Chapter 13

Assessing the Vulnerability of the Alabama Gulf Coast to Intense Hurricane Strikes and Forest Fires in the Light of Long-term Climatic Changes

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Summary

Any realistic assessment of the impacts of future climatic changes on the Gulf coast region must take into consideration the effects of global warming on hurricane activity. It has been hypothesized that the hazard of wildfire increases significantly after an intense hurricane strike. However, the lack of long-term records on intense hurricane landfalls and major wildfires has prevented a vigorous evaluation of the hypothesis of hurricane-fire interactions. In this paper, we present a 1200-year record of intense hurricane strikes and wildfires on the Gulf coast based on a study of overwash sand layers, fossil pollen and dinoflagellates, and microscopic charcoal particles in a sediment core retrieved from Little Lake, Alabama. Our data suggest that intense hurricanes (category 3-5 according to the Saffir-Simpson scale) directly struck coastal Alabama at least seven times during the past 1250 years, implying an overall return period of about 180 years. Three of the four peaks in charcoal concentrations are associated with overwash sand layers, implying that major wildfires occurred shortly after intense hurricane strikes. Recent studies suggest that a climatic shift after 1995 may result in heightened hurricane activity along the Gulf coast in the next several decades. This could also lead to increased fire hazard for the forests of the Gulf coast states.

13.1 Introduction

Any comprehensive assessment of climate change impacts on the Gulf of Mexico coast must take into consideration the physical, ecological, and societal impacts of intense hurricanes. During the past 100 years for which instrumental observations are available, the Gulf coast was repeatedly struck by hurricanes, including catastrophic ones like Camille of 1969, a category 5 hurricane that is the strongest to have made landfall on the mainland U.S. coast during the historical period. How vulnerable is the Gulf coast to destructive impacts due to landfalling hurricanes of category 3 – 5 intensities (here referred to as intense hurricanes)? This question can be tackled by statistically analyzing the historical record of hurricane landfalls to derive an estimate of return period or landfall probability for each county along the Gulf coast (Elsner and Kara, 1999; Murnane et al., 2000). However, the period of instrumental observation for hurricane activity is essentially confined to the past 100 years (Neumann et al., 1999), a period too short to include many direct hits by intense hurricanes for most coastal locations. An alternative approach to address this question is by means of *paleotempestology,* a new field of science that studies past hurricane activity by means of geological proxy techniques (Liu and Fearn, 2000a, 2000b). In their pioneer study on Lake Shelby, Alabama, Liu and Fearn (1993) used overwash sand layers found in

