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Abstract: In this paper, we identified the following potential physical impacts of climate change on North Carolina (NC): a.) An increase in sea level would have a significant negative effect on the NC coastal region leading to flooding, erosion and increased salinity; b) Potential increases in intensity and/or frequency of Atlantic hurricanes will have direct, negative impacts on NC's coastal plain; stronger hurricanes will extend their reach to the Piedmont and mountains leading to heavy rainfall, possible flooding, and landslides in the mountains; c.) The temperature increase in NC is likely to be uneven due to the state's complicated physical geography and influences from atmospheric motion and processes in nearby states; d.) Other effects of rising temperatures are heat waves during the summer months, which will have significant impact on agriculture, health, and air quality. The impact of global warming on NC cannot be ignored or overestimated. For example, projections for Atlantic hurricanes are highly uncertain, and could therefore be easily under/over-estimated. More research is needed to improve the weather and climate models, computing facilities, and observations, so that effects of global warming on the weather in North Carolina, with its distinct geographical areas, can be identified and more precisely predicted. Recommendations for concrete actions are given.

Keywords: Climate Change, Global Warming, North Carolina, Hurricanes, Snow Storms, Floods, Drought, Agriculture, Health, Air Quality, Streams, Scientific Evidence, Technical, Political and Social Responses

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Introduction

ALTHOUGH THERE ARE still limitations in the coverage of global climate and weather data, numerous data sets have been significantly improved and extended due to improvements in data analysis, geographical coverage in data sets, and a wide variety of measurements. Observations of increases in average global air and ocean temperatures, widespread melting of snow and ice at the poles, and rising sea level provide unequivocal evidence that the average global temperature is rising. Since 1960, increasingly comprehensive observations have become available for sea surface temperature (SST) and the amount of Arctic sea ice, snow cover, carbon dioxide (CO_2), etc. Any remaining controversy is about the causes of the recent warming trend, its magnitude and future trends, and the actions that need to be taken in North Carolina (NC). Some of the evidence includes:

- According to all major temperature reconstructions published in peer-reviewed journals (Fig. 1), the increase in temperature in the 20th century and the temperature in the late 20th century are the highest on record (Mann et al., 1998).
- Temperatures at the Earth's surface increased by an estimated 1.4°F (0.8°C) between 1900 and 2005. The past decade was the hottest in the last 150 years (IPCC, 2007). The increase in NC's temperature was 1.2°F (CIER, 2008).
- Ocean temperature, measured from the surface to a depth of 10,000 feet, has increased by about 0.09°F since the 1950s (NRC, 2001; Harrison and Carson, 2007, 2008).
- The Arctic ice cap declined to a record minimum size in the summer of 2007 (NSIDC, 2007a, b).
- The observed loss of sea ice from 1953 to 2006 occurred three times faster than projected if the average rate had remained constant (IPCC, 2007).
- The concentration of greenhouse gases in the lower atmosphere is steadily increasing; CO_2 has reached a level of about 380 ppm. Analysis of ice core samples shows that both CO_2 and methane levels are higher than at any time (IPCC, 2007).

Several projections and model predictions of future change suggest a global temperature increase of 1 to 6°C (1.8 to 10.8°F) from 1990 to 2100; warming in most of the US is expected to be even higher. The effects of global warming include increases in sea level and changes in precipitation patterns resulting in more frequent floods and droughts (Wigley, 1999).

The Science of Global Warming

The greenhouse effect is a natural phenomenon in which certain gases, known as greenhouse gases, in the Earth's atmosphere absorb heat that would otherwise escape to space. In colloquial usage it often refers to the *enhanced* global warming which is predicted to occur because of the increasing concentrations of greenhouse gases in the atmosphere. In absence of these gases, solar radiation passes through the atmosphere and most of the radiation is absorbed by the Earth's surface causing it to warm. Some of the radiation is reflected by the Earth's surface and atmosphere as infrared (longwave) radiation. Part of this infrared radiation passes through the atmosphere while part of it is absorbed and re-emitted in all directions by the blanket of pollutants and greenhouse gases around the Earth that warm its lower atmosphere and surface. The absorption of infrared radiation can occur throughout the atmosphere and on the Earth's surface.

