ABSTRACT

Flood hazard is a reality in the Southeastern U.S., which is exacerbated by the high uncertainty of flood hazard as a result of short, discontinuous stream gauge records. Extreme flood events captured in the instrumental record often represent outliers, however, paleorecords reveal these extreme floods are not as uncommon as indicated by the gauge record. This thesis used radiocarbon-dated alluvial units from published literature and unpublished archaeological reports to develop the Fluvial Activity Database for the Southeastern United States (FADSU). The database aggregates individual fluvial paleorecords along southeastern rivers in order to understand spatial and temporal patterns of flood frequency throughout the Holocene. A meta-analysis of radiocarbon samples from alluvial units was used to create chronologies of floodplain depositional activity (e.g., flooding) and floodplain stability (e.g., soil). Fluvial chronologies were built from summed probability curves that represent the likelihood of age for a radiocarbon sample created in calibration process. Sensitivity analysis of flood ages determined that chronologies are only suitable for basin-wide analysis. Thus, fluvial activity and stability chronologies were created for the Lower Mississippi Basin, Tennessee River Basin, and South Atlantic-Gulf Coast river basins. The Tennessee basin fluvial activity chronology did not show any clear correspondence with only pluvial mechanisms. The Lower Mississippi and South Atlantic-Gulf Coast basins show increased flood probability with reconstructed paleohurricanes from over-wash deposits in Lake Shelby, Alabama. Notably, when one basin demonstrated increased fluvial activity in response to land-falling hurricanes, the other did not show increased fluvial activity at the same time suggesting that the spatio-temporal nature of this meta-analysis
can determine storm tracks of paleohurricanes. This thesis found two high-intensity storm tracks; hurricanes predominately tracked west through the Lower Mississippi 1,300 years ago and east through the South Atlantic-Gulf Coast 700 years ago. The connection of fluvial and coastal paleorecords in the Southeastern U.S. is a novel perspective, and based on these findings, warrants further multi-proxy investigations.
DEDICATION

This thesis is dedicated to those who have supported me throughout my thesis work. Especially my parents, Coleen and Kevin Lombardi, who have always encouraged and supported me in my pursuit of higher education.
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<tr>
<td>C</td>
<td>Radiocarbon Isotope</td>
</tr>
<tr>
<td>AEP</td>
<td>Annual Exceedance Probability</td>
</tr>
<tr>
<td>BP</td>
<td>Before Present</td>
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<tr>
<td>CE</td>
<td>Common Era</td>
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<tr>
<td>CPF</td>
<td>Cumulative Probability Function</td>
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<tr>
<td>FADEU</td>
<td>Fluvial Activity Database of Eastern United States</td>
</tr>
<tr>
<td>FADSU</td>
<td>Fluvial Activity Database of Southeastern United States</td>
</tr>
<tr>
<td>HCO</td>
<td>Holocene Climatic Optimum</td>
</tr>
<tr>
<td>HHA</td>
<td>Hydrologic Hazard Analysis</td>
</tr>
<tr>
<td>kyr</td>
<td>thousand years</td>
</tr>
<tr>
<td>LIA</td>
<td>Little Ice Age</td>
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<td>MCA</td>
<td>Medieval Climate Anomaly</td>
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<td>PMF</td>
<td>Probable Maximum Flood</td>
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<td>SWD</td>
<td>Slackwater Deposits</td>
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<td>U.S.</td>
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ACKNOWLEDGEMENTS

Dr. Gary Stinchcomb and Lance Stewart from Murray State assisted with and contributed to the development of the Fluvial Activity Database of the Eastern U.S. (FADEU). Matt Gage provided access to the archives at the Office of Archaeological Research at the University of Alabama. I would also like to thank my committee and in particular my advisor, Dr. Lisa Davis, for their support and mentorship throughout the entire process of my thesis work. Electric Power Research Institute provided financial support for this project.
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1. INTRODUCTION