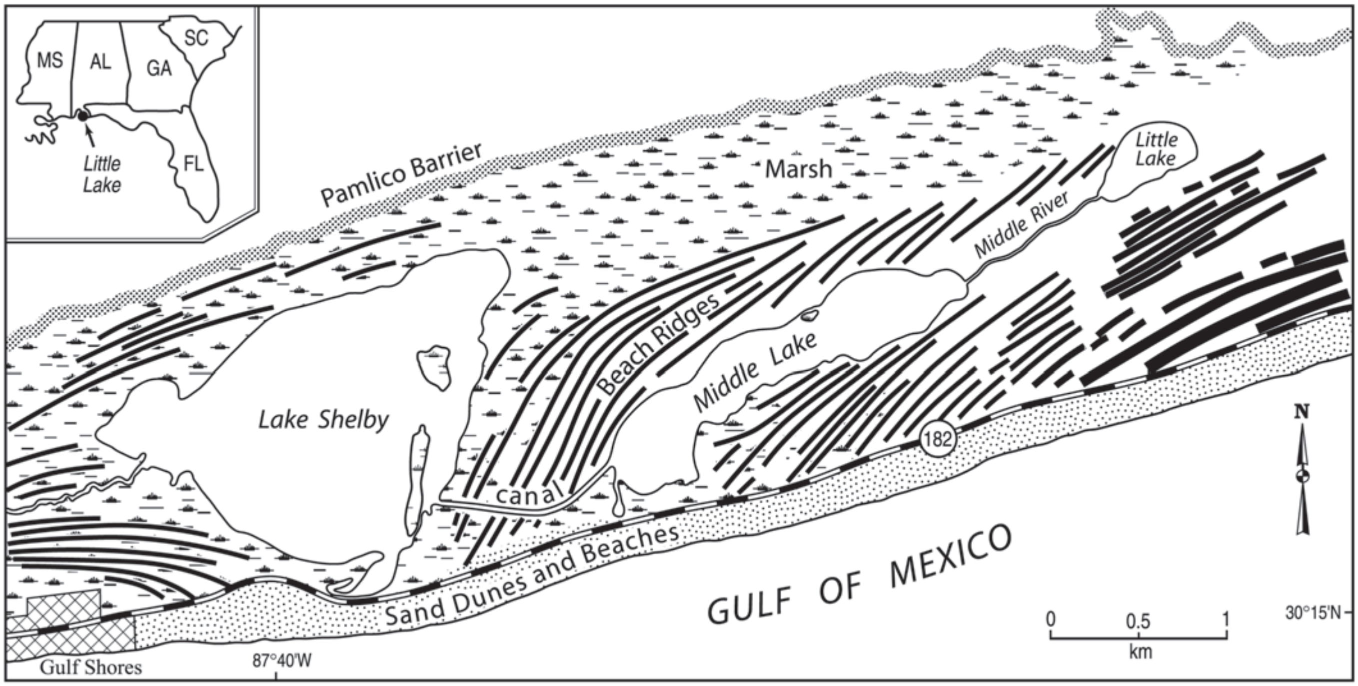

Figure 1. Map showing the location and geomorphic setting of Little Lake, Middle Lake, and Lake Shelby in coastal Alabama. Thick black lines are beach ridges. Black and white line is Alabama State Highway 182.

coastal lake-sediment cores as a proxy for catastrophic landfalls by hurricanes of category 4-5 intensity. Their results suggest that the Alabama Gulf coast near Lake Shelby was directly hit by catastrophic hurricanes about once every 300 years during the last 3200 years (Liu and Fearn, 1993, 2000a, 2000b; Liu, 1999). In this paper, we present a sediment-stratigraphic record from Little Lake, Alabama, a small lake adjacent to Lake Shelby, from which a 1200-year history of intense hurricane landfalls was reconstructed. The Little Lake record supplements the paleotempestological record from neighboring Lake Shelby because this new record registers not only strikes by categories 4 and 5 hurricanes but those by category 3 hurricanes as well.

In addition to disturbance from hurricanes, ecosystems along the Gulf of Mexico coast are also vulnerable to significant disturbance and destruction caused by fires, both of natural and anthropogenic origins. Southeastern pine forests, which are an important natural resource for the Gulf Coast states, are especially fire-prone (Platt, 1999). The linkage between hurricanes and fires has been the subject of many speculations and field observations (e.g., Myers and van Lear, 1998; Webb, 1958; Wade, et al., 1993; Putz and Sharitz, 1991). However, none of these previous studies is based on long-term observations that span more than a few years or at most a few decades after the hurricane impact. Does the risk of fire increase significantly after a severe hurricane impact? One way to answer that question is to study the microscopic charcoal fragments associated with the hurricane overwash sand layers in a sediment core, and compare the charcoal abundance quantitatively with the background charcoal abundance occurring in the organic (non-hurricane) sediments. In this study, we also investigated the history of wildfires in coastal Alabama by means of charcoal and pollen analyses of the same sediment core from Little Lake that has yielded the paleotempestological record. The results allow us to address questions concerning the interactions between hurricane impacts and fire, and shed light on the variability of fire hazard as a function of long-term changes in the hurricane climate along the Gulf coast.