The most important greenhouse gases in the Earth's atmosphere include carbon dioxide (CO_2), methane, nitrous oxide, water vapor, ozone, and the chlorofluorocarbons (EPA, 1998). Concentrations of these gases have increased significantly during the 20th century because of natural and /or anthropogenic changes. Often these gases are removed from the atmosphere in hours, days, or weeks. The gases, with an average lifetime of a year or more, may be spread to the lower atmosphere.

The growing scientific consensus is that (1) global temperatures of the atmosphere and ocean have increased and (2) the emissions of greenhouse gases from human activities (industrial processes, combustion of fossil fuel, changes in land use, and deforestation) enhance the warming effects. Observations of human-induced changes underlie the current concerns about climate change.

The global increase in CO_2 concentration is due primarily to emissions from burning fossil fuels and changes in land use (IPCC, 2007); the CO_2 concentration has increased from a pre-industrial value of ~280 to 384 parts per million (ppm) in 2008 (NOAA, 2008). This exceeds the natural range of concentrations over the last 650,000 years as determined by analysis of ice cores. The primary source of the increased concentrations of methane and nitrous oxide is agricultural activity. These gases have increased from a pre-industrial value of ~715 to 1780 ppb in 2008. The global atmospheric nitrous oxide concentration increased from a pre-industrial value of ~270 to 322 ppb in 2008.

Two classes of carbonaceous aerosols (sulfate and carbon-bearing compounds associated with particles) affect radiative balances and therefore influence climate. Other potentially important climate factors include solar variability, volcanic aerosols, and land use by humans.

Opponents of global warming argue that warmer weather extends growing seasons and generally improves the habitability of colder regions (Florides and Christodoulides, 2008). They believe that increases in CO_2 will improve the health, longevity, prosperity and productivity by accelerating the growth rates of plants. However, the scientific consensus is that the results of increased CO_2 will be mixed. Plant productivity will increase only until another resource (water, nitrogen) becomes limiting (Long et al., 2004). Plants have adapted to certain ranges of temperature. Temperatures that are above a given plant's maximum tolerance reduce photosynthesis and may result in damage or death. For example, at temperatures in the mid-90^{o}F and above, crops like corn cannot set seed and many fruits and vegetables can be sun scorched. Agricultural pests and diseases that are sensitive to cold weather will have a higher rate of survival in milder winters (Harvell et al., 2002).

While there is little debate on the existence of global warming since the Little Ice Age (Fig. 1), questions remain about the anthropogenic contributions to global warming. In particular, there is some doubt about whether there is sufficient evidence to justify immediate and far-reaching actions to mitigate these effects (IPCC, 2007). For example, Fig. 2 shows that reductions in glaciers occurred before and are unaffected by hydrocarbon use. In fact, global temperature correlates with solar radiance rather than hydrocarbon use. This does not mean that global warming does not affect deglaciation today, however.

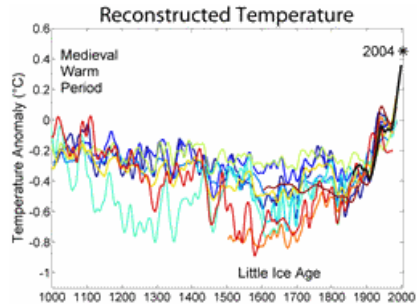

Figure 1: Reconstructions of Northern Hemisphere Temperatures for the 2nd Millennium According to Various Older Articles (Bluish Lines), Newer Articles (Reddish Lines), and Instrumental Records (Black line) (Wikipedia, 2011)

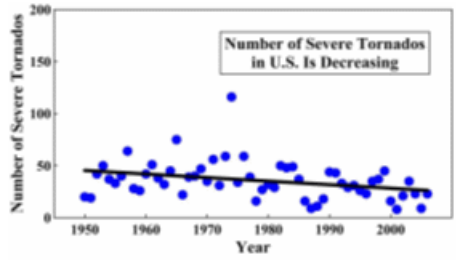

Figure 2: Average Length of 169 Glaciers from 1700 to 2000 (Oerlemanns, 2005).

Note that the global warming is not uniform on a regional scale (e.g., see Fig. 2 of Wanner et al. 2008). For example, the annual statewide average for NC versus the global temperature average since 1895 (Fig. 3 of SCO, 2011) shows two significant differences can be found: (a) the NC temperature is far more variable from year to year compared to the global temperature variation, and (2) the NC average temperature show no warming trend, at least in linear sense, unlike the global average temperature. This highlights one of the primary challenges with climate change analysis at local and even statewide scales: local climate variability is so high in NC that significant trends are difficult to deduce (SCO 2011).

