TACCIMO
Template for Assessing Climate Change Impacts and Management Options

TACCIMO Literature Report

Literature Report – Annotated Bibliography Format
Report Date: March 6, 2013

Content Selections:
FACTORS – Extreme Weather
CATEGORIES – General Impacts, Interactions with other Factors, Precipitation Extremes, Severe Storms, Temperature Extremes, Tropical Cyclones
REGIONS – National, East, R8: Southern, South Atlantic, South Central

How to cite the information contained within this report

Each source found within the TACICMO literature report should be cited individually. APA 6th edition formatted citations are given for each source. The use of TACCIMO may be recognized using the following acknowledgement:

"*We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science. Support of this database is provided by the Eastern Forest Environmental Threat Assessment Center, USDA Forest Service.*"

Best available scientific information justification

Content in this Literature report is based on peer reviewed literature available and reviewed as of the date of this report. The inclusion of information in TACCIMO is performed following documented methods and criteria designed to ensure scientific credibility. This information reflects a comprehensive literature review process concentrating on focal resources within the geographic areas of interest.

Suggested next steps

TACCIMO provides information to support the initial phase of a more comprehensive and rigorous evaluation of climate change within a broader science assessment and decision support framework. Possible next steps include:

1. Highlighting key sources and excerpts
2. Reviewing primary sources where needed
3. Consulting with local experts
4. Summarizing excerpts within a broader context

More information can be found in the user guide. The section entitled Content Guidance provides a detailed explanation of the purpose, strengths, limitations, and intended applications of the provided information.

Where this document goes

The TACCIMO literature report may be appropriate as an appendix to the main document or may simply be included in the administrative record.

Brief content methods

Content in the Literature Reports is the product of a rigorous literature review process focused on cataloguing sources describing the effects of climate change on natural resources and adaptive management options to use in the face of climate change. Excerpts are selected from the body of the source papers to capture key points, focusing on the results and discussions sections and those results that are most pertinent to land managers and natural resource planners. Both primary effects (e.g., increasing temperatures and changing precipitation patterns) and secondary effects (e.g., impacts of high temperatures on biological communities) are considered. Guidelines and other background information are documented in the user guide. The section entitled Content Production System fully explains methods and criteria for the inclusion of content in TACCIMO.

TABLE OF CONTENTS

Effects by Source

Wednesday, March 06, 2013

RESOURCE AREA (FACTOR): EXTREME WEATHER

GENERAL IMPACTS

NATIONAL

Dale, V. H., Joyce, L. A., McNulty, S., & Neilson, R. P. (2001). The interplay between climate change, forests, and disturbances. The Science of the Total Environment, 262,

Because forests are so long-lived, it may be that many climate change effects on forests are most easily observed in places where the successional pathway has been disrupted by a disturbance.

Peterson, T. C., Taylor, M. A., Demeritte, R., Duncombe, D. L., Burton, S., Thompson, F., … & Gleason, B. (2002). Recent changes in climate extremes in the Caribbean region. Journal of Geophysical Research, 107(D21), 4601. doi:10.1029/2002JD002251

Frich et al. [2002] report that on a ‘‘globally’’ averaged basis since the early 1950s, ETR [Intra-Annual Extreme Temperature Range, simply the warmest maximum temperature reading for the year minus the coldest minimum temperature] is decreasing, Tn90 [Percent of time that the minimum temperature is greater than or equal to the 90th Percentile of Daily Minimum Temperature] is increasing, SDII [The Simple Daily Precipitation Intensity Index, the annual total precipitation divided by the total number of days with precipitation above 1.0 mm] is increasing, R10 [The number of days with precipitation greater than or equal to 10 mm] is increasing, measures of extreme precipitation, R5D [the greatest 5-day rainfall total] and R95T [the percentage of total precipitation due to events above the 95th percentile] are both increasing, and CDD [the annual maximum number of consecutive dry days] is decreasing.

R8: SOUTHERN

Beckage, B., Gross, L. J., & Platt, W. J. (2006). Modelling responses of pine savannas to climate change and large-scale disturbance. Applied Vegetation Science, 9, 75-82.

These changes to the ENSO [El Niño/La Niña-Southern Oscillation] cycle will create conditions that favor less frequent large-scale fires and decreased hurricane frequency in southeastern savannas Global warming is expected to affect the frequency of ENSO [El Niño/La Niña-Southern Oscillation] events, which will influence disturbance regimes in southeastern savannas.

INTERACTIONS WITH OTHER FACTORS

NATIONAL

Galik, C. S. & Jackson, R. B. (2009). Risks to forest carbon offset projects in a changing climate. Forest Ecology and Management, 257(11), 2209-2216. doi:10.1016/j.foreco.2009.03.017

Natural disturbances pose the greatest challenge to forest [carbon] offset project accounting because of the inherent unpredictability and potential scale that characterize such disturbances.

PRECIPITATION EXTREMES

NATIONAL

Breshears, D. D., Cobb, N. S., Rich, P. M., Price, K. P., Allen, C. D., Balice, R. G., . . . Meyer, C. W. (2005). Regional vegetation die-off in response to global-change-type drought. PNAS, 102(42), 15144-15148.

Global climate change is projected to yield increases in frequency and intensity of drought occurring under warming temperatures. 622

Fay, P. A., Kaufman, D. M., Nippert, J. B., Carlisle, J. D. & Harper, C. W. (2008). Changes in grassland ecosystem function due to extreme rainfall events: implications for responses to climate change. Global Change Biology, 14, 1600 – 1608.

Most climate change scenarios forecast an increasing occurrence of extreme precipitation events (Christensen & Hewitson, 2007), which will likely result in increased intra-annual rainfall variability. Indeed, increases in both total rainfall amounts and in the frequency of extreme events have been documented and are likely to continue during the 21st century (Karl & Knight, 1998; Easterling et al., 2000; Groisman et al., 2005; Alley et al., 2007). 4753

Hanson, J. P., & Weltzin, J. F. (2000). Drought disturbance from climate change: Response of united states forests. The Science of the Total Environment, 262, 205-220.

These temperature increases are expected to modify global hydrologic budgets leading to increased winter precipitation at high latitudes, more extreme temperature days, and more or less droughts or floods depending on location.

