Climate Change and the Nature Coast: Anticipating and Adapting to Future Impacts

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Forum Leader: Don Wright, NCUU Member
e-mail: donwright171@yahoo.com

Abstract

Because of climate change, sea level rise, altered river discharge, changes in the intensity and size of storms and changing demographics, coastal systems and communities of the future are seriously imperiled. Florida's Gulf coast is among the world's most vulnerable coasts and the Nature Coast and Tampa Bay are especially at risk. Understandings of climate change and its increasingly deleterious impacts are based on a huge and highly credible body of scientific evidence.

Introduction

Most of the world now realizes that climate change is very real and is posing a crisis that must be addressed soon. The young activist Greta Thunberg is obsessed by the grim plight of future generations for good reason. Beyond concerns for wildlife and nature, the need for the world to become more aware of climate change and its tightly interwoven aspects of poverty, immigration, racism, famine and human health is urgent. Today, the threats to humanity presented by global climate change are orders of magnitude worse than at any time in our history. The impending pressures on the borders of the US and other affluent countries by climate change refugees will be unprecedented according to Todd Miller in his recent book "*Storming the Wall: Climate Change, Migration and Homeland Security".* Worldwide, tens of millions of people are in jeopardy of becoming climate change refugees within a decade. Non-whites and the poor are most vulnerable. Denial of climate change by the public and politicians will only exacerbate, not eliminate, the threats. Everyone must realize that climate change is not a hoax. Low elevation coastal environments and coastal communities are the most vulnerable and the Florida Gulf Coast is among the most threatened.

The Reality of Climate Change

The sources of information on climate change are impeccable. Scientific reports on climate change have undergone tens of thousands of rigorous scientific peer reviews. The University Corporation for Atmospheric Research and the National Center for Atmospheric Research, The United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) along with the NOAA Climate Prediction Center are among the numerous sources of data and model results on which global change projections are based. The *Intergovernmental Panel on Climate Change* (IPCC) is a definitive source of current scientific consensus on the causes and consequences of global change. Their sixth report, published in 2022, presents exhaustive and conclusive evidence that air temperatures at the earth's surface as

well as sea temperatures are rising leading to a host of other climate and ocean changes. The report expresses 93% confidence that warming is the result of emissions of greenhouse gases from fossil fuels. Part 1 of the IPCC report is authored by 234 scientists from 66 nations and is underpinned by more than 14,000 peer reviewed scientific publications. It details the physical causes of climate change and concludes that: ***"It is unequivocal that human influence has warmed the atmosphere, ocean, and land."***

Some Impacts of Climate Change

Part 2 of the Sixth IPCC report focuses on the anticipated impacts of predicted climate changes including draughts, famines, sea level rises, increased storminess, human health impacts, ecosystem degradation, and economic impacts. The latest draft report by the US Global Change Research Program, just released for review about two weeks ago, concludes that the severity and risks of coastal hazards are increasing rapidly. Florida's west coast, like all low elevation coastal zones and including the Nature Coast, is particularly vulnerable to flooding by high storm surges. Computer projections indicate that a landfalling Category 3 hurricane could cause severe flooding to reach more than 5 miles inland from the present shoreline. Vulnerable Nature Coast communities include Crystal River, Homosassa, Yankeetown, Inglis and Cedar Key. Progressive rises in sea level are gradually extending the vulnerable zones eastward.

Here is a brief summary of what the future global changes include:

Atmospheric warming- Global temperatures have risen 1°C as greenhouse gases have trapped ever more heat from solar radiation. By the end of the century, the globally averaged temperature increase is expected to be somewhere between 1.8° and 4.0° Celsius (3.2° and 7.2° F). Most of the warming will be concentrated in the higher latitude and polar regions rather than in the tropics. The Arctic is warming more than twice as fast as the rest of the world.

Ocean warming- Of the global warming that has taken place over the past two decades or so, roughly 93% of the heat is currently estimated to be stored within the upper kilometer or so of the ocean. Ocean temperatures are expected to continue to rise significantly.