13.2 The Study Site

Little Lake is the smallest of three coastal lakes situated in Gulf State Park between Gulf Shores and Orange Beach, Alabama (Fig. 1). All three lakes (Little Lake, Middle Lake, Lake Shelby) are enclosed by a complex system of beach ridges that may be formed at different times after the mid-Holocene (Liu and Fearn, 1993). The beach ridge plain separating Little Lake from the Gulf of Mexico is about 1.1 km wide, and is fringed on the seaward side by a sandy beach with 1-2 m high dunes. Much of the narrow

Figure 2. Photograph of Little Lake showing the usual calm conditions and the pine-dominated forest along the north shore of the lake.

land strip behind the beach has been converted to paved roads (state highway 182), condominiums, and tourist facilities. Little Lake is a freshwater lake (salinity 0.1 ppt) that drains only a small basin. It has no inflowing stream and connects downstream with Middle Lake only by a very small channel. The lake is about 1.2 m (4 ft) deep, has a flat bottom, and has a maximum length of about 600 m.

Vegetation around Little Lake is a subtropical maritime forest characterized by a diverse association of pines, oaks, hickories, hollies, waxmyrtle, magnolia, and sweetgum (Fig. 2). Pines and sclerophyllous oaks are especially abundant on the sandy beach ridge plain and in drier sites, often with saw palmetto in the understory. Like many pine-dominated communities in the southeastern U.S., the vegetation around Little Lake is a fire-adapted ecosystem.

13.3 Material and Methods

A piston core (core 3) about 60 cm long was taken from Little Lake in the summer of 1997. In the laboratory, the entire core was sampled continuously at 1 cm interval for loss-on-ignition analysis. The sediment samples were heated at 105^{o}C, 550^{o}C, and 1000^{o}C to determine the water content, organic matter content, and carbonate content, respectively (Dean, 1974). The loss-on-ignition technique has been proven to be an effective way to reveal the sediment stratigraphy and to detect the presence of sand layers in the core (Liu and Fearn, 2000a).

Sixty samples, each 0.9 ml in volume and also taken consecutively at 1 cm intervals, were collected throughout the core for pollen and charcoal analyses. Chemical processing for pollen and charcoal analysis followed standard laboratory procedure, which involved treating the samples with 10% hydrochloric acid (HCl), 10% potassium hydroxide (KOH), 49% hydroflouric acid (HF), acetolysis solution, glacial acetic acid, tertiary butanol alcohol (TBA), and repeated centrifuging and decanting (Faegri and Iversen, 1975). During chemical treatment, the samples were stirred gently with a wooden applicator to ensure thorough contact between sediment and the chemical, but caution was taken not to cause excessive breakup of fragile pollen and charcoal particles. One *Lycopodium* tablet containing 12,542 +/- 200 spores was added to each sample before chemical processing to permit estimation of pollen and charcoal concentration in the sample (Stockmarr, 1971). The residues were suspended in silicone oil and mounted on microscopic slides for pollen and charcoal counting.

At least 300 pollen grains were counted in each sample. For *Pinus* (pine) pollen, the intact and broken grains were tallied separately. The number of broken pine pollen (usually fragments of the saccus or corpus) was summed and divided by 3, and that quotient was added to the number of intact pine pollen for the calculation of total *Pinus* percentage in each sample. The abundance of broken pine pollen was also calculated as a percentage of total pine pollen, and this percentage was used as a measure of the degree of mechanical breakage during deposition or during laboratory processing (see below). Dinoflagellates, a marine microorganism, were counted on the same slide as pollen; their presence was used as