As cities and their populations grow in the Southeastern United States (U.S.), understanding flood hazard and management is important for ensuring communities are prepared for inevitable flooding events. Despite considerable management efforts, floods in the U.S. have caused an average of $7.96 billion/year in damages and 82 fatalities/year over the last 30 years (NWS, 2015). In 2016 alone, 126 flood-related deaths occurred in the Eastern U.S. (NWS, 2017). Shortcomings in flood management result, in part, from large uncertainty associated with flood hazard due to a lack of information regarding the frequency and spatial variability of large and rare floods that cause loss of life and infrastructure. Conventional flood frequency analyses depend on short and discontinuous stream gauge data that rarely extend 100 years to estimate recurrence intervals of floods (Lurry, 2011), which is insufficient for understanding the frequencies, magnitudes, or causes of large flood events. Paleoflood hydrology — a geoscience sub-discipline — uses sedimentary and botanical evidence to reconstruct past flood events and extend flood records by thousands of years (Baker, 1987).

Paleo-reconstructions of natural hazards are essential for placing low frequency, extreme flood events, which can be outliers in the instrumental record, in context relative to similar events that have occurred over millennia. For example, a flood that caused 238 deaths occurred in Rapid City, South Dakota in 1972. In the context of only the instrumental record, this flood was a high-outlier and was estimated to have a 500-year recurrence interval, but with the inclusion of seven reconstructed paleofloods and four historic floods, the 1972 flood was estimated as a 200-year recurrence interval and was not an outlier within the flood frequency
model (Harden et al., 2011). This thesis presents chronologies of fluvial active (i.e., rivers are depositing because of flooding or lateral accretion) and inactive periods (i.e., soil or peat development) for major basins of the Southeastern U.S., extending fluvial activity information for the region to the onset of the Holocene. The fluvial chronologies developed for this thesis are used to ask the following questions:

1. How does the frequency of fluvial activity vary across the Southeastern U.S. through the Holocene?

2. Can spatio-temporal patterns of fluvial activity provide insights into flood mechanisms, such as climate change, pluvial mechanism (e.g., hurricanes), or localized phenomena?

Paleofloods are past floods that have not been recorded either through direct, instrumental measurements or documented accounts by non-hydrologists of historical floods (Baker, 1987; 2008). Overbank floodwaters encounter topographic features that create a decrease in velocity (e.g., natural levees and caves) which result in the deposition of suspended sediment load (Benito and O’Connor, 2013). These deposits are called slackwater deposits (SWD), and they can preserve information about the timing and magnitude of the floods from which they were deposited. Paleoflood size can be estimated using indirect energy-based calculations of stratigraphic and hydraulic variables, and can be added to the systematic record (Baker, 2008). Other stratigraphic evidence left by paleofloods, also referred to as paleostage indicators, include silt lines and scour features (Figure 1) (Baker, 1987; Kochel and Baker, 1988; Jarrett and England, 2002). Other types of paleoflood evidence include seed lines, flotsam, and tree scars - referred to as high water marks (Figure 1). Biological evidence of floods may not be preserved long in temperate environments (Benito and O’Connor, 2013).
The term paleoflood hydrology was coined by Kochel and Baker (1982) as a method for incorporating paleofloods into flood frequency analysis, particularly in the case of rare floods. Early concepts of paleoflood hydrology date back to the early 19th century (Costa, 1987). The earliest studies of catastrophic floods in the U.S. consisted of qualitative studies on the origins of wind and water gaps in the Appalachian Mountains from the breached dams of ancient lakes (Thompson, 1800; Mitchill, 1818). One of the first quantitative paleoflood studies (Jackson, 1839) estimated depth and velocity of a past flood by interpreting erosional and depositional features in Maine. Dana (1882) took quantitative analysis of paleofloods a step further by employing hydrologic equations to reconstruct a hypothetical flood in the Connecticut River. The trajectory of progress halted following wide adoption of the glacial drift theory in the United States; as part of the adoption of more uniformitarian explanations of surficial geology and the abandonment of catastrophist ideas (Costa, 1987). Evidence of flood geomorphology is found globally, however, and has restructured how geomorphologists understand fluvial systems (Baker, 2009).