Impacts on Weather and Environment in North Carolina

It is difficult to draw a conclusion on climate variability in NC's mountains, Piedmont and coastal plain due to their geographical complexity and the uncertainty of climate models; these uncertainties include the impacts of global warming on the intensity and frequency of hurricanes, floods, ice storms, blizzards, tornadoes, droughts, and heat waves. The complicated topography in NC and influences from (1) large-scale climate variability such as ENSO and NAO, and (2) atmospheric motion and processes in other remote regions through the north-south and east-west *teleconnection s* make temperature projections more difficult. For example, recent studies by the State Climate Office (SCO 2011) of North Carolina indicated that there may be a decreased potential for wintry weather in NC due to the lack of available

cold air and above average temperatures associated with a positive NAO in this region. Another example is shown in Fig. 3; in general, the Piedmont and mountains are experiencing lower average maximum temperatures. Nominal warming trends are seen just along the coast.

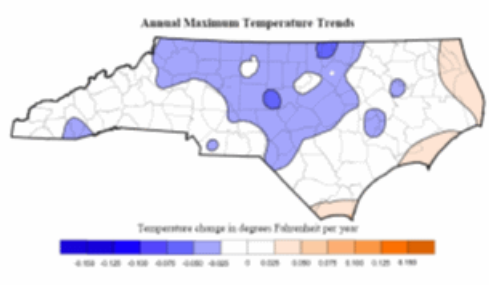

Figure 3: Annual Maximum Temperature Trends for the Period 1949-1998 (Boyer and Raman, 2003)

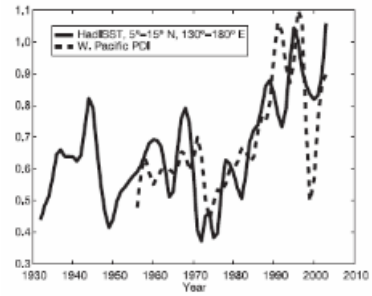

Figure 4: A Measure of the Total Power Dissipated Index Annually by Tropical Cyclones in the North Atlantic Compared to September SST (Emanuel, 2005)

Weather

Analysis of past tropical cyclones (TCs) shows that both the intensity and frequency of TCs have increased since the 1970s (Fig. 4; Emanuel, 2005; Webster et al., 2005) due to global SST increases. Note that the net hurricane power dissipation index is highly correlated with the tropical SST, reflecting well-documented climate signals (Emanuel, 2005). However, these findings have sparked debates on whether warmer tropical SSTs are causing more intense, longer-lived TCs. Opponents argue that the apparent increase in hurricane frequency is due to better observational equipment, such as satellites, and inaccurate calculations (Landsea, 2005; Klotzbach, 2006). However, if the intensity and frequency of TCs do indeed increase due to global warming, these increases will have strong negative impacts on human activities and increase property losses along coastlines, including NC's coast. Note that the Geophysical Fluid Dynamics Laboratory model projects a decrease in the number of Atlantic hurricanes under global warming conditions (Knutson et al. 2008). The increase in frequency

and intensity of hurricanes will also affect the Piedmont and NC's mountains since more of the landfalling hurricanes would be able to reach these regions; these hurricanes have the potential to produce heavy rainfall leading to flooding and landslides as they cross the Appalachian Mountains. The connection between TC frequency and the frequency and intensity of landfalling TCs needs further investigation.

According to the 2009 US Climate Impacts Report, large-scale, cold-weather storm systems have shifted farther north in the US over the past 50 years. Global warming has caused a decrease in the frequency of storms in middle latitudes; however, it has also caused the intensity of those storms to worsen. Climate models also suggest that global warming can make them more intense and destructive. Thus, if the global temperature continues to increase, we might see fewer but stronger ice storms and blizzards in the Piedmont. In the mountains we might see more storms and blizzards due to the decrease of cyclone frequency at middle latitudes and the increase of cyclone intensity (McCabe et al. 2001). Milder winters could benefit economic activities in general, and reduce energy use for home heating. On the other hand, this might have a negative effect on the ski industry in NC's mountains.

Based on NCDC's record, the incidence of F3-F5 tornados in the US has decreased (Fig. 5). In addition, some general circulation models (GCMs) predicted more intense convection during the global warming period, which may produce more severe storms and tornadoes to occur (Del Genio et al., 2007). Due to concerns about the accuracy and reliability of today's GCM, further studies on the effects of climate change on the number and intensity of tornado outbreaks are necessary (Lin, 2011).