Huber, D. G. & Gulledge, J. (2011). Extreme weather and climate change: Understanding the link, managing the risk. Arlington, VA: Pew Center on Global Climate Change. Available at: http://www.pewclimate.org/publications/extreme-weather-and-climate-

Over the past 50 years, total rainfall has increased by 7% globally, much of which is due to increased frequency of heavy downpours. In the United States, the amount of precipitation falling in the heaviest 1% of rain events has increased by nearly 20 percent overall, while the frequency of light and moderate events has been steady or decreasing (Figure 1, Karl et al 2008). 1502

Karl, T. R., Melillo, J. M., & Peterson, T. C. (2009). Global climate change impacts in the United States. New York, NY, USA: Cambridge University Press.

Much of the Southeast and West has had reductions in precipitation and increases in drought severity and duration, especially in the Southwest.

Flooding often occurs when heavy precipitation persists for weeks to months in large river basins. Such extended periods of heavy precipitation have also been increasing over the past century, most notably in the past two to three decades in the United States (Kunkel et al., 2008).

For the future, precipitation intensity is projected to increase everywhere, with the largest increases occurring in areas in which average precipitation increases the most.

Nicholls, N. & Alexander, L. (2007) Has the climate become more variable or extreme? Progress 1992-2006. Progress in Physical Geography, 31(1), 77-87.

There appear to have been increases in the number of heavy precipitation events (eg, 95th percentile) across many land regions in the second half of the twentieth century, even in those where there has been a reduction in total precipitation amount. Increases have also been reported for rarer precipitation events (1 in 50-year return period), but only a few regions have sufficient data to assess such trends reliably. However, precipitation extremes do not exhibit as much spatial coherence as do temperature extremes (Alexander et al., 2006), ie, there are areas where the frequency of heavy precipitation has decreased.

Peacock, S. (2012). Projected twenty-first century changes in temperature, precipitation, and snow cover over North America in CCSM4. Journal of Climate, 25, 4405 – 4429. DOI: 10.1175/JCLI-D-11-00214.1.

For very heavy rain events (>50 mm day-1), the model results indicate that some regions on the east and 3487
west coasts will experience on average one more day per year with very high precipitation, while the rest of North America shows little change. By contrast, large parts of North America are projected to experience order 10 more days yr-1with precipitation greater than 10 mm day-1.

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., … & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B et al. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, and New York, NY, USA: Cambridge University Press, 109-230.

The overall most consistent trends toward heavier precipitation events are found in North America (likely 2854
increase over the continent). There is low confidence in observed trends in phenomena such as hail because of historical data inhomogeneities and inadequacies in monitoring systems.

Zhu, J., Forsee, W., Schumer, R. & Gautam, M. (2012). Future projections and uncertainty assessment of extreme rainfall intensity in the United States from an ensemble of climate models. Climatic Change, DOI 10.1007/s10584-012-0639-6.

For all study locations [multiple locations in the US] the RCMs [regional climate models] predict a 4299
more intense extreme rainfall regime for the future scenarios. However, the rate of increase varies greatly among locations ranging from 1.7 % for Denver to about 24 % for St. Paul.

R8: SOUTHERN

Chen, G., Tian, H., Zhang, C., Liu, M., Ren, W., Zhu, W., … & Lockaby, G. (2012). Drought in the southern United States over the 20th century: variability and its impacts on terrestrial ecosystem productivity and carbon storage. Climatic Change, 114(2), 379-397. doi:10.1007/s10584-012-0410-z

Based on SPI [standard precipitation index], we characterized drought intensity and duration in the SUS 4573
during 1895–2007. No significant changes in drought intensity and duration were found for this time period. However, we found that the areas in the SUS [southern United States] experiencing extreme high rainfall events appeared to be increasing, which might imply an increased flooding frequency.

Karl, T. R., Melillo, J. M., & Peterson, T. C. (2009). Global climate change impacts in the United States. New York, NY, USA: Cambridge University Press.

There has been an increase in heavy downpours in many parts of the region,(Karl and Knight, 1998; Keim, 1997) while the percentage of the region experiencing moderate to severe drought increased over the past three decades.

The area of moderate to severe spring and summer drought has increased by 12 percent and 14 percent, respectively, since the mid- 1970s. Even in the fall months, when precipitation tended to increase in most of the region, the extent of drought increased by 9 percent. 161

Li, W., Li, L., Fu, R., Deng, Y., & Wang, H. (2010). Changes to the north Atlantic subtropical high and its role in the intensification of summer rainfall variability in the southeastern United States. Journal of Climate, 24(5), 1499-1506.

Our analysis of the IPCC AR4 [Assessment Report 4] models suggests that the NASH [North Atlantic Subtropical High] system will likely intensify, expand, and move farther westward in the twenty-first century with the increase of CO2, indicating increased likelihoods of both extreme rainfall events and droughts over the SE [southeastern] United States in the future. 4620

R9: EASTERN

Karl, T. R., Melillo, J. M., & Peterson, T. C. (2009). Global climate change impacts in the United States. New York, NY, USA: Cambridge University Press.

For example, the Midwest and Northeast, where total precipitation is expected to increase the most, would also experience the largest increases in heavy precipitation events.

Wu, W., Clark, J. S., and Vose, J. M. (2012). Response of hydrology to climate change in the southern Appalachian Mountains using Bayesian inferences. Hydrological Processes, Accepted 1 December, 2012. doi:10.1002/hyp.9677

Temperature increases will intensify the hydrological cycle, and extremes (floods and droughts) are likely to increase in frequency and magnitude [Jackson et al., 2001; Oki and Kanae, 2006; Gedney et al., 2006; Sivakumar, 2011; Chiew et al., 2011]. Risks of extreme hydrological events depend not only on the possible changes in climate in the future, but also on the current status of the hydrological conditions, and they vary by region [Groisman and Knight, 2008]. In the US, a simple reduction in total annual precipitation might increase drought severity in the 'annual, seasonal drought' regions which are dependent on dormant season precipitation and soil recharge, but it would not have the same impact on forests of the 'random, occasional drought' regions of the eastern US [Penninckx et al., 1999; Hanson and Weltzin, 2000]. 4586

SOUTH ATLANTIC

Laseter, S. H., Ford, C. R., Vose, J. M., & Swift Jr., L. W. (2012). Long-term temperature and precipitation trends at the Coweeta Hydrologic Laboratory, Otto, North Carolina, USA. Hydrology Research, 43(6), 890-900. doi:10.2166/nh.2012.067

In September [at the Coweeta Hydrologic Laboratory, Otto, North Carolina], only the most extreme part (>85%) of the distribution increased over time due to an increase in high intensity, shorter duration storm events, such as tropical storms, as opposed to an increase in the number of storms per month. For example, the number of storms occurring in September did not increase over time (R = –0.01, Figure 6(a)), but the percentage of September storms that fell above the 75th percentile (16.5 mm) appears to increase substantially in the latter part of the record (Figure 6(b)).