![Figure 1](image.png)

**Figure 1.** Types of paleostage indicators used to reconstruct paleofloods (Jarrett, 1991).
1.1 Paleoflood Hydrology

For over 30 years, paleoflood hydrology has proven to be an effective tool for flood reconstruction and for assessing flood hazard, particularly in arid and semi-arid regions (Ely and Baker, 1985; O’Connor et al., 1994; England et al., 2010). Arid climates help preserve SWD from large floods for several millennia (Kochel and Baker, 1982). These studies are often prompted by the need for flood hazard assessment (Levish, 2002; Harden et al., 2011; England, 2012). There are four general approaches in paleoflood hydrology: establishing non-exceedance thresholds, regime-based paleoflow, floodplain stratigraphy, and paleocompetence (Baker et al, 2002). Although each approach differs in methods and data resolution, all four require geomorphic interpretations and provide improved understanding of a river’s history.

The non-exceedance approach is used to constrain the minimum stage of paleofloods by identifying and dating geomorphic features that lack evidence of inundation (a non-exceedance surface) and therefore, indicate long-term stability (Costa, 1978; Levish, 2002; England et al., 2010). Hydraulic models and shear stress calculations are used to estimate the discharge and the stage required for flood water to inundate a surface (Levish, 2002). A non-exceedance bound is defined as a time interval during which a given flood magnitude has not been exceeded (Levish, 2002). Including non-exceedance bounds into flood frequency curves decreases uncertainty by constraining the upper end of the frequency curve (Levish et al., 1994; Levish, 2002; O’Connell et al., 2002).

The regime-based paleoflow approach does not seek to reconstruct low frequency, extreme floods but instead, aims to extend the systematic record of moderate flow conditions (Baker, 2008). This approach estimates values of high probability events based on observed relationships between mean annual bankfull discharge, paleochannel dimensions and gradients,
sediment types present in the river, and other relevant field observations (Baker, 2008). Regression models based on the aforementioned data are created to determine past discharges. Dury (1976) used this approach to reconstruct discharges for Amazon River paleochannels. Knox (1993) used the regime-based method to reconstruct flood magnitudes and frequencies in the Upper Mississippi basin to understand hydrologic response global climate change. This highly cited work demonstrated non-stationarity of floods and found that only modest increases in temperature (< 1°C) throughout the Holocene resulted in significant increases in the magnitude and frequency of floods in the Upper Mississippi Valley (Knox, 1993).

Paleocompetence approaches use hydraulic variables, such as shear stress, velocity, and stream power to estimate paleofloods based on observed deposition and sediment size (Baker, 2000; 2008). These simple empirical relationships can determine magnitude of a particular paleoflood if the paleochannel dimensions are known; often this is accomplished using hydraulic models such as HEC-RAS. Examples of studies utilizing the paleocompetence approach including O’Connor (1993), which reconstructed a Pleistocene glacial outburst flood from Lake Bonneville spanning four river basins, and Carling et al., (2002), which used laboratory experiments to model initial motion of boulders in bedrock to improve paleohydraulic reconstruction.

Floodplain stratigraphy provides a high-resolution chronology of fluvial activity and morphology (Baker et al, 2002). Benito et al., (2003) also found strong evidence of non-stationarity of floods explained by climate variability on the Tagus River in Spain using combined floodplain stratigraphy and paleocompetence approaches. The paleoflood record from the Tagus River shows increases in flood frequencies that temporally correlate with chronologies in Europe (Starkel, 1991), Israel (Greenbaum et al., 2000), and the Southwestern U.S. (Ely et al.,
1993). The Tagus River paleoflood record did not align with the timing of flood clustering in the Upper Mississippi Valley (Knox, 1993), suggesting that climate’s effect on flood frequency and magnitude varies spatially (Benito et al., 2003).

