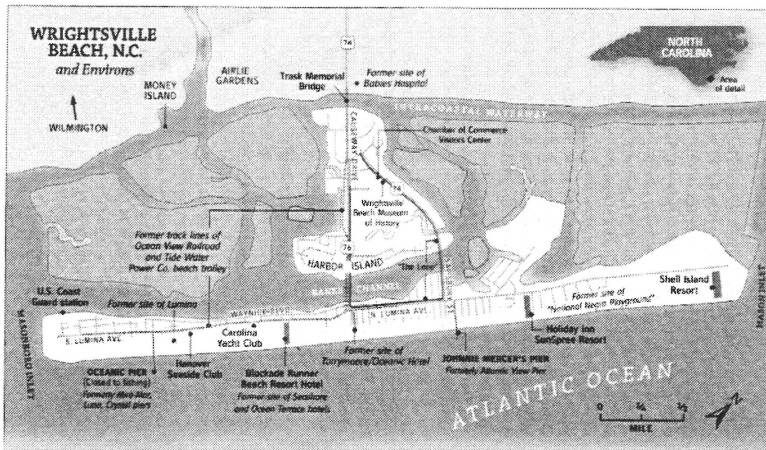


Figure 4. Changing coastal features at Wrightsville Beach, North Carolina, 2007 (top) and 1923 (bottom). Notice the loss of marsh habitat. In 1923, Harbor Island was almost all marsh as well as the area landward of Moores inlet. Harbor Island was expanded for residential property by infill of the marsh in 1925. In 1965, Moores Inlet was infilled connecting Wrightsville Beach and Shell Island, allowing for development of nearby marshes. (Map Sources: 1923 Map – North Carolina State Board of Education. 2007 Map: McAllister, R. 2007. *Wrightsville Beach: The Luminous Island*. Winton-Salem, NC: John F. Blair Publisher, pp. 243).

accelerated continental ice sheet melting and ice loss to the oceans.

The greatest shortcomings of the IPCC report and of climate change science in general, are that findings are based upon global and continental-scale climate models. Given the poor spatial resolution and limited data available for climate models, it is very difficult to precisely downscale global projections to a local or regional scale. Consequently, the confidence in local or regional impacts of climate change is much lower than on the global scale and there is less certainty as to potential outcomes of climate change for a specific location.

However, predictions for coastal North Carolina can still be provided in the descriptive form as opposed to a precise numeric prediction, providing important and relevant information that allow residents and governments of North Carolina to prepare for future impacts of climate change. Of particular concern to North Carolina is the IPCC's AR4 report of very high confidence that "coastal communities and habitats [in North America] will be increasingly stressed by climate change impacts interacting with development and pollution" (Field et al., 2007: 619). In other words, the rise in sea level along the coast (and the rate of change will increase in the future) will be exacerbated by the impacts of progressive inundation, storm-surge flooding, and shoreline erosion, a more than feasible result given previous discussion of coastal processes in North Carolina.

Recent geological investigations of historic relative sea level rise in North America (e.g., Maine and Connecticut) have identified accelerated rates beginning in the late 1800's and early 1900's. Kemp et al. (2008) investigate the rate of relative sea level rise in North Carolina based on foraminifera preserved in salt-marsh sediments on Roanoke Island, North Carolina. They suggest that in North Carolina the onset of rapid relative sea level rise began earlier (at the beginning of the 1800's) and has featured two distinct accelerations: an increase at the start of the 1800's from 8.0 $\pm$ 0.4 cm/century to 15

cm/century ($\pm$ 1.6 cm/century) and a second acceleration around 1900 to 43 cm/century. This rate has been reconciled with the available tide gauge record data. Local rates of relative sea level rise for the North Carolina coast are highest along the northeast coastline and less in the Cape Fear region due to small variations in land elevation changes along the North Carolina coast. In the northern region of the state, rates of sea level rise are up to 40 cm per century, decreasing somewhat to 32 cm per century in the southern coastal region. Consequently, sea level rise projections like those offered for coastal North Carolina (13-50 cm over the next 100 years) are well within what is possible when we add in the glacial movement source.