In addition to more intense precipitation [at the Coweeta Hydrologic Laboratory, Otto, North Carolina], recent climate patterns trend toward more frequent periods of prolonged drought (Figure 7) as inferred by comparing annual totals against the long-term mean. In addition, drought severity (accumulated deficit in precipitation over time) is increasing with time ($R = -0.35$, $t_{0.05,37} = -2.29$, $Pr = 0.01$). Beginning with a severe drought in 1985, a 1,600 mm deficit in rainfall accumulated through 2008.

SOUTH CENTRAL

Biasutti, M., Sobel, A. H., Camargo, S. J., & Creyts, T. T. (2011) Projected changes in the physical climate of the Gulf Coast and Caribbean. Climatic Change, early online, 1-27. doi:10.1007/s10584-011-0254-y

During summer and fall, the projections of the IPCC [Intergovernmental Panel on Climate Change] models for the Gulf are moderately more significant: more than 75% of the models project dry anomalies extending over Louisiana and Mississippi in summer and positive anomalies in the northern-Gulf Coast in the fall. These projections are also confirmed by the NARCCAP ensemble, which projects more extensive dry anomalies, centered over Arkansas but also covering Louisiana and Mississippi (cf. Figs. 6 and 7).

The regional models (Fig. 10) support the conclusion that the average intensity of precipitation will increase over all the southeastern states, and suggest that the intensification might be largest in close proximity to the Gulf coast. The projected changes in the number of consecutive dry days and the number of heavy rainy days can again be related to the mean summertime rainfall anomalies, which, in the regional models, showed dry anomalies in the west of Mississippi and wet anomalies to the east. The maximum dry spell lengthens to the west, and is uncertain to the east. The number of days with rainfall exceeding 10 mm/day increases in the east and is uncertain elsewhere. This pattern of anomalies supports the idea that changes in warm weather convection are responsible for the changes in precipitation extremes.

EAST

Pitchford, J. L., Wu, C., Lin, L., Petty, J. T., Thomas, R. Veselka IV, W. E., … & Anderson, J. T. (2011). Climate Change Effects on Hydrology and Ecology of Wetlands in the Mid-Atlantic Highlands. Wetlands, 32(1), 21-33. doi: 10.1007/s13157-011-0259-3

An increasing trend in precipitation events greater than the 95th percentile (i.e., high intensity) is evident 2787
for the MAH [Mid-Atlantic Highlands]. We detected increasing trends of high intensity precipitation at 16 of 20 stations with an annual average increase of 0.07 cm/yr for high intensity events.

SEVERE STORMS

NATIONAL

Irland, L. C. (2000). Ice storms and forest impacts. Science of the Total Environment, 262, 231-242.

At present, how ice storm frequency and severity may change with future climate change is unknown.

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

Winds from severe storms (e.g., from tornadoes, hurricanes, derechos, and nor'easters) occurring at very

infrequent intervals also replace stands at various spatial scales (0.2-3,785 ha; Seymour, White, and deMaynadier, 2002; see also McNulty, 2002).
Worrall, Lee, and Harrington (2005) found that windthrow, windsnap, and chronic wind stress expand gaps initiated by insects, parasites, and disease in New Hampshire subalpine spruce-fir forests.
The extent to which trees suffer from the stress and damage caused by ice appears to vary with species, slope, aspect, and whether severe winds accompany or follow the ice storm (Bruederle and Stearns, 1985; De Steven, Kline, and Matthiae, 1991; Rhoads et al., 2002; Yorks and Adams, 2005).

McCarthy, H. R., Oren, R., Kin, H.-, Johnson, K. H., Maier, C., Pritchard, S. G., & Davis, M. A. (2006). Interaction of ice storms and management practices on current carbon sequestration in forests with potential mitigation under future CO2 atmosphere. Journal of Geophysical Research, 111.

These results suggest that forests may suffer less damage during each ice storm event of similar severity 228
in a future with higher atmospheric CO2.

Peterson, C. J. (2000). Catastrophic wind damage to North American forests and the potential impact of climate change. Science of the Total Environment, 262(3), 287-311.

Because tornadoes and downbursts are in part products of thermodynamic climatic circumstances, they 216
may be affected by anticipated changes in climatic conditions as the 21st century progresses. However, the current understanding of tornado and downburst formation from supercell storms is very incomplete, and climate-change model predictions sufficiently coarse, that predictions of changes in frequency, size, intensity, or timing of these extreme events must be regarded as highly uncertain.

While there have been few published studies that consider how projected climate change might influence 2782
the tornado and downburst disturbance regime, numerous publications mention that climate change models predict increased frequency and intensity of catastrophic wind storms (e.g. Pearce, 1995; O'Hare, 1999). One line of thought is that with warmer air masses over middle latitudes such as North America, the temperature contrast with polar air masses will be greater, providing more energy and thus, more violent storms over the US.

For example, Munich Re, the world's largest reinsurance company, hired a meteorologist, Gerhard Berz, to head its technical research division. In a recent publication (Berz, 1993), he says 'the increased intensity of all convective processes in the atmosphere will force up the frequency and severity of tropical cyclones, tornadoes, hailstorms, floods and storm surges'.

Etkin (1995) predicted increased frequency of tornadoes in western Canada during the coming century (see also White and Etkin, 1997), based on a historical increase in tornado frequency in 'shoulder' months of May, June, August and September, when temperatures were warmer and more 'July-like'.