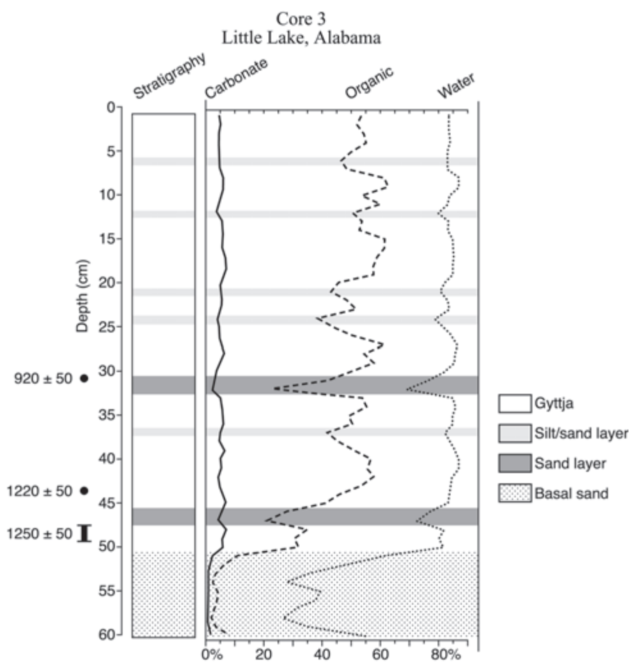

Figure 3. Sediment stratigraphy and loss-on-ignition curves for the core from Little Lake, showing percentages of water, organic matter content, and carbonate content. The AMS radiocarbon date is shown on the left of the depth scale.

an indicator of saltwater influx into this freshwater lake. Microscopic charcoal was also counted on the same slide. Only those charcoal fragments >10 micron in size were counted. Charcoal counts range from 57 to 515, but for most samples the counts are between 100 and 400. In this report, we focus on the information derived from the charcoal, dinoflagellates, and broken pine pollen.

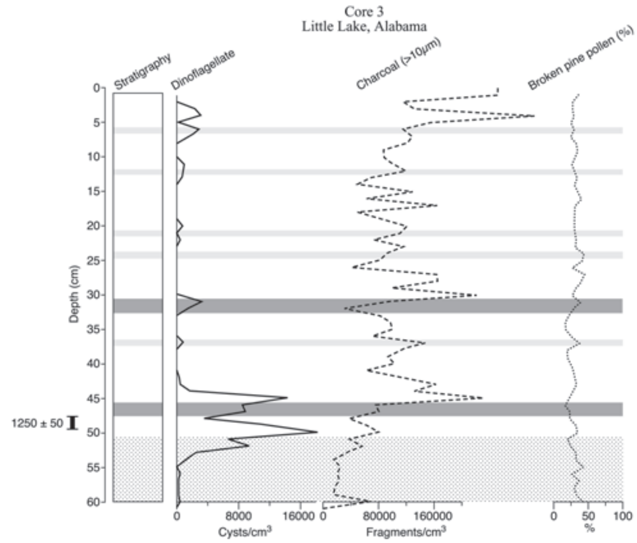

Figure 4. Curves showing the abundance of dinoflagellates, microscopic charcoal, and broken pine pollen (as a percentage of total pine pollen) in the Little Lake core, plotted in relation to the sediment stratigraphy. Sediment symbols are the same as Figure 3.

13.4 Results and Discussion

13.4.1 Sediment Stratigraphy and Hurricane History

The sediment stratigraphy consists of 50 cm of gyttja (organic lake mud) overlying 10 cm of basal sand. An AMS radiocarbon date of 1250 +/- 50 yr BP was obtained from the bulk organic sediment near the base. Two thin but distinct layers of sand were observed at 32 cm and 47 cm in the core. Loss-on-ignition analysis revealed the presence of another five indistinct layers of fine sand or silt (Fig. 3). These sand or silt layers were probably caused by storm overwash associated with intense hurricane landfalls in the past. Little Lake is a small, quiet-water lake with no inflowing streams (Fig. 2). It is situated on a flat topography with virtually no slopes in its surrounding basin. Given this geomorphic setting, it is highly unlikely under normal circumstances for sand or silt to be transported and deposited in the central part of the lake, as evidenced by the highly organic (organic matter content 50 – 60%) sediments contained in the core. Only high-energy events, such as hurricane-force wind and storm overwash occurring during an intense hurricane landfall, would have been possible to mobilize the sand or silt from the beach ridges and sand dunes to deposit in the middle of this otherwise quiet-water lake.