As mentioned earlier in this subsection, weather can be changed by global warming, and through differences in physical processes, atmospheric circulations, teleconnection, and nonlinear interactions in a weakly unstable atmosphere. The complexities of these processes make weather and climate prediction highly uncertain. Thus, more research is needed to improve the weather and climate models. This will require better computing facilities and observations to identify and predict the effects of global warming on the weather in NC and its distinct geographical areas.

Sea Level Rise

An increase in sea level due to climate change could significantly influence the world's coastal zones, adversely affecting ecologically and economically important coastal systems (IPCC 1990, 1996). Major physical impacts of sea level rise include: (1) Erosion of beaches and shores; (2) Permanent inundation of wetlands; (3) Increased flooding and erosion of marshes and wetlands; (4) Increased flooding and storm damage in low-lying coastal areas; and (5) Increased salinity in estuaries, marshes, and coastal rivers.

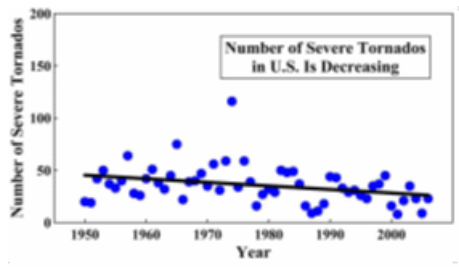

Figure 5: Annual Number of Strong-to-violent Category F3 to F5 Tornados During the March-to- August tornado Seasons in the U.S. between 1950 and 2006. The Data Source is NCDC

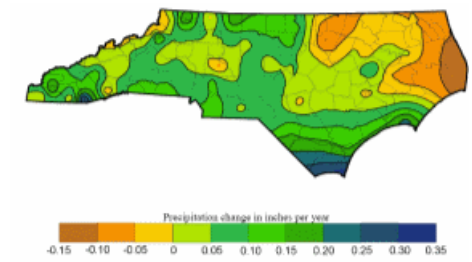

Figure 6: Annual Precipitation Trends in North Carolina for the Period 1949-99 (Boyer and Raman, 2003)

The coastal region plays an integral role in NC's economy. This region is home to a large number of people and provides recreational opportunities and valuable ecological services for many. This area faces natural and human induced stresses that include increased erosion, frequency of storms, flooding, and residential and commercial development. The sea level rise is expected to increase the volume of water through thermal expansion of ocean water and melting of polar ice and mountain glaciers. In the past 150 years, sea level has risen at a rate of 18 cm per century (Neumann et al., 2000). The possibility of stronger destructive hurricanes will affect the erosion of the coastal line of North Carolina; adverse publicity about these changing conditions will change human behavior thus affect the economy of North Carolina's coastal regions. As global temperatures rise, the average surface temperatures of the Gulf of Mexico and the North Atlantic Changes in sea level may differ at different locations around the world. With the expected rise in sea levels, storm surges from intense hurricanes could easily submerge large areas of the coastline and drastically alter coastal habitats. Associated rainfall and flooding could be catastrophic as was the case with Hurricane Floyd (1999). To mitigate the negative effects of catastrophic flooding and wind damage, building codes for communities along the coast should be examined critically and revised as needed.

Observation indicates that North Carolina's sea level has risen approximately 1 foot since 1930s, which is closely linked to broader global warming (SCO 2011). As a coastal state with a dynamic coastline and large estuarine system, North Carolina is sensitive to a rising

sea level. NC's Piedmont and mountain regions are less directly influenced by sea level rise; however, people living along coastal areas would be influenced more directly by sea level rise. In addition, flooding coastal cities, such as Wilmington, would have a much larger impact than flooding a swampy area (SCO 2011).

Erosion

Global warming may also affect erosion. Erosion is an intrinsic natural process that can be enhanced by human activities. Poor land use, such as extensive deforestation, overgrazing, and unmanaged construction activity on roads and buildings, can accelerate erosion. Excessive erosion results in increasing sediments in water and loss of topsoil. The rate of erosion depends on climatic factors (precipitation, temperature, wind speed and storm frequency), geologic factors (soil and rock type, porosity, permeability, and slope of the land), biological factors (vegetation type, faunal composition), and land-use (cropping pattern, tillage).