Floodplain paleoflood reconstruction is also used to apply flood frequency and magnitude information to understanding human environments, such as movements of Native American populations in North America. There have been several theories for cause of the abandonment of Cahokia, a pre-historic population center along the central Mississippi River, including drought, resource exploitation, and conflict. An 1,800-yr paleoflood record in the region, however, suggested that periods of emergence and decline of Cahokia correspond with fluvial stability and high-magnitude floods, respectively (Munoz et al., 2015). The consideration of extreme floods as a factor in population movement is a novel perspective and Munoz et al. (2015) suggests that it should be utilized to understand movements of agricultural societies in other parts of the world. Floodplain studies are also used to demonstrate human effects on flooding. Knox (2001) examined overbank floodplain deposition of the Upper Mississippi River and several of its tributaries to understand the different response to post-European settlement agricultural practices beginning in the early 19th century. Knox (2001) demonstrated that land-use change does not need to be large to begin to affect river flooding and geomorphology. The study identified spatially variable geomorphic response including tributaries that responded quickly (pre-1940) and stabilized by 1950, while the Upper Mississippi River has continued to have high sedimentation rates since 1950. The important message for fluvial geomorphology and flood hazard planning uncovered by this floodplain study was that there is a prolonged lag-time in the effects of poor land-use practices before equilibrium is reached (Knox, 2001). Similar trends are observed by Macklin et al. (2010) in British river systems. A regional fluvial history (~12,000
years) in Britain reveals a gradual decrease in sedimentation through the Holocene post-deglaciation with an abrupt acceleration 1,000 years ago, which corresponded with agricultural activity in Europe (Macklin et al., 2010). These floodplain stratigraphy studies clearly demonstrate the need for spatially and temporally detailed paleoflood context in order to understand complex impacts of human environments on river systems and vice versa.

Flood hazard assessment is frequently the motivation for paleoflood studies in the U.S. Notably, the Bureau of Reclamation, a federal agency that maintains 350 dams in the western U.S., uses a non-exceedance approach by replacing traditional loading models called the Probable Maximum Flood (PMF) with Hydrologic Hazard Analysis (HHA) (England, 2012). The HHA process plots the hydrologic hazard curve – a relationship between peak flow and reservoir volume – against Annual Exceedance Probability (AEP), which represents a range of AEPs to get a complete understanding of loading conditions on the dams (England, 2012). For the rare AEPs, the non-exceedance approach is used to decrease uncertainty in HHA in comparison to statistically extrapolated AEP values (Levish, 2002; England et al., 2010). Studies comparing the PMF and flood discharges derived through paleoflood analyses found it to be a poor metric of flood hazard when compared to physically-derived paleoflood discharges because the PMF is a largely hypothetical model (Jarrett and Tomlinson, 2000). Therefore, slackwater and non-exceedance approaches offer flood hazard insights that can save lives when the PMF underestimates flood discharge or save money when the PMF overestimates flood discharge.

1.2 Regional Syntheses of Fluvial Proxies

Most paleoflood studies provide extensive temporal context of floods for specific locations, such as a 2,000-year Colorado River flood record near Moab, Utah (Greenbaum et al., 2014) or a 4,5000-year Colorado River flood record in Grand Canyon, Arizona (O’Connor et al.,
Each paleoflood reconstruction for a single river reach has its own scientific merit but additional insights can be gained by synthesizing individual fluvial records to develop regional chronologies of floods. Macklin and Lewin (1993) made one of the first attempts at synthesizing fluvial sedimentary archives into a database using radiocarbon dates as a proxy to understand spatial and temporal changes in river systems in Britain. This meta-analysis approach used methods adapted from archaeologists (Williams, 2012) and took advantage of the many published radiocarbon-dated alluvial units that were available in Britain. This earliest version of the British fluvial radiocarbon database developed alluviation chronologies, which found that fluvial episodes over the last 5,000 years were synchronized regionally, suggesting that primarily climate drove flooding events.

After several iterations of the British database, Johnstone et al. (2006) published a landmark paper detailing the development and uses of a radiocarbon fluvial database for regional syntheses. As a result, regional fluvial chronologies were created for river systems worldwide. In Spain, Thorndycraft and Benito (2006) found that in some cases regional flooding was associated with climate variability, but intensive impacts of human land-use caused most of the alluviation in the chronology since most of their radiocarbon dates found were 1,300 years before present or younger. In Germany, Hoffman et al. (2008) developed a 12,000-year fluvial chronology that showed nine periods of increased fluvial activity, and human population density as the main control on sedimentation over the last 3,450 years. Human impacts on fluvial deposition are seen in fluvial chronologies throughout Europe because of Europe’s long history of dense human settlement (Macklin et al., 2006).