Wind disturbances, while poorly studied, can affect areas up to thousands of hectares per event and in locations where fire is rare, may be the most important disturbance type in terms of influences on forest composition and dynamics (Everham and Brokaw, 1996 and Turner et al., 1997).

Another, more general, expectation [of how climate change might influence tornado and downburst 4785
disturbance regimes in North America] is that with increased mean temperature, if variance around that mean remains constant, extreme weather events become statistically more probable (O'Hare, 1999); however, the assumption of constant variance about an increased mean appears to be questionable (O'Hare, 1999).

If warmer mid-latitude climates contribute to greater levels of convective storms, then increased frequencies and perhaps intensities of tornadoes and downbursts [across the US] would not be surprising.

Until knowledge of supercell thunderstorm formation, both in 'tornado alley' and elsewhere, is much improved, we can have only limited confidence in long-term projections about tornado and downburst climatology under a changed 21st-century climate, although some very general suggestions warn that an increase in number and severity would be consistent with predicted continental and regional-scale changes in climate. 4787

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., … & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B et al. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, and New York, NY, USA: Cambridge University Press, 109-230.

An increase in atmospheric greenhouse gas concentrations may cause some of the atmospheric conditions conducive to tornadoes such as atmospheric instability to increase due to increasing temperature and humidity, while others such as vertical shear to decrease due to a reduced pole-to-equator temperature gradient (Diffenbaugh et al., 2008), but the literature on these phenomena is extremely limited at this time. There is thus low confidence in projections of changes in such small-scale systems because of limited studies, inability of climate models to resolve these phenomena, and possible competing factors affecting future changes. 2856

Based on reanalyses, North American [extratropical] cyclone numbers have increased over the last 50 years, with no statistically significant change in cyclone intensity (X.D. Zhang et al., 2004). Hourly MSLP [mean sea level pressure] data from Canadian stations showed that winter cyclones have become significantly more frequent, longer lasting, and stronger in the lower Canadian Arctic over the last 50 years (1953-2002), but less frequent and weaker in the south, especially along the southeast and southwest Canadian coasts (Wang et al., 2006). Further south, a tendency toward weaker low-pressure systems over the past few decades was found for US East Coast winter cyclones using reanalyses, but no statistically significant trends in the frequency of occurrence of systems (Hirsch et al., 2001). 2860

R8: SOUTHERN

Bragg, D. C., Shelton, M. G., & Zeide, B. (2003). Impacts and forest management implications of ice storms in forests in the southern United States. Forest Ecology and Management, 186, 99-123.

Ice storms increase potential fire risk by elevating fuel loads and limiting stand access (Irland, 2000). The Mississippi Forestry Commission (1994) estimated that the 1994 ice storm increased fuel loads 3–6 times above normal. Unless salvaged, these accumulations rapidly dry and elevate fire risk until sufficiently decomposed.

Any disturbance that causes widespread decline in forest health and creates large volumes of dead material improves the conditions for other damaging agents, including insects, disease, and fire. These secondary events may prove at least as damaging as the original ice storm by killing injured trees and healthy survivors.

Although ice storms are unpredictable events, we can anticipate their potential impact and plan accordingly. Since the risk of ice damage in the south grows with increasing latitude, selection of species adapted to ice loads common to the region should provide a more robust stand. The practice of low-cost forestry shows promise for reducing the economic impact of catastrophic disturbances (Straka and Baker, 1991; Haight et al., 1996). Overstocked stands suffer considerably fromglazing, yet well-managed, regularly thinned forests yield fast growing, healthy, and sound trees that can survive inclement weather.

McNulty, S. G. (2002). Hurricane impacts on us forest carbon sequestration.

Environmental Pollution, 116, 817-824. doi:10.1016/S0269-7491(01)00242-1

A single storm can convert the equivalent of 10% of the total annual US carbon sequestration to dead and downed biomass.

R9: EASTERN

Bruederle, L. P., & Stearns, F. W. (1985). Ice storm damage to a Southern Wisconsin mesic forest. Bulletin of the Torrey Botanical Club, 112(2), 167-175.

Slippery elm [Ulmus fulva] and white ash [Fraxinus americana] appear most susceptible to glaze damage and were characterized by high susceptibility ratios. Additionally, both of these species sustained high individual damage. Field observations suggest that black cherry (Prunus serotina), trembling aspen (Populus tremu- loides), American elm (Ulmus americana), and large toothed aspen (Populus grandidentata) should also be classified as highly susceptible to glaze damage. Though these species occur infrequently in the stand, they showed heavy damage to individual stems. Sugar maple [Acer saccharum], American beech [Fagus grandifolia], and northern red oak [Quercus rubra] were moderately susceptible. A third group of species which were relatively resistant to glaze damage, includes basswood [Tilia spp.], shagbark hickory (Carya ovata) and ironwood [Carpinus caroliniana]. [Wisconsin]

SOUTH CENTRAL

Harcombe, P. A., Hall, R. B. W., Glitzenstein, J. S., Cook, E. S., Krusic, P., Fulton, M., & Streng D. R. (1998). Chapter 5: Sensitivity of Gulf Coast Forests to Climate Change (Biological Science Report USGS/BRD/BSR-1998-0002). In G. R. Guntenspergen & B.A. Vairin (Eds.), Vulnerability of coastal wetlands in the Southeastern United States: climate change research results, 1992-97. Lafayette, LA: U.S. Department of the Interior, U.S. Geological Survey, National Wetlands Research Center: 44-66.

Consequently, increasing frequency of large storms may maintain uncharacteristically dense shrub populations, with detrimental consequences for canopy tree regeneration. This suppression of tree regeneration, coupled with higher storm-related mortality could result in a decline in the standing biomass (i.e., the carbon storage capacity) of southern upland forests resulting in increased emissions of CO, to the atmosphere.