The impact of erosion varies among the geographical regions in NC. Hurricane activity and heavy rainfall caused by global warming could increase erosion in the mountains and the coastal regions. Studies show that each 1% change in total precipitation with climate change makes approximately a 1.7% change in soil erosion (Pruski and Nearing, 2002).

Droughts and Heat Waves

Dai (2004) found that the amount of land affected by droughts has more than doubled over the last 30 years, mainly due to the rise in global temperatures, instead of decreases in precipitation. It was found that the drought duration, intensity, and severity in North America are, for the most part, decrease with cool "La Nina-like" conditions in the tropical Pacific; on the other hand, they would increase with warm "El Nino-like" conditions (Herweijer et al., 2007; Cook et al., 2007; Sheffield and Wood, 2008). Andreadis et al. (2006) present similar conclusions regarding drought dynamics in the US: "Droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the country over the last century." Mixed conclusions are drawn about the dynamics of global drought. It is also found that "precipitation has increased an average of about 5 percent over the past 50 years. Projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier (NCC, 2011). Thus, it is unclear if this trend is related to global warming.

Global trends in drought do not necessarily imply a similar trend in NC. Figure 6 indicates that total annual precipitation in most of NC increased from 1949 to 1999, but the northeast and southeast) part of the coastal plain became dryer (wetter). Another effect of rising temperatures in NC is an increase in heat waves during the summer months. The heat waves disproportionately affect poor and senior citizensand other vulnerable populations (Kovats and Hajat, 2008). As global temperatures continue to rise, the heat waves would affect the chronically ill, the very young, the poor, and those who work outdoors or in un-air-conditioned locations. The State should make advance preparations to accommodate the vulnerable sectors of the population during heat waves.

Greenhouse Gases

CO_2 emissions in NC have increased by more than 30% since 1990 as a result of increased energy consumption (Munger and Shore, 2005). Electric utilities and the transportation sector are major emission sources in NC (Munger and Shore, 2005). Agriculture is the primary source of methane emissions, which have increased about 60% since 1990 in the state. This is due largely to the increases in the hog and poultry industries in NC (EPA, 2005). The state's hog population, especially that of the coastal plains, has grown to over 10 million from a starting point of 2.6 million in 1897, showing a nearly 300% increase (Munger and Shore, 2005). Wetlands such as swamps also emit methane.

Human activity is a main source of atmospheric aerosols including sulfate particles and black carbon, which are expected to contribute to global warming, particularly over metropolitan areas such as Charlotte and Raleigh. The emission of sulfate particles has been regulated through clean coal technologies and use of low sulfur fuels. Black carbon aerosol is emitted from the incomplete combustion of fossil fuels and burning of biomass (NRC, 2001).

Forests and Forest Fires

Investigations of forest fire activity in the US indicate that warmer temperatures tend to increase the duration and intensity of the wildfire season in the western US. The incidence of large wildfires increased suddenly and markedly in the mid-1980s, with increases in the frequency of large-wildfires their duration, and the length of the fire season. These increases are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

Balshi et al. (2008) found that wildfire activity in boreal North America responds to factors correlated with changes in climate. In mountainous areas, global warning results in an upward shift of the biota (Brown, 2001). Kirilenko and Sedjo (2007) found that a rise in temperature may cause a poleward shift of vegetation of 500 km or more for boreal zones. Although the authors argue that increasing concentrations of CO_2 may also increase plant productivity through the "carbon fertilization effect"; other forest ecologists argue that the "effects will likely differ in direction and magnitude among forest ecosystems" (Gower, 2003).

Based on an analysis for the period of 1949-99, Boyer and Raman (2003; Figs. 3 and 6) found that the mountain region is getting slightly wetter, but the temperature has changed by only a small amount. Thus, the recent impacts on forests and forest fires do not appear to be significant, although it is unclear about the long-term impacts. The Piedmont region became wetter and warmer; the impacts on forest fire frequency and intensity are uncertain. The coastal plains became dryer but the temperature stayed about the same. This implied that there is a slight chance for an increase in forest fire activity. As stated earlier, the uncertainties in the model predictions and of methods used in analysis requires more research to predict trends in forest fire activity and their effects on forests.