Storm intensity- Tropical storm intensity is increasing, largely because of increased sea surface temperatures. The rapid intensification of many recent storms and the record number of hurricanes in 2020 and Hurricane Ian in 2022 have been attributed to unusually warm sea surface temperatures.

Evaporation and precipitation- Rising temperatures are increasing the rates of evaporation, which are countered by increases in precipitation. As a consequence, draughts and floods are both increasing.

Ice melting- Melting of glacial ice in Alaska, Greenland and Antarctica, along with the melt of permafrost are already taking place and expected to accelerate. The Arctic is warming nearly 3 times faster than elsewhere on earth.

Global Sea level –is rising and will continue to do so throughout the 21st century. Sea level is expected to be significantly higher than today by the end of the century. The latest study by the US Global Change Research Program shows that sea levels by 2050 could be 1.5 to 2.0 feet higher than today.

Altered ocean circulation- Major, large scale ocean current systems, such as the Gulf Stream, are *slowing down.* Reduction of Gulf Stream transport causes sea level to rise along the US east coast.

Global Warming is Very Real

Very briefly, I would like to clear up two misunderstandings about global warming and change that are commonly used as rationales for denying climate change. The first is that climate changes have always been going on. That is true. The cooling period that set off the last major Pleistocene glaciation began about 100,000 years and ended about 20,000 years ago after which the earth slowly warmed, and the ice melted. This period was completed about 7,000 years ago. During the time of maximum glaciation sea level was about 450 feet lower than today and by 7,000 years ago it had risen to near its present level. So, warming and sea level rise took place over the 13,000-year period of glacial retreat. However, since the beginning of the industrial revolution the average global temperature has risen 10 times faster than it did during the time of glacial melting accompanying a corresponding increase in atmospheric CO_2. Fossil fuels nurtured the most recent warming.

The second excuse for climate change denial is the increasing frequency of frigid polar vortex events like the one we just had during the week of this past Christmas and Hanukkah. NASA produced a global map of earth surface temperature anomalies for December 23 that shows that the extreme cold temperatures experienced by the US were accompanied by excessively warm temperature anomalies over other parts of the world including Europe, the Arctic Ocean and parts of Antarctica. In turns out that because the Arctic region is warming 2 to 3 times faster than other parts of the world, the polar vortex which has normally stayed over the north pole, episodically becomes unstable and is permitted by a weakening jet stream to migrate southward. The rapid Arctic warming is referred to as the Arctic amplification. It does not have an Antarctic counterpart.

Sea Level Rise and Coastal Flooding

Over the past couple of decades, global sea levels have been rising by a little more than 3 mm per year. On the face of it, predicted rises in mean sea level, and even relative sea level might seem fairly modest. However, it must be remembered that on very gently sloping coastal plains, wetlands, or river deltas a few inches of vertical rise can translate into hundreds of feet of horizontal transgression. In addition, saline ground water can reach landward significant distances into aquifers, contaminating the freshwater supplies of coastal communities. Also, saltwater penetration into previously forested environments can cause die back of land-stabilizing vegetation allowing for enhanced susceptibility to coastal erosion. In addition, relatively small changes in depth can alter the degrees of amplification of tides, storm surges and waves, particularly along crenulated coasts and in bays and estuaries. Relative sea level (RSL) varies considerably because of such things as regional subsidence and provides a shifting baseline on which more extreme short-term water level fluctuations are superimposed. When high perigean spring tides (“king” tides), high storm surges and high waves coincide as they sometimes do during tropical storms or hurricanes, a couple of feet of mean sea level, plus or minus, can mean the difference between a low-lying coastal village or neighborhood being

devastated or not. In such cases, it is the waves and surges that do the damage but the mean sea level that carries these forces onto the coast. Numerical models currently predict maximum rises of 2-3 feet between now and mid century depending on the extent to which greenhouse gas emissions are reduced. Recent estimates indicate that, before the end of the century, the homes of at least 9.3 million people and possibly as many as 20 million people in the US are likely to be inundated.