Further, storm surge flooding can combine with progressive inundation created by sea level rise to flood and damage coastal communities. Hurricanes are one of the most significant contributors to storm surge. The impact of global warming on hurricanes is a controversial topic (Pielke et al. 2005; Trenberth and Shea 2006, Landsea 2005, and Pielke 2005), but there is increasing agreement within the scientific community of the likelihood that greenhouse warming will cause hurricanes in the coming century to be more intense on average and have higher rainfall rates than present-day hurricanes. Pielke et al (2005) have discussed the distinction between event risk, vulnerability and outcome risk. Event risk is the probability of a particular event occurring. Vulnerability is the impact that event could have if it occurred. Outcome risk is the combination of event risk and vulnerability and can be used to characterize the need for preparation for such an event. So, even if the link between increased hurricane intensity is not clear at this point, the potential impact of such an increase is quite large and North Carolina should be preparing for it. The combination of storm events and sea level rise may cause storm surges along the mid-Atlantic coast to exceed 100 yr coastal floods 3 or 4 times more frequently by the end of the 21st century (Najjar et al., 2000).

Of equal importance is determining the physical response of the coastline to sea-level rise and increases in storm surge. Prediction of shoreline retreat and land loss rates is critical to future coastal zone management strategies, and assessing biological impacts. The average slope of the lower coastal plain of North Carolina is of the order of 1:2000 which indicates that the potential for sea level rise induced shoreline erosion is high. Over 5000 km² of land are below 1-m elevation (relative to NAVD 88) and rates of sea level rise in this region are approximately double the global average due to local isostatic subsidence (Douglas and Peltier 2002).

Currently, barrier island thinning, caused by erosion on both the ocean and sound sides, is a global phenomenon on coastal plain barrier islands. This includes most of the barrier islands in North Carolina that are not stabilized in one fashion or another. Most likely this is a response to sea level rise and is the means by which the islands prepare themselves for sea level rise. While current distribution of barrier islands and lagoons along the North Carolina coast are in part a function on rising sea level, specific barrier islands dynamics (i.e. patterns of migration, erosion, deposition, storms) are typically dominated by local factors such as shore orientation, longshore current patterns, and sediment supply. As such, the response of these systems to rising sea level should be considered on local scales and all islands will not likely respond in identical fashions. Inlets and their associated shoals, particularly the ebb deltas will play significant roles in how the barriers will respond to changes in the adjacent estuaries. As sea level rises the tidal prism will increase and in turn so will the nature of the inlets and their influence on the adjacent oceanfront shorelines. This is particularly true for the shorter barriers such as Sunset Beach and Huttuff Island. The spatial and temporal changes will vary along the coast- some barriers will respond very quickly while others will lag behind.

In conclusion, based upon the most recent scientific literature sea level rise is occurring now, and sea level will continue to rise with a

high degree of certainty, along with associated risks. Given recent increase in population along the North Carolina coast, high vulnerability exists to coastal hazards associated with climate change. Further, there is a high degree of scientific certainty that increases in storm and hurricane intensity will occur. However, changes in hurricane frequency cannot be confidently predicted at present. More intense storms generate larger and more powerful ocean waves. The combination of sea level rise and more powerful waves can exacerbate coastal erosion damage risks.

Exercises

In this section, three exercises are provided to be used in conjunction with the background material to engage students and facilitate learning about climate change and the North Carolina coast. Specifically, the exercises are designed to involve students in an activity that promotes deep learning through participation, discussion, and reflection (Agnew & Elton, 1998). As students move from passive learning (typical lecture format of listening and taking notes) to active learning students move beyond receiving knowledge to exploring existing knowledge, and eventually creating their own knowledge (Gold *et al.*, 1991). Specifically, the exercises attempt to utilize resource-based learning schemes where the emphasis is on the use by students of print and electronic based learning resources to solve a problem (Healey, 1998). In such an approach, as opposed to content mastering, the purpose of the exercise is clear, but the methodology and specific learning outcomes for each student are variable, depending on a student's previous knowledge and developed skills.

Exercise 1: Search the online *Charlotte Observer* archives, online *Raleigh News and Observer* archives, and Google Images for the phrase 'Isabel Inlet Outer Banks'. Use the information found in this search to answer the following questions:

What was the Isabel Inlet?

How is the Isabel Inlet related to the dynamic physical systems of barrier islands?

How may future climate change impact phenomenon like the Isabel Inlet?

Exercise 2: Read the article: Martin, W.E. 1993. Storm hazard zones along the Outer Banks of North Carolina, *The North Carolina Geographer* 2 (Summer): 1-11. Compare the results of research to current 1:24000 topographic quads for the Outer Banks or recent aerial photos of the Outer Banks. Based upon this comparison and your knowledge of potential sea level rise, specifically outline locations and structures that may be impacted most by climate change.

Exercise 3: Figure 5 is a copy of a real estate flyer for a property in Rodanthe, North Carolina. What may the phrase "This one won't last" mean to the following people:

Real estate agent

Coastal resource manager

Visiting tourist.