Economic and Societal Implications

General Economic Impact on North Carolina

The global economic impact of climate change is currently a subject of a great debate among economists and other social scientists. Stern (2006) suggested that climate change will cause the greatest and widest-ranging market failure ever seen and concluded that one percent of global GDP must be invested in research to mitigate the effects of climate change; a failure to do so could risk a recession worth up to twenty percent of global GDP. However, Mendelsohn (2004) argued that the impact is likely to differ by region. Countries in the polar regions would benefit from warming, while countries in mid-latitudes would benefit at first and then be harmed. The countries in tropical regions would be harmed immediately by global warming.

The major economic impacts of global warming have been listed by the Center for Integrated Environmental Research (CIER) with the most severe impacts affecting coastal areas of North Carolina. Sea level rise will have a negative effect on the tourism, real estate, and fishing industries and could endanger water supplies there (CIER 2008). Any increase in severe weather will hurt agriculture and forestry. Increasing temperature would increase the incidence of heat stroke and increase the air's ozone level; the increase in ozone exacerbates respiratory problems for sensitive people.

Insurance Industry

The insurance industry is directly affected by the risks of major natural disasters. The number of these disasters has tripled since the 1960s; insured losses have increased fifteen fold in real terms (adjusted for inflation) during this time. In the Mid-Atlantic region, each 1% increase in annual precipitation could enlarge catastrophe losses by as much as 2.8% (Choi and Fisher, 2003). Gross increases in liability in NC are most likely to occur in the vulnerable coastal areas because of increasing population and growing property values (Band and Salvesen 2009).

Weather related risks for households and property in NC are already increasing due an increase in severe weather events such as hurricanes and heavy precipitation. NC lawmakers are currently examining whether the insurance industry is prepared financially to handle a category 5 hurricane and the resulting damage claims. A state-sponsored program for affordable coastal insurance currently exists; however the insurance industry is worried that the program does not have enough money to pay for claims for storm and flood damages from a 100-year storm (Jenkins, 2010). Insurance premiums for coastal residents are likely to increase, as is the risk that flood insurance will become unaffordable for some NC residents.

Financial institutions, including the world's two largest insurance companies, Munich Re and Swiss Re, warned in a 2002 study "the increasing frequency of severe climatic events, coupled with social trends could cost almost US$150 billion each year in the next decade." According to The Associated Press (2008), NC could rack up $3.3 billion in insured losses in 18 coastal areas. These costs, which would be related to property damage, insurance and disaster relief, would burden NC customers, taxpayers, and industry alike.

Effects on Agricultural Production

For some time it was hoped that a positive effect of global warming would be increased agricultural yields, because increased concentrations of CO_2 increase the rate of photosynthesis. More recent studies reveal a more complicated picture, one that is affected by the availability of other resources needed for photosynthesis and the effects of high temperature on other aspects of plant physiology. While local benefits may be felt in some regions, recent evidence is that global yields will be negatively affected (IPCC, 2007). This may lead to food crises, food riots, and civil unrest in general.

Human Displacement

Perhaps the most worrisome problems associated with rising temperatures and sea levels are from large-scale migrations of people -- both inside nations and across existing national borders. Poor and underdeveloped areas are likely to have fewer resources and less ability to deal with climate change in even its very modest and early manifestations. Poorer communities also tend to lack the insurance, savings or access to credit needed to recover from disasters (Peterson, 2002).

Mitigation to Prevent the Long Term Effects of Global Warming

Public Awareness and Education

Interdisciplinary research and education are key areas that will provide the information needed to mitigate the long-term effects of global warming. There are several academic programs, institutes and centers that can work jointly towards addressing the major multidisciplinary and interdisciplinary problem of the century, global climate change. Relevant centers and institutes at the NC A&T State University include:

- *NOAA Interdisciplinary Scientific Environmental Technology Cooperative Science Center* (*ISETCSC*) was established in 2006 and has a yearly funding of $2.5 million. The Center is organized in three research themes that have the potential for making a significant positive impact on NOAA's scientific environmental technologies and contribute to our understanding of climate change.
- *Waste Management Institute* (*WMI*) was established in 1994 as an interdisciplinary academic support unit with research and public service functions. WMI's purpose is to enhance awareness of environmental and sustainability problems and the proposed solutions needed to improve the quality of life and protect the environment.
- *Center for Energy Research and Technology* (*CERT*) was established in 1984. CERT's goals include facilitating the application of energy related technologies to buildings, collaboration with the building industry, and development of University-wide relationships with public and private sectors.
- The *Transportation Institute* addresses improvements in transportation performance through the use of innovative management techniques and advanced technologies in small urban and rural areas.