It is not sea level rise but compound floods from combined storm surge and torrential rains that coastal dwellers should fear most. The joint probability of severe storm surge and pluvial flooding coinciding in U.S. coastal cities has increased significantly over the past century. In cases where rivers are nearby, fluvial flooding further exacerbates the severity of inundation. The International Human Dimensions Program on Global Environmental Change points out that by midcentury, the flood risk to large coastal cities will have increased by nine-fold relative to the present day. According to NOAA's Office of Coastal Management, inundation events are the dominant causes of natural-hazard-related deaths in the U.S. and are also the most frequent and costly of the natural hazards affecting the nation.

Vulnerable Communities

Coastal and flood prone communities face increasing hazards, including compound flooding by coinciding or sequential storm surge and torrential rains, and lingering post-event impacts on human health superimposed on progressively rising sea levels. There is a broad consensus that, because of rising sea levels, communities in Low Elevation Coastal Zones (LECZ) are vulnerable now and will be much more vulnerable in future decades. In the US, it is people of color and the poor who are most seriously impacted. Worldwide, the majority of affected residents are poor and underrepresented, resulting in increasing levels of social vulnerability to coastal hazards. In his recent book *Extreme Cities*, scholar Ashley Dawson discusses the growing vulnerability of impoverished people living in coastal cities, particularly coastal megacities, to the impacts of climate change. Dawson points out that worldwide nearly 2 billion people currently live in densely populated, flood prone urban environments that are subject to storm surges and river floods.

Low income and minority residents are the most at risk from these hazards and they are not empowered to adapt. The vulnerability of these populations, now and in the future, depends not only on the environmental threat and the fragility of the people, but also on the investments that local, state and federal governments are willing and able to make in order to protect the most vulnerable. Part 3 of the sixth IPCC Report explains actions that are needed to mitigate impacts. Where feasible, the "preferred" mitigation strategy for residents of low-lying, flood-prone areas is relocation. However, it is understood that this strategy is unrealistic in the majority of cases for various reasons and is in fact impossible for residents of low elevation island nations such as the Maldives and Marshall Islands. For those people, "relocation" means becoming an environmental refugee.

Florida's Nature Coast

Florida is composed mostly of porous limestone, the remains of relict corals. The emergent subaerial land surface of the state of Florida rests on the eastern side of the much larger calcium carbonate Florida Platform, which now constitutes not only the substrate of the state but also provides the surrounding continental shelf. Because the emergent lands are on the platform's eastern margin, the continental shelf off Florida's southeast coast is very narrow while that off the west coast is exceptionally wide. Florida lies directly in the path of tropical cyclonic systems spawned over the warm waters of the tropical Atlantic Ocean, Caribbean Sea and Gulf of Mexico. Many of these storms originate when hot Saharan winds carry "easterly waves" off the west coast of Africa, across the Cape Verde Islands and out over the Atlantic Ocean in late summer or early autumn. The most intense hurricane to affect Florida in the past 30 years was Category-5 Hurricane Andrew which made landfall near Homestead in south Florida in 1992. But Hurricane Ian which made landfall near Ft. Myers in September 2022 was nearly a category 5 and is the storm that is most prominent in the memory of most Floridians today.

Florida's "Nature Coast" covers 4,000 km^2 (1,500 mi^2) and embraces 8 counties on Florida's Gulf Coast but we focus here on Citrus and Levee Counties, which comprise the central part of the region. Much of this area is water, small islands or intertidal wetlands. This diverse region which includes vital seagrass ecosystems for blue crabs and bay scallops and warm spring and river aquatic ecosystems that support species such as the Florida manatee. The Nature Coast is accessible via a coastal road, the north-south trending U. S. Route 19. There are no expensive resorts or high-rise buildings on the Nature Coast. The threats to the Nature Coast cannot be adequately expressed in monetary terms or even in humanitarian terms. So, what is special about this coast? The natural ecosystem is beautiful, diverse and unique in the world- and it is receding and may soon disappear forever.