Ely et al. (1993) developed the first flood chronology for the southwest U.S., within Arizona and parts of Utah, and discovered that periods of increased flood frequency coincided
with cool, moist climate associated with El Niño. Harden et al. (2010) developed the first fluvial
database to contain bedrock and alluvial river reaches, in the Southwestern U.S. Alluvial reaches
had morphologies that shifted new flood deposition away from previous sites of deposition;
whereas in bedrock channels older deposits were often eroded because of confined settings.
Thus, by combining alluvial flood chronologies, that preferentially preserve older deposits, and
bedrock river flood chronologies, that preferentially preserve younger deposits, a more complete
temporal flood history was created for the region (Harden et al. 2010). This broader regional
chronology revealed that winter storms during cooler climates, and not El Niño/ La Niña patterns
as previously thought (Ely et al., 1993), generated large floods in the southwest U.S. (Harden et
al., 2010).

Over the last two decades, fluvial activity chronologies have been developed in Europe
(Thorndycraft and Benito, 2006; Macklin et al., 2006; Benito et al., 2008; Hoffman et al., 2008;
Turner et al., 2010), North Africa (Zielhofer and Faust, 2008), India (Kale, 2007), New Zealand
(Macklin et al., 2012), and the southwest United States (Harden et al., 2010). Each has
demonstrated the efficacy of regional studies of fluvial activity to help address questions of
fluvial geomorphology, mechanisms for increased or decreased fluvial activity, and human
impacts on river systems. Although, this meta-analysis approach does not explicitly represent
flood histories, fluvial deposition is often tied to an overbank flooding event. To date, no such
fluvial activity chronology has been developed in the Southeastern U.S. and questions regarding
regional flood connectivity and variability through time and space remain unanswered.
2. METHODS

Constructing a regional chronology of fluvial activity requires combining dated fluvial depositional units acquired from different locations into one dataset that can be analyzed for temporal or spatial patterns. Johnstone et al. (2006) used cumulative probability functions, hereafter referred to as CPF, to aggregate radiocarbon-dated alluvial units. The CPF chronologies are constructed by summing the radiocarbon calibration curve probability associated with individual radiocarbon-dated materials. A radiocarbon calibration curve represents the probability that a radiocarbon date represents the true age of a sample. This probability is derived from comparison of the radiocarbon concentration in a sample to the radiocarbon concentration of samples with known ages. Typically, samples with known ages are trees dated with dendrochronology (OxCal, 2017; Figure 2). Figure 3 demonstrates how radiocarbon age probability plots of different samples and alluvial units, but within the same basin, produce age probabilities that overlap in time. For example, probability curves ‘A’, ‘B’, and ‘C’ from two different locations result in the articulation of a peak of relative probability for fluvial activity at that time (Figure 3). These probabilities are summed to identify the overlap of radiocarbon age probability that can be interpreted as being indicative of relative probability of active deposition.
Figure 2. Example of how the radiocarbon concentration of a sample (red curve) is calibrated with tree-ring carbon concentrations (blue cumulative curve) to create a calibration curve of age probability for a single radiocarbon sample (dark grey). (OxCal, 2017).

Figure 3. Example of summed probability curves plots (this study), where A and B = Old River, LA; C = Big Bayou, LA; D and E = Mississippi River, LA. Image is a screenshot from OxCal 4.2 software (Bronk Ramsey, 2009).

Summed cumulative probability plots are used widely by archaeologists across the world to estimate human population sizes from radiocarbon-dated archaeological materials (Rick, 1987; Gamble et al., 2005; Peros et al., 2010; Steele, 2010), and to test hypotheses regarding
demographic response to climate (Williams, 2012). Johnstone et al. (2006) refined the methods of Macklin and Lewin (1993) for using the CPFs to test fluvial hypotheses, and the method was quickly replicated for other river systems (Thorndycraft and Benito, 2006; Hoffman et al., 2008).