EAST

Galik, C. S. & Jackson, R. B. (2009). Risks to forest carbon offset projects in a changing climate. Forest Ecology and Management, 257(11), 2209-2216. doi:10.1016/j.foreco.2009.03.017

In other forests, ice storms are the primary cause of tree mortality (Lafon, 2006), with substantial ice damage historically occurring at least once a decade along a belt from Texas to New England (Irland, 2000). Single ice storms can inflict damage equivalent to approximately 10% of total U.S. annual forest carbon sequestration (McCarthy et al., 2006). In addition to direct mortality, ice storm damage can increase susceptibility to disease (Bragg et al., 2003). In a changing climate, the Mid-Atlantic is likely to experience less snow and ice but increased rainfall and wind (McKenney-Easterling et al., 2000). 1961

TEMPERATURE EXTREMES

NATIONAL

Morak, S., Hegerl, G. C., & Kenyon, J. (2011). Detectable regional changes in the number of warm nights. Geophysical Research Letters, 38(17), L17703.

The changes in extremes described above show distinct geographical patterns. For instance, a strong reduction in frost days accompanied by an increase in season length are found in the north western region of the US and Eastern Europe, while South Western North America shows a development towards higher numbers of heat waves [Tebaldi et al., 2006]. In contrast, increases in the number of hot extremes across Eastern North America are modest, with decreases in parts of the South Eastern North America region [Portmann et al., 2009].

Nicholls, N. & Alexander, L. (2007) Has the climate become more variable or extreme? Progress 1992-2006. Progress in Physical Geography, 31(1), 77-87.

Globally, there have been large-scale warming trends in the extremes of temperature, especially minimum temperature, and the evidence suggests that these trends have occurred since the beginning of the twentieth century. Alexander et al. (2006) found that over 70% of the global land area sampled showed a significant decrease in the annual occurrence of cold nights and a significant increase in the annual occurrence of warm nights. Some regions experienced a doubling (or halving) of the occurrence of these indices. This implies a positive shift in the distribution of daily minimum temperature throughout the globe. Daily maximum temperature indices showed similar changes but with smaller magnitudes. 2109

The IPCC [Intergovernmental Panel on Climate Change] TAR [Third Assessment] concluded (IPCC, 2001) that: • Since 1950 it is very likely that there had been a reduction in the frequency of extreme low temperatures, with a smaller increase in the frequency of extreme high temperatures. 4136

Peacock, S. (2012). Projected twenty-first century changes in temperature, precipitation, and snow cover over North America in CCSM4. Journal of Climate, 25, 4405 – 4429. DOI: 10.1175/JCLI-D-11-00214.1.

For example, 4σ–6σ [4-6 standard deviations from the mean] events are never seen in the model before the year 2000; yet, by the end of the twenty-first century, these events typically cover more than 20% of the area of North America in the summer (note that the Russian heat wave of 2010 was considered a 3σ event; J. Hansen et al. 2012, unpublished manuscript). The increase in 4σ and higher events in winter is much smaller than the summertime increase. This may be in part because the standard deviation of temperature is very much higher in winter than in summer over North America (e.g., see Fig. 4, middle column), so it is ''harder'' to have very extreme events in the winter by this metric. The events in the 1σ –3σ window increase in summer until about 2050 and then decrease (at the expense of events of 3σ and higher), while in winter these 1σ –3σ events progressively increase through the twenty-first century. 3484

Raisanen, J. & Ylhaisi, J. S. (2011). Cold months in a warming climate. Geophysical Research Letters, 38 (L22704), 1 – 6, doi:10.1029/2011GL049758

The simulated frequency of cold months decreases gradually with time (Figure 3). For the A1B scenario, the multi-model mean frequency of cool months over land north of 60°S is 22% in 2011–2020, 8% in 2041–2050 and only 3% in 2091–2098. The reduction in very cold and record-cold months is even steeper, exceeding an order of magnitude from the beginning to the end of the century. 2098

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., … & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B et al. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, and New York, NY, USA: Cambridge University Press, 109-230.

In summary, regional and global analyses of temperature extremes on land generally show recent changes consistent with a warming climate at the global scale, in agreement with the previous assessment in AR4 [IPCC Assessment Report 4]. Only a few regions show changes in temperature extremes consistent with cooling, most notably for some extremes in central North America, the eastern United States, and also parts of South America. Based on the available evidence we conclude that it is very likely that there has been an overall decrease in the number of cold days and nights and very likely that there has been an overall increase in the number of warm days and nights in most regions, that is, for land areas with data (corresponding to about 70 to 80% of all land areas; see Table 3-2).

Regarding projections of extreme temperatures, the AR4 [IPCC Assessment Report 4] (Meehl et al., 2850
2007b) noted that cold episodes were projected to decrease significantly in a future warmer climate and considered it very likely that heat waves would be more intense, more frequent, and last longer in a future warmer climate. Post-AR4 studies of temperature extremes have utilized larger model ensembles (Kharin et al., 2007; Sterl et al., 2008; Orlowsky and Seneviratne, 2011) and generally confirm the conclusions of the AR4, while also providing more specific assessments both in terms of the range of considered extremes and the level of regional detail (see also Table 3-3).

Based on the analyses of Tebaldi et al. (2006) and Orlowsky and Seneviratne (2011), as well as physical considerations, we assess that increases in the number of warm days and nights and decreases in the number of cold days and nights (defined with respect to present regional climate, i.e., the 1961-1990 reference period, see Box 3-1) are virtually certain at the global scale. Further, given the assessed changes in hot and cold days and nights and available analyses of projected changes in heat wave length in the two studies, we assess that it is very likely that the length, frequency, and/or intensity of heat waves will increase over most land areas.

For the SRES [Special Report on Emissions Scenarios] A2 and A1B emission scenarios a 1-in-20 year 2853
annual hottest day is likely to become a 1-in-2 year annual extreme by the end of the 21st century in most regions, except in the high latitudes of the Northern Hemisphere where it is likely to become a 1-in-5 year annual extreme. In terms of absolute values, 20-year extreme annual daily maximum temperature (i.e., return value) will likely increase by about 1 to 3°C by mid-21st century and by about 2 to 5°C by the late 21st century, depending on the region and emissions scenario (Figure 3-5).

R8: SOUTHERN

Karl, T. R., Melillo, J. M., & Peterson, T. C. (2009). Global climate change impacts in the United States. New York, NY, USA: Cambridge University Press.

The number of freezing days in the Southeast has declined by four to seven days per year for most of the 158
region since the mid-1970s.