Our interpretation that these sand or silt layers represent overwash events associated with past intense hurricane landfalls is supported by data from dinoflagellates in the core. Dinoflagellates are marine microorganisms that are normally absent or rare in coastal freshwater environments. In the Little Lake core, dinoflagellate cysts are absent in the core top and in most samples in the organic sediments above 44 cm (Fig. 4). However, they occur in great abundance in the lower part of the core from 54 to 44 cm, especially at the top of the basal sand and in and above the distinct sand layer at 47 cm. In the organic section, dinoflagellates occur only sporadically, but virtually all the isolated peaks are associated with the sand or silt layers. The dinoflagellate evidence therefore supports the notion that these sand and silt layers were formed by overwash events, which also introduced seawater into this otherwise freshwater lake.

The two distinct sand layers at 47 and 32 cm have interpolated ^{14}C ages of ca. 1200 yr BP and 830 yr BP, respectively. These are correlative with two major sand layers found in a series of sediment cores from neighboring Lake Shelby, which have been directly dated to 1330 +/- 60 and 1360 +/- 80 yr BP, and 770 +/- 70, 770 +/- 60 and 980 +/- 60 yr BP, respectively (Liu and Fearn, 1993). The sand layers from Lake Shelby have been interpreted to reflect direct hits by catastrophic hurricanes of category 4-5 intensity during prehistoric times. The two sand layers identified from the Little Lake core corroborate the Lake Shelby record and most probably reflect the same catastrophic hurricanes that made landfall on the Alabama coast around 1300 and 800 ^{14}C years ago.

The other five sand or silt layers, at 6, 12, 21, 24, and 37 cm, were less distinct than the two just described (Fig. 3), and probably reflect events of somewhat lower magnitude. Notably, Hurricane Frederic, a category 3 hurricane that devastated the Gulf Shore area when it made landfall in Alabama in 1979, caused a 4.8 m-high storm surge that inundated the coastal plain adjacent to Little Lake (Liu and Fearn, 1993). Thus these five sand or silt layers probably reflect overwash events caused by category 3 hurricanes. Their inferred ages are approximately 940, 630, 520, 290, and 160 ^{14}C yr BP.

The sediment-stratigraphic record from Little Lake therefore suggests that the Alabama Gulf coast near Gulf Shores was directly hit by intense hurricanes (i.e., category 3-5) at least seven times over the last 1250 years, implying an overall return period of 180 years. It should be pointed out, however, that on a millennial timescale, the past millennium was marked by relatively low hurricane activity along the Gulf of Mexico coast. Liu (1999) has reported that the landfall probabilities on the Gulf Coast increased dramatically during a "hyperactive" period between 3400 and 1000 ^{14}C years ago. These millennial-scale variations in hurricane landfalls are probably controlled by long-term shifts in the position of the Bermuda High, which may be ultimately related to long-term changes in the North Atlantic Oscillation (NAO) (Elsner et al., 2000a).

13.4.2 Charcoal Record and Fire History

The curve for microscopic charcoal fragments has a saw-tooth shape with multiple peaks and troughs, but four spikes stand out at 1 cm, 4 cm, 30 cm, and 45 cm (Fig. 4). Remarkably, three of these four peaks occur immediately above a sand layer. This invites the speculation that a connection exists between intense hurricane strikes and fire occurrence. It has been hypothesized that fire hazard in coastal plain forests in the southeastern U.S. increases significantly after an intense hurricane strike (Myers and van Lear, 1998). This is mainly due to an increase in fuel accumulation caused by a great abundance of dry litter on the forest floor, as well as the creation of a drier microclimate resulting from increased insolation and higher wind velocity due to a more open canopy. Although such hurricane-fire interaction has been postulated in a number of post-hurricane ecological studies (Webb, 1958; Craighead and Gilbert, 1962; Loope et al., 1994; Wade et al., 1993; Putz and Sharitz, 1991), few empirical data or direct observations are available to test it. This hypothesis may not be easily testable based on recent hurricane events due to fire suppression and post-hurricane mitigation efforts conducted by modern societies, which alter the natural fire regime of forest ecosystems. Our long-term charcoal record from Little Lake seems to support the hypothesis that catastrophic fire is likely to occur shortly after an intense hurricane strike.