Chiverrell et al. (2011) outlined three specific critiques of the CPF method, which follow: first, fluvial systems are dynamic and often re-work previously deposited organic materials used for radiocarbon dating. In these cases, non-contemporary radiocarbon samples may be re-deposited and represent a date older than the event in question. The CPFs in this study rely on reported data from published literature and from archaeological reports. This meta-analysis must operate under the assumption that authors reported correctly interpreted radiocarbon samples. Second, appropriate geomorphological context should be defined for each radiocarbon date to avoid misinterpretation. For example, a radiocarbon date located at the contact of two stratigraphic units represents both the minimum age of the unit below it and the maximum age of the unit above it (Harden et al., 2010). Because of this issue, only studies that provide sedimentological context should be included in a database. The final critique is that radiocarbon, as a geochronology technique, in and of itself, introduces a level of uncertainty because the age is a probable age and not an absolute age. It is challenging to determine whether increased probability is representative of an event or random statistical scatter. A variety of methods have been suggested for dealing with this issue. Originally, the CPF was subtracted by a simulated CPF constructed from evenly distributed radiocarbon data to remove random calibration error (Johnstone et al., 2006). Hoffman et al. (2008) removed the random error associated with the radiocarbon calibration curve by dividing a subset (i.e., a river basin or other geographically-based grouping of data) CPF by the total CPF (i.e., all database entries) created from a much larger dataset of real radiocarbon-dated deposits. It is not guaranteed that all
random error is removed, and as such, Harden et al. (2010) removed individual radiocarbon dates with error ranges > 400 years from subset CPF analysis.

2.1 Fluvial Activity Database for the Southeastern U.S. (FADSU)

The Fluvial Activity Database for the Southeastern U.S. (FADSU) was created from data published in scientific manuscripts and archaeological reports. The decision-making process for the inclusion of a radiocarbon sample shown in Figure 4 has two phases of information acquisition. Phase 1 information must be provided by the published literature or report with enough detail to inform depositional context interpretation. Phase 2 is information that may not be explicitly stated in the text of the report and can be gathered from figures or will be inconsequential to analysis. Many papers do not provide coordinates of their site but latitude and longitude can be estimated using vicinity maps from the publication and finding the area with online satellite and mapping software. All dates in FADSU have lab codes and type of dated material; while this is helpful for rigorous metadata collection, it ultimately does not affect interpretation or analysis. The final step, Phase 3, in the decision-making process is the interpretation of depositional context – based on sedimentary context, and alluvial assemblage – based on the type of fluvial system. Alluvial assemblage designations in FADSU were either actively meandering systems or upland rivers/gullies. Types of depositional contexts include: floodplain fine-grained material, sandy/gravelly alluvium, soil, and peat/wetland/back swamps. Active deposition is represented in the database with the following depositional contexts: floodplain fine-grained deposits, or sandy/gravelly deposits. Periods of stability are represented in the database with the following depositional context: peat/wetland/back swamps, and soils. Radiocarbon-dated units that represent active deposition are referred to as activity dates. Radiocarbon-dated units that represent periods of stability are referred to as stability dates.
Figure 5 shows the site locations of radiocarbon-dated alluvial units in published literature and archaeological reports; site details are found in Table 1 and Appendix 1.

![Decision-making diagram](image)

**Figure 4.** Decision-making diagram for whether a single radiocarbon sample should be included in FADSU for CPF chronology analysis.

In addition to the FADSU, a Fluvial Activity Database for the Eastern U.S. (FADEU) is in preparation. FADEU will include the Ohio River Basin, Mid-Atlantic river basins, and New England river basins, and the FADSU. In this thesis, FADEU was used to improve variation in radiocarbon dates used in the standardization process.
Figure 5. Locations of study samples included in FASDU. Site numbers correspond with publications in Table 1.