Academic programs include:

- A *PhD Concentration in Atmospheric Sciences*, that includes climate modeling, has been established in the Department of Energy and Environmental Systems.
- The *Atmospheric Sciences Meteorology BS Program* was established in 2008 in the Department of Physics. A *concentration in environmental geophysics* was also established.
- The *Earth and Environmental Sciences Program* was established in the School of Agriculture and Environmental Sciences for research on environmental issues.

Preparedness

Our understanding of global warming is far from complete because of the complexity of the Earth System. However, our current scientific understanding of climate change is sufficiently clear to justify serious efforts to prepare for and mitigate the long-term effects of global warming. In this context, public awareness and education are a significant part of the preparedness and mitigation efforts. Environmental protection and sustainable development are key priorities in meeting the challenge of global warming.

Preparation for global warming demands concerted and collaborative efforts among federal, state, and local governments. There is a need to curb the emissions of greenhouse gases. Inaction on the part of policy makers could have large and unforeseen adverse effects on society and the economy. Effective responses to this will require a national and state preparedness plans which may include: (1) Mapping of vulnerabilities via National Global Warming Community Impact Assessment, (2) Developing of state-level global warming preparedness plans, (3) Creating a county-by-county Disaster Resilience Index, (4) Setting financial disclosure requirements for documented threats, (5) Establishing a fund for critical infrastructure investments, (6) Building of smart micro grids for emergency energy security with a focus on onsite power generation from renewable energy sources (wind, solar, geothermal and biofuels), (7) Planning to reduce carbon foot prints through conservation, waste minimization and energy efficiency, and (8) Planning for human responses and adaptations to coastal threats that includes protection, accommodation and planned retreat.

To meet the challenges posed by global warming, academic institutions must increase policy makers' and the general public's awareness of the causes and potential consequences of climate change through education, research and outreach. Both formal and informal education and outreach will be vital. Research and innovation to meet the challenges of global warming should be a cornerstone in the national plan.

Recommendations

NC's first efforts should focus on mitigation and management of the local catastrophic effects of global warming on its population and environment. Since this requires collaborations with other states and countries, NC should lobby the Federal government to increase its support for research on global warming and to increase public awareness and consciousness of this threat. A greater investment in research to improve weather and climate models is needed. This type of research requires more powerful computing facilities, and more observations to identify and predict the effects of global warming on the weather in NC and its distinct geographical areas.

Environmental research and academic programs are strengths of NCA&T; however, the strengths need to be nurtured in areas in which NCA&T can provide unique contributions to address the critical energy and environmental problems that affect NC. These areas include advancing the knowledge of climate change, providing continuing education and community awareness programs for the public in the Piedmont Triad and surrounding areas, enhancing and supporting holistic interdisciplinary research involving physical sciences, social sciences, environmental sciences and engineering. The best way to meet these goals is to establish Earth System Science Institutes at several campuses of the UNC system.

North Carolina can contribute significantly to world- and nation-wide mitigation of climate change effects. Emerging carbon markets and the growing biofuels industry are expected to have a significant impact on energy and transportation sectors, farmers, agribusinesses, and rural communities in general. Some of the opportunities for the state and its agricultural sector include:

- Co-firing biomass: Research (1) to identify the economic implications of global warming for the state's energy and transportation sectors and (2) to evaluate the spatial distribution of the changes in cropping patterns and practices that may be brought about by tax or other potential incentives to increase climate change mitigation.
- Carbon sequestration: The state's agricultural sector can develop and apply techniques for sequestering carbon in agricultural soils and might profit significantly as carbon markets emerge and strengthen. Viable carbon credit markets or other incentives such as those provided under carbon offset projects or the current federal agricultural conservation programs may lead to significant changes in farming practices and sizeable revenues for the state's agricultural sector.
- Mitigation: As climate change affects precipitation patterns and the probability and intensity of storm events, additional CRP acreage may be needed to alleviate the effects of the increased probability and severity of erosion, nutrient runoff, and pollution from agricultural fields.
- Developing biofuels markets: On-going research at NCA&T indicates that the growth of biofuels industry needs to balance the economic benefits to rural development and farmers with environmental quality.
- Developing dedicated energy crop: With the development of the newer, lingo-cellulosic biofuels production technologies, other types of biomass could be utilized for the production of biofuels.

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