An alternative explanation for the stratigraphic association between sand layers and charcoal abundance is that charcoal particles are more likely to break up into smaller fragments in the turbulent depositional environment during and after an overwash event, thus resulting in an inflated count of broken charcoal fragments. It is also possible that upon vigorous stirring of the sediment sample during laboratory processing, charcoal particles are more likely to break up into small pieces in a sandy matrix than in a more soft organic matrix, which would also result in higher counts of charcoal fragments in sandy samples. To test this hypothesis, we plotted the percentages of broken pine pollen in relation to the charcoal curve and the stratigraphy of the sand layers (Fig. 4). The rationale is that if charcoal abundance is mainly a function of the degree of mechanical breakup of charcoal fragments due to a turbulent depositional environment or stirring vigor, then the abundance of broken pine pollen would also be high in the same samples where charcoal abundance is high. The results show that the four prominent peaks in charcoal abundance do not correspond with peaks in broken pine percentages. Therefore we conclude that the four charcoal peaks reflect the occurrence of wildfires and are not an artifact of the depositional process or the laboratory processing technique.

13.5 Conclusions and Implications for the Future

Long-range socio-economic development and planning for the Gulf coast must be based on realistic assessments of the risks posed by intense hurricane strikes and, perhaps to a somewhat lesser extent, catastrophic wildfires. Until recently there was no empirical means by which both hurricane and fire risks could be estimated, because long-term records (i.e. those spanning more than one or two centuries) of these hazards were lacking. In this paper, we have presented a 1200-year record of intense hurricane strikes and wildfires for the Alabama Gulf coast based on a stratigraphic study of overwash deposits, charcoal, and microfossils in a core from Little Lake. The major findings are summarized as follows.

(1) Over the last 1250 years, the Little Lake area of the Alabama Gulf coast was directly struck by intense hurricanes at least 7 times. Five of these strikes may have been by hurricanes of category 3 intensity, and the other two were probably by hurricanes of category 4 – 5 intensity. The two catastrophic hurricane landfalls, at ca. 800 and 1200 ^{14}C yr BP, were also recorded in the sediments of neighboring Lake Shelby.

(2) For the Alabama Gulf coast around Little Lake, the return period for a direct hit by an intense hurricane (category 3 – 5) is approximately 180 years (7 times in 1250 years). The return period for catastrophic hurricanes (category 4 – 5) only is approximately 600 years (twice in 1250 years). These translate into landfall probabilities of 0.56% per year for all intense (category 3 – 5) hurricanes, and 0.17% per year for category 4 – 5 hurricanes. However, these should be regarded as minimum estimates, because the proxy record may be incomplete (see discussion in Liu and Fearn, 2000a), especially in view of the fact that the Little Lake record is only based on one core. Another caveat is that on a millennial scale, the past millennium, which spans most of the Little Lake record, is characterized by relatively few catastrophic hurricane landfalls along the Gulf coast as compared with the "hyperactive" period 1000 – 3400 years ago (Liu, 1999; Liu and Fearn, 2000a).

(3) The abundance of microscopic charcoal fragments in the Little Lake sediments suggests that wildfires have been common in the coastal ecosystems in Alabama. Of the four prominent charcoal peaks found in the Little Lake core, three lie immediately above sand or silt layers, suggesting that these large fires probably occurred within a few years after an overwash event. These preliminary findings lend support to the hypothesis (Myers and van Lear, 1998) that fire hazard increases significantly after an intense hurricane strike. Since wildfire is a major factor in the management of forest resources for the Gulf coast states, an understanding of the history of fire, and its interaction with hurricanes and climatic changes, is of both scientific and societal significance.