2.2 Sensitivity Analysis of FADSU

Activity dates were tested using a Kruskal-Wallis, non-parametric variance test, to determine whether the temporal variability of fluvial activity recorded in FADSU is representative of the entire Southeastern U.S. or whether there is a difference in sensitivity of fluvial activity between basins. The test was performed by sorting FADSU radiocarbon data into activity or stability dates and then grouping these data into the Lower Mississippi River Basin, the Tennessee River Basin, or the South Atlantic-Gulf Coast River Basin (Figure 3). The median calendar age of activity radiocarbon dates for each basin were calibrated using INTCAL 13 (Reimer et al., 2013) in OxCal 4.3 (Bronk Ramsey, 2009). Differences in temporal fluvial
activity variability between basins was tested with the Kruskal-Wallis test at a confidence interval of 95%.

2.3 Fluvial Chronologies for the Southeastern U.S.

Building FADSU and testing data sensitivity resulted in the creation of a summed CPF for each river basin. First, the data were extracted from FADEU and organized to suit the required input for OxCal 4.3 (Bronk Ramsey, 2009). Input was ‘Lab-code’, ‘Uncalibrated Radiocarbon Year’, and ‘Error’ in that specific order. Data were sorted from oldest to youngest ‘Uncalibrated Radiocarbon Year’. Next, data were input into OxCal and extracted from the program via the methods outlined in detail by Macklin et al. (2012). Imported OxcCal data represents five year bins that span the range of the data and the CPFs. Each of these five-year bins contains the summed probability of an event corresponding to one or more radiocarbon dates. Finally, a new column was labeled ‘Date cal. BP’, meaning calendar year before present (1950), and a function added that subtracts 1950 from ‘Date BP’. The above steps were executed individually for Total Population (all FADEU), Lower Mississippi Activity, Lower Mississippi Stability, Tennessee Activity, Tennessee Stability, South Atlantic-Gulf Coast Activity, and South Atlantic-Gulf Coast Stability.

Each grouped (i.e., drainage basin) CPF was divided by the total CPF to remove the influence of the radiocarbon calibration curve and create a standardized CPF (Hoffman et al., 2008; Macklin et al., 2010). The standardized CPF was then divided by the maximum probability of the same dataset to create relative probability (Harden et al., 2010). The relative probability curves were plotted with their respective average probability to highlight peaks of higher likelihood of basin-wide fluvial activity.
Per methods developed by Hoffman et al. (2008), Macklin et al. (2012), and Harden et al. (2010), the following equations were applied to the CPFs in order to standardize these data:

\[
\text{[Eq. 1]} \quad \frac{\text{Subset CPF}}{\text{Total CPF}} = \text{Standard CPF}
\]

\[
\text{[Eq. 2]} \quad \frac{\text{Standard CPF}}{\text{Maximum Standard CPF Probability}} = \text{Relative Probability}
\]

Where:

- **Subset CPF** = CPF of radiocarbon dates only from specific region
- **Total CPF** = CPF of all radiocarbon dates including only CPF values that correspond with temporal extent of Subset CPF

Each basin activity chronology was compared to its respective stability chronology, to other long-term (Holocene) reconstructions of environmental change such as tree-ring chronologies, and to possible mechanisms for increased fluvial activity. Additionally, basin activity chronologies were analyzed to understand the effect of three major climate periods: Holocene Climatic Optimum (HCO) from 6,000 – 4,500 yrs BP, Medieval Climate Anomaly (MCA) from 1,050 – 650 yrs BP, and Little Ice Age (LIA) from 500 – 100 yrs BP. The activity CPF for each region was analyzed for the time interval each climate period represents. In order to compare differences regionally and temporally, a normalized percent activity per region was calculated with the following equation:

\[
\text{[Eq. 3]} \quad \frac{\# \text{ of five–year intervals with above average fluvial activity probability}}{\# \text{ of five–year intervals in climate period}} = \% \text{ Fluvial Activity}
\]

### 2.4 Compiled Fluvial Activity Database of Southeastern U.S.

FADSU is composed of 147 radiocarbon dates from alluvial settings across the southeastern U.S. (Figure 5; Table 1). Three radiocarbon dates with associated error greater than 400 years were excluded from subset analysis. Figure 6 shows the distribution of the number of radiocarbon dates for each basin per depositional context.
Table 1. Fluvial Activity Database for the Southeastern U.S.