Sobolowski, S. & Pavelsky, T. (2012). Evaluation of present and future North American Regional Climate Change Assessment Program (NARCCAP) regional climate simulations over the southeast United States. Journal of Geophysical Research, 117(D1), D01101+. doi: 10.1029/2011JD016430

Maximum ~ΔT [average change in temperature] occurs in the summer with temperatures rising over 3°C over much of the Southeast. This intense warming continues into the fall and decreases slightly in the winter and spring when ~ΔT is between 1.5°C and 2°C.

SOUTH CENTRAL

Biasutti, M., Sobel, A. H., Camargo, S. J., & Creyts, T. T. (2011) Projected changes in the physical climate of the Gulf Coast and Caribbean. Climatic Change, early online, 1-27.

doi:10.1007/s10584-011-0254-y

In the Gulf, a typical winter in the last decades of this century will be as warm as the warmest winter ever recorded and the coolest summers will be as hot or hotter than any summer in the last century; in 95% of the years, summer temperatures will be unprecedented. 1852

EAST

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

In northern hardwoods, freezing, as opposed to drought, was significantly correlated with increasing global mean annual temperatures and low values of the Pacific tropical Southern Oscillation Index (Auclair, Lill, and Revenga, 1996).

TROPICAL CYCLONES

NATIONAL

Beckage, B., Gross, L. J., & Platt, W. J. (2006). Modelling responses of pine savannas to climate change and large-scale disturbance. Applied Vegetation Science, 9, 75-82.

In addition, if the current relationship between ENSO [El Niño/La Niña-Southern Oscillation] and NAO [North Atlantic Oscillation] remains intact with global warming, then the hurricanes that do form will be more likely to track toward the northeastern rather than the southeastern coast of the U.S.. 411

Day, J. W., Christian, R. R., Boesch, D. M., Yбcaz-Arancibia, A., Morris, J., Twilley, R. R., … & Stevenson, C. (2008). Consequences of Climate Change on the Ecogeomorphology of Coastal Wetlands. Estuaries and Coasts, 31, 477-491. doi: 10.1007/s12237-008-9047-

Emanuel (2005) reported that sea surface temperatures in the tropics increased by about 1 C over the past half century, and during this same period, total hurricane intensity or power increased by about 80%.

Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. Nature, 436, 686-688. doi: 10.1038/nature03906

My results suggest that future warming may lead to an upward trend in tropical cyclone destructive potential, and-taking into account an increasing coastal population- a substantial increase in hurricane-related losses in the twenty-first century. 223

Nicholls, N. & Alexander, L. (2007) Has the climate become more variable or extreme? Progress 1992-2006. Progress in Physical Geography, 31(1), 77-87.

The numbers and proportion of tropical cyclones reaching categories 4 and 5 appear to have increased since 1970, while total numbers of cyclones and cyclone days decreased slightly in most basins (Webster et al., 2005). However, data quality and coverage issues, particularly prior to the satellite era, means that there is low confidence, as yet, in this assessment. Nevertheless the numbers of strong tropical cyclones in the North Atlantic (the best observed basin) have been above normal (based on 1981–2000) in nine of the last 11 years, culminating in the record breaking 2005 season. Globally, estimates of the potential destructiveness of hurricanes show a substantial upward trend since the mid-1970s, with a trend toward longer lifetimes and greater storm intensity (Emanuel, 2005).

Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., … & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B et al. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, and New York, NY, USA: Cambridge University Press, 109-230.

The AR4 [IPCC Assessment Report 4] concluded (Meehl et al., 2007b) that a broad range of modeling studies project a likely increase in peak wind intensity and near-storm precipitation in future tropical cyclones. A reduction of the overall number of storms was also projected (but with lower confidence), with a greater reduction in weaker storms in most basins and an increase in the frequency of the most intense storms.

R8: SOUTHERN

Karl, T. R., Melillo, J. M., & Peterson, T. C. (2009). Global climate change impacts in the United States. New York, NY, USA: Cambridge University Press.

The destructive potential of Atlantic hurricanes has increased since 1970, correlated with an increase in sea surface temperature. A similar relationship with the frequency of landfalling hurricanes has not been established (Emanuel, 2005; Hoyos et al, 2006; Mann and Emanuel, 2006; Trenberth and Shea, 2006).

An increase in average summer wave heights along the U.S. Atlantic coastline since 1975 has been 169
attributed to a progressive increase in hurricane power.(Kunkel et al., 2008; Komar and Allan, 2007)

The intensity of Atlantic hurricanes is likely to increase during this century with higher peak wind 170
speeds, rainfall intensity, and storm surge height and strength.(Meehl et al., 2007; Kunkel et al., 2008).

McNulty, S. G. (2002). Hurricane impacts on us forest carbon sequestration. Environmental Pollution, 116, 817-824. doi:10.1016/S0269-7491(01)00242-1

Hurricanes do not immediately change the state of carbon in downed wood. However, shortly after the biomass has been uprooted or broken off, it begins to decompose. The fine, high nitrogen content leaves are first decomposed, followed by branch, stem and roots. It is the relative proportion of the downed salvaged wood to down non-salvaged wood that will determine how much of the post-hurricane debris is lost from the carbon sequestration pool.

Given that most of the downed wood is never salvaged, the debris and litter becomes fuel for wild fires during the following years. For example, following Hurricane Hugo, forest debris was 1.5–3 m deep in many areas (Miranda, 1996). In addition to the original damage caused by the hurricane, wildfires fueled by post hurricane slash posed a real threat to surviving vegetation.

Following a hurricane, photosynthetic capacity can be reduced by 50% which could lead to a reduced in oleoresin flow (in pines), and increased susceptibility to insect attack (Fredericksen et al., 1995). Hurricanes preferentially remove the most mature vegetation, and thus allow the potentially more productive forest understory to replace the overstory.

Tree species with a greater proportion of total carbon biomass above ground and in leaf tissue are more 2496
susceptible to uprooting (King, 1986). The two ends of the species susceptibility to hurricane damage are loblolly pine (Pinus taeda) and Baldcypress (Taxodium distichum). Mature pines have closed, compact

crown far from the ground, on stems with little taper. The pines often grow on sandy soils with poorly anchored root systems. Old growth baldcypress have a highly tapered trunk, is extremely well rooted, and has an open canopy. When both these southern Florida forest types were exposed to Hurricane Andrew in 1992, the pines experienced 25–40% damage while the bald cypress was less than 10% (Davis et al., 1996).