A long-term perspective is necessary for any realistic assessment of hurricane and wildfire risks confronting the Gulf coast region. Our study offers such a long-term perspective by providing a 1250-year proxy record of intense hurricane strikes and wildfire occurrences from coastal Alabama, and documents a possible link between hurricane and fire. What are the implications for the future? Modeling results and theoretical considerations suggest that tropical cyclones (hurricanes) could become more intense in the future if global warming occurs (Emanuel, 1987, 1997; Knutson et al., 1998). Liu and Fearn (2000a) found that, from 3400 to 1000 years ago, the Gulf coast experienced a much more active hurricane regime than what has occurred during the past millennium, implying that if future climatic conditions return to those characteristic of the "hyperactive" period, the Gulf coast may conceivably experience a much higher frequency of catastrophic hurricane strikes. On a decadal timescale, recent studies have revealed a dramatic increase in North Atlantic hurricane activity since 1995 (Goldenberg et al., 2001; Elsner et al., 2000b). The post-1995 increase, which is due to an increase in North

Atlantic sea surface temperature and a decrease in vertical wind shear, is likely to persist for another 10-40 years (Goldenberg et al., 2001). Of greatest relevance to the future climate of the Gulf coast region is the fact that this recent trend is also associated with a return of the "tropical-only" type of hurricanes to the Atlantic basin and a relaxation of the North Atlantic Oscillation (Elsner et al., 2000b; Kimberlain and Elsner, 1998). This may be a bad omen for the Gulf coast region because a weak or neutral NAO is statistically linked to higher probabilities of major hurricane landfall on the Gulf coast (Elsner et al., 2000a; Jagger et al., 2001).

If landfalls by intense hurricanes become more frequent in the Gulf coast region in the next several decades, how would that affect wildfire occurrence? Given the association between hurricane strikes and wildfire occurrence established in this study, it is expected that the overall fire hazard from the aftermaths of hurricane strikes will also increase. Currently, Alabama and adjacent Florida have the highest frequency of wildfires among the Gulf coast states (National Interagency Fire Center, 2001). Moreover, the Gulf coastal zones of Alabama and Florida have the highest frequency of thunderstorm days in the nation (Christopherson, 2000, p. 216), where the hazard of lightning is also high (Curran et al., 1997; Marshall Space Flight Center, 1998). Collectively, these factors suggest that, if there is no human intervention, the risk of post-hurricane wildfires should be high in the Gulf coast region. If future climate change results in more frequent intense hurricane landfalls and increased post-hurricane fire risks for the Gulf coast region, new strategies should be made in our societal response to these important natural hazards.

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References

Craighead, F. C., and Gilbert, V. C. 1962. The effects of Hurricane Donna on the vegetation of southern Florida. Quarterly Journal of the Florida Academy of Sciences 25: 1-28.

Christopherson, R. W. 2000. Geosystems: An Introduction to Physical Geography, 4th edition. Upper Saddle River: Prentice Hall.

Curran, E. B., Holle, R. L., and Lopez, R. E. 1997. Lightning fatalities, injuries, and damage reports in the United States from 1959-1994. NOAA Technical Memorandum, NWS SR-193.

Dean, W. E. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods. Journal of Sedimentary Petrology 44: 242-248.

Elsner, J. B. and Kara, A. B. 1999. Hurricanes of the North Atlantic: Climate and Society. New York: Oxford University Press, 488 p.

Elsner, J. B., Liu, K-b., and Kocher, B. 2000a. Spatial variations in major U.S. hurricane activity: Statistics and a physical mechanism. Journal of Climate 13: 2293-2305.

Elnser, J. B., Jagger, T., and Niu, X. F. 2000b. Changes in the rates of North Atlantic major hurricane activity during the 20th century. Geophysical Research Letters 27: 1743-1746.

Emanuel, K. A. 1987. The dependence of hurricane intensity on climate. Nature 326: 483-485.

Emanuel, K. A. 1997. Climate variations and hurricane activity: Some theoretical issues, in Hurricanes: Climate and Socioeconomic Impacts, ed. H.F. Diaz and R.S. Pulwarty, pp. 55-65. Berlin: Springer-Verlag.

Faegri, K. and Iversen, J. 1975. Textbook of Pollen Analysis. Copenhagen: Munksgaard, 295 p.

Goldenberg, S. B., Landsea, C. W., Mestas-Nunez, A. M., and Gray, W. M. 2001. The recent increase in Atlantic hurricane activity: Causes and implications. Science 293: 474-479.