Assessment of these resource based learning exercises is a bit more challenging than typical content mastery exercises. Broad latitude should be given to students for finding a creative and unique solution to the exercises, and quite honestly there is not one definitive answer for each exercise. Consequently, guiding principles as opposed to rigid rubrics should be developed to assess the exercises and these principles should be aligned to course objectives. For example, for exercise 1, guiding principles for assessment can be: a) student displays ability to use search engines to effectively gather information to answer the questions, b) the student can clearly define Isabel Inlet, and c) the student explains in a logical fashion the potential impact of climate change on storm surge inlets. Each student can then be marked as above expectation, meets expectation, or performs below expectation for each principle. Such principles and grading standards should be developed for each exercise by each instructor in order to align with course objectives and student learning outcomes.



This one won't last
SANDSCAPE
\$299,000

- 4 Bedrooms
- 2 Bathrooms
- Heated Living Area: 1230 sq. ft.
- Furnishings Convey
- Screened Porch
- Sun Deck
- Outside Shower
- Great Location!!!
- MLS 49599

OCEAN FRONT

Figure 6. A real estate advertisement for a property located in Rodanthe, North Carolina.

References

- Agnew, C. and Elton, 1998. Lecturing in geography. Cheltenham, UK: Geography Discipline Network.
- Bizikova, L., Robinson, J., Cohenv, S., 2007. Linking climate change and sustainable development at the local level. *Climate Policy* 7, 271–277.
- Douglas, B. C., and W. R. Peltier, 2002. The puzzle of global sea level rise. *Physics Today* 55:35–40.
- Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, and M.J. Scott, 2007. North America. *Climate Change 2007: Impacts, Adaption and Vulnerability*.
- Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 617–652.

- Frankenberg, Dirk**, 1995. The nature of the Outer Banks. Chapel Hill, NC: The University of Chapel Hill Press.
- Gold, J.R., A. Jenkins, R. Lee, J. Monk, J. Riley, I. Shepard, and D. Unwin**, 1991. Teaching geography in higher education: A manual of good practice. Oxford: Blackwell.
- Healey, M.**, 1998. Resource-based Learning in geography. Cheltenham, UK: Geography Discipline Network.
- IPCC**, 2007. Climate Change 2007: The Physical Basis. *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, IPCC Geneva, <http://www.ipcc.ch/>, <http://www.ipcc.ch/>, Geneva.
- Kemp, A., B. Horton, S. Culver, R. Corbett, O. Van de Plassche and R. Edwards**, 2008. Early Onset of Accelerated Relative Sea Level Rise in North Carolina, USA. Abstracts: Geological Society of America Annual Meeting.
- Landsea, C.W.** 2005. Hurricanes and global warming. *Nature*. 438:E11.
- Leatherman, S.** 1988. Barrier Island Handbook. College Park, MD: Laboratory for Coastal Research, The University of Maryland.
- Najjar, R.G.**, H.A. Walker, P. J. Anderson, E.J. Barron, R.J. Bord, J.R. Gibson, V.S. Kennedy, J.P. Megonigal, R.E. O'Connor, C.D. Polsky, N. P. Psuty, B.A. Richards, L.G. Sorenson, E.M. Steele, R.S. Swanson, 2000. The potential impacts of climate change on the mid-Atlantic coastal region, *Climate Research* 14:219-233.
- Nicholls, R.J., and C. Small**, 2002. Improved estimates of coastal population and exposure to hazards released. *Eos* 83:301, 305.
- Pielke, R.A., Jr.** 2005. Are there trends in hurricane destruction? *Nature*. 438:E11.
- Pielke, R.A., Jr.**, C. Landsea, M. Mayfield, J. Laver and R. Pasch. 2005. Hurricanes and Global Warming. *Bulletin of the American Meteorological Society*. 1571-1575
- Shaw, A., S. Sheppard, S. Burch, D. Flanders, A. Wiek, J. Carmichael, J. Robinson, and S. Cohen**, 2009. Making local futures tangible – Synthesizing, downscaling and visualizing climate change scenarios for participatory capacity building. *Global Environmental Change* 19: 447-463.
- Trenberth, K.E., and D.J. Shea**. 2006. Atlantic hurricanes and natural variability in 2005. *Geophysical Research Letters*. 33: L12704, doi:10.1029/2006GL026894.
- United States Census Bureau**, 2010. Population estimates. (<http://www.census.gov/popest/estimates.html>).
- Valiela, Ivan**, 2006. Global coastal change. Malcen, MA: Blackwell Publishing.