Unlike the shores of southeast Florida, the Nature Coast is not fringed by sandy beaches, but by brackish marshlands that grade almost imperceptibly into shallow open water bays and, ultimately, the Gulf of Mexico. The extremely wide and shallow shelf fronting this coast dissipates waves (but amplifies storm surges) and this is one of the reasons why there are no beaches. The other reason is that there is no supply of silica sand. From sea to land the coastal environments progress from open water to tidal flats to salt marsh to transitional salt marsh to coastal forest (aka "swamp" or "hammock") yielding an extraordinarily diverse ecosystem in the aggregate. These wetlands have long been undergoing gradual flooding by the recent sea level transgression and are slowly receding eastward, often leaving behind relict shorelines beneath the shallow waters.

Despite the deficiency of sediment, it is the rivers that contribute one of the most unique environmental attributes of the Nature Coast: all are fed by freshwater springs from the Floridan aquifer. The waters issuing from these numerous springs maintain a constant temperature of 22 °C (72° F) year-round and this allows the coastal rivers to support manatees with refuges from the winter waters of the Gulf of Mexico. Manatee watching is the main industry of the city of Crystal River in Citrus County. In addition to the input of freshwater to the coast from rivers, the Floridan aquifer also has numerous subsurface connections with the Gulf and sub-sea springs are common on the inner shelf. In some cases, seawater penetrates upstream within the underground

rivers and when this occurs the water from some wells can become brackish. As sea level rises, the penetration of salt water into the aquifer progressively becomes more problematic.

Of course, by far, the greatest threats to the nature coast come from tropical cyclones which are now becoming larger and more intense because of elevated sea surface temperatures. It is not just the winds that are the threats but more commonly the storm surges that the winds generate. The low gradient continental shelf fronting Florida's entire west coast amplifies storm surges. NOAA's National Hurricane Center uses the SLOSH model to generate maps of worse case scenarios of flooding expressed as *Maximum Envelopes of Water (MEOWs)* and the *Maximum of MEOWS (MOMS).* The next slide shows corresponding MOMS map for the Nature Coast in the event of a hypothetical Category 3 Hurricane. Note that inundation in excess of 9 ft (~3 M) above the level of normally dry ground is predicted to extend as far as 5 miles landward of the present coast. (More Text to come)

Hurricane Ian's Lessons

When Hurricane Ian made landfall on Florida's Gulf coast near Ft. Myers on September 28, 2022, it was the most recent, and one of the five most severe, storms to hit this coast. Ian began as a tropical wave that moved off the coast of West Africa and eventually entered the Caribbean on September 21, 2022. It became a tropical depression on September 23 and a tropical storm the next day. Then within only 24 hours it strengthened from a tropical storm to a major category 3 hurricane before making landfall on western Cuba and then tracking northward to Florida over the warm (88 deg. F) Gulf of Mexico and ultimately making its Florida landfall as a huge category 4 storm, nearly a category 5. Like several other storms that have impacted the U.S. coasts in recent years, the rapid intensification and large size of Ian was almost certainly caused by the higher-than-normal sea surface temperatures. These effects are expected to become more severe over the coming years. There are some serious lessons from Ian that should be remembered. Let's look briefly at some of Ian's behaviors that departed from "traditional" behaviors.

On September 26, 2 days prior to Ian's ultimate landfall, the predicted "cone of uncertainty" for the storm's predicted future path, showed the most likely region of landfall to be in the "Big Bend" near the northern extremity of the Nature Coast and well to the north of Tampa Bay. By the following day, Tuesday, September 27, the cone of the possible track of Ian extended from the Big Bend in the north to Charlotte Harbor in the south with the centerline passing over Tampa Bay where the storm surge was then forecast to potentially exceed 10 feet. However, as the storm crossed the western end of Cuba, the track began a turn to the right and in a more easterly direction. Ian ultimately made landfall well to the south of the Tampa Bay area with the eye passing over Ft. Myers. The counterclockwise circulation caused onshore winds to south of the eye and offshore winds to the north. National Hurricane Center storm surge predictions about 2 hours before landfall were for surge heights south of the eye to exceed 9 feet above ground level as far south as the Everglades. The storm surge caused widespread devastation to the south of the eye but spared the Tampa Bay region and the Nature Coast because the offshore winds suppressed water level by pushing water out of the bay and out to sea along the coast to the north.