R9: EASTERN

Leonard, J. & Law, K. (2012). Spatial and temporal variations in West Virginia's precipitation, 1931–2000. Southeastern Geographer, 52(1), 5-19.

Using a conservative 200 km buffer first (see Matyas 2006), we observed several trends in the tropical 2888
cyclone data: 1) an increased number of tracks crossed the state; 2) an increased number of tracks fell within 200 km of the state; 3) tropical cyclones increasingly were fall events (SON [September, October, November]) for the state, with the same number, but slightly smaller percentage of summer (JJA [June, July, August]) storms; 4) the length of tropical cyclone tracks within 200 km of the state increased; and 5) the amount of time (as measured by the number of storm points) that tropical cyclones were within 200 km of the state increased (Table 3).

SOUTH ATLANTIC

Johnsen, K. H., Butnor, J. R., Kush, J. S., Schmidtling, R. C., & Nelson, C. D. (2009). Hurricane Katrina winds damaged longleaf pine less than loblolly pine. Southern Journal of Applied Forestry, 33(4), 178-181.

In a study of the Hobcaw Forest in coastal South Carolina, after Hurricane Hugo, Gresham et al. (1991) 4353
reported that longleaf pine [Pinus palustris] suffered less damage than loblolly pine [Pinus taeda]. It was noted that species native to the coastal plain are possibly better adapted to the disturbance regimes found there; for example, longleaf pine, baldcypress (Taxodium distichum), and live oak (Quercus virginiana) suffered less damage than forest species with broad distribution ranges.

SOUTH CENTRAL

Johnsen, K. H., Butnor, J. R., Kush, J. S., Schmidtling, R. C., & Nelson, C. D. (2009). Hurricane Katrina winds damaged longleaf pine less than loblolly pine. Southern Journal of Applied Forestry, 33(4), 178-181.

Mortality [from Hurricane Kartina winds in southeast Mississippi] generally increased with mean plot height, but at any given height, mortality was greatest in loblolly pine [Pinus taeda], followed by slash pine [Pinus elliotii] and lowest in longleaf pine [Pinus palustris] (Figure 3).

Damage to longleaf pine [Pinus palustris] from Hurricane Katrina was clearly the least severe, followed by 4352
slash [Pinus elliotii] and loblolly pines [Pinus taeda]. As this study [in southeast Mississippi] is replicated on one site, variation among neither soil conditions nor topography was responsible for differential species mortality. Other stand attributes do not appear to be responsible for the species differences.

Warner, N. N. & Tissot, P. E. (2012). Storm flooding sensitivity to sea level rise for Galveston Bay, Texas. Ocean Engineering, 44, 23-32.

For events leading to smaller maximum water levels [in Galveston Bay, Texas] the increase is limited by a rapid rise to a 100% probability, i.e. the events are predicted to take place every year. The largest proportional increase is computed for a 1.1 m water level, which is predicted to occur 6.5 times as often in 2100. For events leading to larger surges, the relative exceedance probability ratio decreases progressively to about a factor 1.85 for the maximum water levels generated by 2008 Hurricane Ike.

For the faster sea level rise scenario, by 2100 the maximum water level expected every year in Galveston [Bay, Texas] is greater than the water levels of all but four hurricanes from the historical record, while the return period of an event of the magnitude of Hurricane Ike is predicted to decrease to 29 years from presently 105 years.

By year 2100 water level exceedance probabilities [in Galveston Bay, Texas] are expected to double for the impact of the largest storms such as Hurricane Ike, but increase by a factor over six times for the impact of smaller storm surges associated locally with the impact of storms such as Hurricanes Cindy, Alicia, and Rita for the conservative scenario.

EAST

Biasutti, M., Sobel, A. H., Camargo, S. J., & Creyts, T. T. (2011) Projected changes in the physical climate of the Gulf Coast and Caribbean. Climatic Change, early online, 1-27. doi:10.1007/s10584-011-0254-y

In the north Atlantic, in the decades since the 1970s (the best observed region and time period in the global TC record) there has been an increasing trend in the number of intense storms (Webster et al. 2005), as well as in the power dissipation index (PDI), a measure which combines the number, intensity, and lifetime of all storms in a season (Emanuel 2005).

Tropical cyclones [TC] form only in regions of relatively high sea surface temperature (SST). SST has long been recognized as one of the factors that influences both TC formation (Gray 1979) and the maximum intensity attainable by a mature TC (Emanuel 1987; Holland 1997). This relationship has spurred the concern that future SST increases in response to increased greenhouse gases will be associated with increases in the number and intensity of TCs. Yet, much of the observed relationship between SST and TC activity in the historical record can be explained as well or better by relative SST—the difference between the local SST at a given location and the tropical mean—than by absolute SST (Vecchi and Soden 2007b; Vecchi et al. 2008).

If the absolute value of SST were considered the primary variable controlling TC activity, one would expect dramatic increases in TC activity as the climate warms. On the other hand, the picture is very different if one considers relative SST to be the more relevant variable. There is no reason to expect that future changes in relative SST will be anywhere near as large as changes in absolute SST. Future SST patterns are projected to be broadly similar to those today (with changes in spatial structure that are significant, but still small compared to the mean change, as can be seen from Fig. 12), except warmer. If one were to assume that statistical relationships between relative SST and TC activity from the present will continue to hold in the future, one would then expect relatively little change in TC activity, as shown in Fig. 15 (Vecchi and Soden 2007b; Vecchi et al. 2008).

Results from studies with both of these new methodologies show considerable diversity, but also an 1866
emerging consensus on the broad outlines of the changes in global TC [tropical cyclone] activity that are expected in the warming climate. On average across the globe, assuming global climate changes within the range deemed most likely, the average intensity of tropical cyclones is expected to increase by 2–11% while the frequency of TC occurrence is expected to decrease by 6–34% (Knutson et al. 2010). This projected decrease in frequency of all storms (from tropical storm up to category 5 hurricane strength) is not comforting, because the frequency of the most intense storms in particular is projected to increase. The most intense storms produce by far the greatest damage.

Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30

years. Nature, 436, 686-688. doi: 10.1038/nature03906

The large increase in power dissipation over the past 30 yr or so may be because storms have become more intense, on the average, and/or have survived at high intensity for longer periods of time. The accumulated annual duration of storms in the North Atlantic and western North Pacific has indeed increased by roughly 60% since 1949, though this may partially reflect changes in reporting practices, as discussed in Methods. The annual average storm peak wind speed summed over the North Atlantic and eastern and western North Pacific has also increased during this period, by about 50%. Thus both duration and peak intensity trends are contributing to the overall increase in net power dissipation.

In theory, the peak wind speed of tropical cyclones should increase by about 5% for every 1 °C increase 1881
in tropical ocean temperature (Emanuel 1987). Given that the observed increase has only been about 0.5 °C, these peak winds should have only increased by 2–3%, and the power dissipation therefore by 6–9%. When coupled with the expected increase in storm lifetime, one might expect a total increase of PDI [power dissipation index] of around 8–12%, far short of the observed change.

In an effort to quantify a global signal, annual average smoothed SST [sea surface temperature] between 30°N and 30°S is compared to the sum of the North Atlantic and western North Pacific smoothed PDI [power dissipation index] values in Fig. 3. The two time series are correlated with an r2 of 0.69. The upturn in tropical mean surface temperature since 1975 has been generally ascribed to global warming, suggesting that the upward trend in tropical cyclone PDI values is at least partially anthropogenic.

Galik, C. S. & Jackson, R. B. (2009). Risks to forest carbon offset projects in a changing climate. Forest Ecology and Management, 257(11), 2209-2216. doi:10.1016/j.foreco.2009.03.017

A recent analysis suggested that a single event – Hurricane Katrina in 2005 – converted an equivalent of 50–140% of the average annual U.S. forest carbon storage rate into downed or dead biomass (Chambers et al., 2007). Hurricane intensity and destructive potential are likely to increase this century (Emanuel, 1987, 2005).

Knutson, T. R., McBride, J. L., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J. P., Srivastava, A. K., & Sugi, M. (2010). Tropical cyclones and climate change. Nature Geoscience, 3(3), 157-163. doi:10.1038/ngeo779

Based on existing modelling studies (Supplementary Table S1) and limited existing observations, we judge that it is likely that global mean tropical-cyclone-frequency will either decrease or remain essentially unchanged owing to greenhouse warming. Late twenty-first-century model projections indicate decreases ranging from −6 to −34% globally, with a comparatively more robust decrease for the Southern Hemisphere mean counts than for the Northern Hemisphere mean counts. Among the proposed mechanisms for the decrease in global tropical cyclone frequency is a weakening of the tropical circulation [Begtsson et al. 2007, Sugi et al. 2002] associated with a decrease in the upward mass flux accompanying deep convection, or an increase in the saturation deficit of the middle troposphere [Emanuel et al. 2008].

Some increase in the mean maximum wind speed of tropical cyclones is likely with projected twenty-first century warming, although increases may not occur in all tropical regions.

Studies based on potential intensity theory and the higher resolution (<20-km grid) models project mean 2778
global [tropical cyclone] maximum wind speed increases of +2 to +11% (roughly +3 to +21% central pressure fall; Supplementary Information S2) over the twenty-first century. At the individual basin scale, existing multimodel ensemble mean projections show a range of intensity changes from about −1 to +9%.

Even a relatively small shift or expansion of the intensity distribution of storms towards higher intensities can lead to a relatively large fractional increase in the occurrence rate of the strongest (rarest) tropical cyclones. For example, a recent downscaling study [Knutson et al. 2008] using an operational (9-km grid) hurricane prediction model shows a tendency towards increased frequency of Atlantic Category 4 and 5 hurricanes over the twenty-first century. 2779

Tropical-cyclone-related rainfall rates are likely to increase with greenhouse warming. This is a robust projection in model simulations of tropical cyclones in a warmer climate: all seven available studies report substantial increases in storm-centred rainfall rates (Supplementary Information S3 and Supplementary Table S3). The range of projections for the late twenty-first century between existing studies is +3 to +37%. 2780

Changes in tropical cyclone storm-surge potential depend on future projections of sea-level rise — which are uncertain at the global scale [IPCC 2007] and in regional structure — as well as on storm characteristics. Even assuming no future changes in tropical cyclone behaviour, storm-surge incidence from tropical cyclones, the most damaging aspect of tropical cyclone impacts in coastal regions, would be expected to increase because of highly confident predictions that at least some future increase in sea level will occur [IPCC 2007].

Mann, M. E., & Emanuel, K. A. (2006). Atlantic Hurricane Trends Linked to Climate Change. Eos, 87(24), 233-244. doi:10.1029/2006EO240001

The linear correlation between the decadally smoothed series, $r = 0.73$ ($p < 0.001$ for decadally smoothed data, and a one-tailed hypothesis test), indicates that the overall trend and more than half of the total decadal variance in annual tropical cyclone counts can be resolved by SST [sea surface temperature] variations ($r = 0.61$; $p < 0.001$ is obtained if the bivariate statistical model for T(t) is used in place of T(t) itself). R(t), which must include any AMO [The multidecadal oscillatory pattern in Atlantic sea surface temperature] contribution, explains an insignificant four percent (Figure 2) of the decadal tropical cyclone variance ($r = 0.20$, $p > 0.1$ for a one-sided test). In other words, the SST variability underlying increased Atlantic tropical cyclone activity appears unrelated to the AMO.

O'Brien, S. T., Hayden, B. P., & Shugart, H. H. (1992). Global climatic change, hurricanes, and a tropical forest. Climatic Change, 22, 175-190.

Wendland (1977) calculated that if the SST isotherm configuration remains similar, an increase in the SST of the tropical Atlantic of 1.1 °C could result in 19 Atlantic hurricanes per year.
In addition to increasing the SST [sea surface temperature], global warming can be expected to lengthen the hurricane season. This adds to the potential number of hurricanes which can be expected in a given year.

Emanuel (1987), using a Carnot cycle model and 2 x C02 equilibrium temperatures projected by the Goddard Institute for Space Studies GCM II, calculated that the maximum destructive potential of hurricanes can be expected to increase by 40% to 60%.