Jagger, T., Elsner, J. B., and Niu, X. F. 2001. A dynamic probability model of hurricane winds in coastal counties of the United States. Journal of Applied Meteorology 40: 853-863.

Kimberlain, T. B. and Elsner, J. B. 1998. The 1995 and 1996 North Atlantic hurricane seasons: A return of the tropical-only hurricane. Journal of Climate 11: 2062-2069.

Knutson, T. R., Tuleya, R. E., and Kurihara, Y. 1998. Simulated increase of hurricane intensities in a CO2-warmed climate. Science 279: 1018-1020.

Liu, K-b. 1999. Millennial-scale variability in catastrophic hurricane landfalls along the Gulf of Mexico coast. Preprint Volume of the 23rd Conference on Hurricanes and Tropical Meteorology, January 10-15, 1999, Dallas, Texas, pp. 374-377. Boston: American Meteorological Society.

Liu, K-b., and Fearn, M. L. 1993. Lake-sediment record of late Holocene hurricane activities from coastal Alabama. Geology 21: 793-796.

Liu, K-b., and Fearn, M. L. 2000a. Reconstruction of prehistoric landfall frequencies of catastrophic hurricanes in NW Florida from lake sediment records. Quaternary Research 54: 238-245.

Liu, K-b., and Fearn, M. L. 2000b. Holocene history of catastrophic hurricane landfalls along the Gulf of Mexico coast reconstructed from coastal lake and marsh sediments. In Current Stresses and Potential Vulnerabilities: Implications of Global Change for the Gulf Coast Region of the United States, eds. Z. H. Ning and K. Abdollahi, pp. 38-47. Baton Rouge: Franklin Press.

Loope, L., Duever, M., Herndon, A., Snyder, J., and Jansen, D. 1994. Hurricane impact on uplands and freshwater swamp forest. BioScience 44: 238-246.

Marshall Space Flight Center, 1998. Lightning likes land: First three months of data show surprising pattern (http://science.msfc.noaa.gov/newhome/headlines/essd19May98_2.htm)

Murnane, R. J., Barton, C., Collins, E., Donnelly, J., Elsner, J., Emanuel, K., Ginis, I., Howard, S., Landsea, C., Liu, K-b., Malmquist, D., McKay, M., Michaels, A., Nelson, N., O'Brien, J., Scott, D., Webb III T. 2000. Model estimates hurricane wind speed probabilities, EOS, Transactions of the American Geophysical Union 81(38), 433-438.

Myers, R. K. and van Lear, D. H. 1998. Hurricane-fire interactions in coastal forests of the south: A review and hypothesis. Forest Ecology and Management 103: 265-276.

National Interagency Fire Center, 2001. National fire news (http://www.nifc.gov/fireinfo/nfnmap.html)

Neumann, C. J., Jarvinen, B. R., McAdie, C. J., and Hammer, G. R. 1999. Tropical Cyclones of the North Atlantic Ocean 1871-1998. 5th revision. DOC/NOAA Historical Climatology Series 6-2. Asheville: National Climatic Data Center.

Platt, W. J. 1999. Southeastern pine savannas. In The Savanna, Barren, and Rock Outcrop Communities of North America, eds. R.C. Anderson, J.S. Fralish, and J. Baskin, pp. 23-51. Cambridge: Cambridge University Press.

Putz, F. E. and Sharitz, R. R. 1991. Hurricane damage to old-growth forest in Congaree Swamp National Monument, South Carolina, USA. Canadian Journal of Forest Research 21: 1765-1770.

Stockmarr, J. 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores 13: 615-621.

Wade, D. D., Forbus, J. K., and Saveland, J. M. 1993. Photo series for estimating post-hurricane residues and fire behavior in southern pine. USDA Forest Service General Technical Report SE-82. Asheville: Southeastern Forest Experiment Station.

Webb, L. J. 1958. Cyclones as an ecological factor in tropical lowland rain forest north of Queensland. Australian Journal of Botany 6: 220-228.