I would like to highlight some of the most important lessons that we have learned from Ian and other recent storms. First, storm intensification is becoming more rapid, and several recent storms, including Hurricane Ian, have grown from tropical storms to major hurricanes over periods of one or two days. This considerably shortens the lead times of forecasts and advance preparations. In addition, the storms are increasingly accompanied by torrential rainfall which adds to storm surges to produce compound flooding. To date, however, there is no significant evidence that tropical cyclones are becoming more frequent, just that they develop faster and become larger and stronger than in the past. Hence, the storms that do form are more dangerous. **So, the message here is: don't assume that just because you have safely weathered past hurricanes you can do it again and survive. Please do not plan to "ride out" future storms. Instead, heed evacuation notices even if you don't really believe them. And after the storm has passed, beware of lingering storm waters. They often contain diseases, snakes and alligators.**

The Global Threats

To finish, I would like to point out, with a few case examples, the severe global threats that face much the rest of the world. ***Future changes in climate will alter the natural and built coastal environments and displace millions of people globally. Worldwide, nearly 2 billion people live in densely populated, flood prone environments that are subject to storm surges and river floods. Tens of millions of people are in jeopardy of becoming climate change refugees within a decade.***

-Land Loss and Storm Impacts on the Louisiana Coast

The Louisiana Coastal Protection and Reclamation Authority projects that by 2050 most of Louisiana's wetlands will have been replaced by open water. Residents are increasingly faced with difficult decisions on whether to adapt or relocate. Residents of Isle de Jean Charles, an indigenous community located within Louisiana's bayou region, have already reached a critical tipping point and over 75 percent of the community has been displaced to the town of Houma by land loss. In summer 2020, Hurricane Laura, Hurricane Sally, Tropical Storm Beta and Hurricane Delta caused extensive flooding and serious damages in coastal Louisiana.

The most intense storm of the 20th Century and early 21st Century was Category 5 Hurricane Camille in August 1969, which struck Plaquemines Parish and completely leveled the towns of Venice and Buras. Camille also severely damaged coastal counties of Mississippi and Alabama. The warm waters of the Gulf of Mexico contributed to the intensification of Camille as it progressed northward. Although it was less intense than Camille, Hurricane Katrina caused far more damage, loss of life and general devastation in eastern Louisiana than Camille, primarily because of losses of protective wetlands over the 36-year period separating the two storms. Less than 4 weeks after Katrina, Hurricane Rita made landfall near the Louisiana-Texas state line inflicting damage on the western part of Louisiana's coast.

-The Pearl River Delta, China

The Peoples Republic of China (PRC) is the most threatened East Asian nation in terms of the number of people who may be forced, by sea level rise, to relocate. By 2050 millions of

PRC coastal residents may be displaced. The greatest threat in the PRC is to Guangzhou and the Pearl River Delta. Like Miami, Florida, Guangzhou has been built at an elevation of only about 1 m above sea level. With its many high-rise buildings, it is "very heavy" and it rests on a deltaic surface and is sinking at an average rate of 2.5 mm/year. This subsidence, combined with rising sea level, increased intensity of impact from typhoons and storm surge and projections for increased urban expansion have placed Guangzhou at, or near the top of the list of the world's most threatened coastal cities.

-***The Alaskan Arctic is Warming Quickly***

Most Americans are unaware that rapid warming of the Arctic Ocean and coast is already impacting the unique Arctic ecosystem and Native Alaskan subsistence, health and culture. These assets are tightly bound to, and dependent on, a frozen ocean and frozen permafrost on land. The media tends to emphasize the impact of ice melting on Polar bears. The bears are certainly threatened; but the total environmental and human impacts are of equal concern. Recent studies indicate that near-surface air temperatures in the Arctic are rising 2 to 3 times faster than are temperatures elsewhere on the earth's surface. The most serious and damaging socioeconomic impacts of the unfolding changes will be felt by indigenous Alaskan people. Native Inuit, Athabaskan, Métis, and other indigenous inhabitants of Arctic Alaska have long understood that they have a delicate and complex symbiotic relationship with their natural realm and have depended on this relationship for their subsistence livelihood. Today, decreases in fish stocks and marine mammals are limiting the availability of traditional food sources. Many indigenous Alaskans are likely to become refugees within a decade.

-***The Bay of Bengal Awaits Epic Tragedy***

1.4 billion people occupy the nations of Thailand, Myanmar, Bangladesh and India surrounding the Bay of Bengal and about 200millions of those people live within coastal and river flood zones at elevations less than 10 m or about 30 feet above sea level. The convergence of increases in sea level, tropical storm severity and the growing populations of dreadful urban slums are setting the stage for unprecedented future tragedy. In terms of vulnerability to human tragedy, Bangladesh and India are probably at the opposite extreme from most affluent nations because of the poverty of the people and the general lack of infrastructure and resources. Much of Bangladesh is near or only slightly above sea level. Added to this is the fact that summer monsoons bring torrential rains that cause floods of the Ganges and Brahmaputra Rivers as well as tropical cyclones that generate storm surges. A study conducted in 2007 found that residents with the lowest incomes had the highest level of exposure to floods and concluded that these most vulnerable low-income residents had minimal access to flood preparation and post-flood recovery community assets. The major impacts of Bangladesh floods are death by drowning, water borne disease, severe diarrhea and snakebites; 75% of Bangladesh flood victims drown. Non-fatal impacts in Bangladesh include complete destruction of housing, loss of income, loss of livestock and grain and general loss of food supply. Increases in soil salinity of agricultural lands in the Ganges Brahmaputra Delta are seriously reducing rice production.

Addressing the Complex Problem

The scientific community possesses talent and tools that could not have been imagined fifty years ago. Deployment of those capabilities, along with emissions reductions, could offer salvation. It has long been understood that there are three general categories of actions that must be undertaken soon: (1) reductions of greenhouse gas emissions; (2) implementing regionally specific adaptation strategies; and (3) communicating scientific projections and their potential impacts to the public and policy makers at all levels. So far, the third action has proven to be the most challenging of all. Uncertainties in predictions are used by many policy makers as excuses for complete denial of science. Whether or not our leaders have the will to respond to the expected changes is more uncertain than are the predictions. The future of my grandson, his generation, and subsequent generations depend, critically, on the enlightenment of local, regional, national, and global leaders. Slowing, or halting global warming must be addressed globally by dramatically cutting carbon emissions. Adaptation requires regional collaboration. A prominent example of such collaborative programs is the Tampa Bay Regional Resiliency Action Plan which involves 32 local governments and seven counties spanning the region from Citrus County to Sarasota County. Roughly 4 million people live in this region.

Fortunately, mitigating engineering and management strategies are out there but their acceptance and implementation will require significant changes in priorities, lifestyle and compassion by society as a whole. Concerns for global humanity and nature must supersede the goals of excess wealth and corporate profit. In addition to reducing carbon emissions and enhancing the resilience of threatened communities, we must reinvent our immigration policies to make them more compassionate and capable of addressing global challenges. As Naomi Klein points out in her book *On Fire,* "We can only meet this tremendous challenge together as part of a massive and organized global movement".

Looking forward a few decades, most of the people who will have to adapt to and live with the world of tomorrow have not yet been born and, among those who have, few have so far completed their formal education. It is time to transmit the understandings and values that future generations will need in order to slow climate change and adapt to a changing world. The essential education process should begin with preschoolers and continue through higher education and beyond. Appreciation of natural environments and humanity's dependence and impacts on them should be instilled in children at the earliest possible age and reinforced throughout their lives. For children in their formative years, it is important for parents and educators not to perpetuate the dualistic notion that humanity and nature are distinct and that the former must conquer the latter. Instead, the idea of "*intelligent co-operation with nature"* should be promoted as a human virtue.

Some further reading for those who want to know more about all this.

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Some useful online resources for planning

1. **National Hurricane Center http://www.nhc.noaa.gov**
2. **Climate Risk and Resilience Portal** https://www.anl.gov/ccrds/ClimRR
3. **Risk Factor Pro** https://help.riskfactor.com/hc/en-us/categories/360003790314-Risk-Factor-Pro-
4. **Climate Central** https://www.climatecentral.org/