<table>
<thead>
<tr>
<th>Region</th>
<th>Site Number</th>
<th># of $^{14}$C Dates</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Mississippi</td>
<td>1</td>
<td>26</td>
<td>Kesel, 2008</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>Alford et al., 1982</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kesel, 2008; Munoz et al. (In Review)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>13</td>
<td>Saunders and Allen, 2003</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3</td>
<td>Barnhart, 1988; Dotterweich et al, 2014</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>Alexander and Prior, 1971</td>
</tr>
<tr>
<td>Tennessee</td>
<td>8</td>
<td>1</td>
<td>Nance, 1986</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>17</td>
<td>Sherwood et al, 2004</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>13</td>
<td>Brakenridge, 1984</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>1</td>
<td>Kocis, 2011</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>4</td>
<td>Kocis, 2011</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>4</td>
<td>Kocis, 2011</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>2</td>
<td>Leigh, 1996</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>4</td>
<td>Leigh and Webb, 2006</td>
</tr>
<tr>
<td>South Atlantic-Gulf</td>
<td>16</td>
<td>2</td>
<td>Webb and Leigh, 1995</td>
</tr>
<tr>
<td>Coast</td>
<td>17</td>
<td>13</td>
<td>Willard et al., 2010</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>1</td>
<td>Bamann and Bradley, 2009</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>4</td>
<td>Gorman and Leigh, 2004</td>
</tr>
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<td></td>
<td>20</td>
<td>1</td>
<td>Leigh et al., 2004</td>
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<tr>
<td></td>
<td>21</td>
<td>2</td>
<td>Waters et al., 2009</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>3</td>
<td>LaMoreaux et al. 2009</td>
</tr>
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<td>3</td>
<td>Leigh and Feeney, 1995</td>
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<tr>
<td></td>
<td>24</td>
<td>6</td>
<td>Leigh, 2006</td>
</tr>
</tbody>
</table>
Figure 6. Composition of radiocarbon data per drainage basin: the Lower Mississippi basin (grey), the Tennessee (horizontal lines), and the South Atlantic-Gulf Coast (black).
3. RESULTS

3.1 Sensitivity Analysis

A Kruskal-Wallis test found that the variation in ages of active deposition between the Lower Mississippi, Tennessee, and South Atlantic-Gulf Coast Basins are significantly different. This means that within basins these data are representative of a homogenous population. For the Kruskal-Wallis test, the H-statistic calculated between basins was 18.29 which is greater than the critical value of the null hypothesis, 5.99. With these findings, significant difference in variation suggests that, in the current state of FADSU, temporal variability of fluvial activity may be sensitive to the difference between basins and are not suitable for explaining a single fluvial activity chronology for the Southeastern U.S. Possible differences affecting fluvial activity between basins include: number and spatial distribution of activity dates in publications used in FADSU, geomorphology, localized pluvial mechanisms, and human impacts.

3.2 Major River Basin Fluvial Chronologies

The Tennessee Basin CPF has five periods of increased fluvial activity probability (Figure 7). Periods with higher than average fluvial activity probability include: 11.5 - 11, 9.5 - 7.9, 6.4 - 6.2, 5.5 - 5.3, and 0.4 -0 kyr BP (thousands of years before present). The Tennessee Basin stability CPFs complement these fluvial activity periods (Figure 7) with above average periods of stability having occurred during: 7.8 - 7.5, 5.9 - 5.6, 5.2 - 3.2, and 0.6 kyr BP. The Lower Mississippi Basin CPF has nine periods of above average fluvial activity probability (Figure 7), including: 11.2 - 10.7, 10.2 - 8.7, 8.4 - 8, 6.2, 5.4 - 5.0, 4.4 - 3.3, 2.7 - 2.4, 0.7,
and 0.4 -0 kyr BP. Periods of above average periods of stability in Lower Mississippi include: 8.7-8.4, 7.9 -5.9, 3.6 -3.3, 0.24, and 0.12 - 0.04 kyr BP. The South Atlantic-Gulf Coast CPF has seven periods of above average fluvial activity probability (Figure 7). Fluvial activity periods include: 11.5 - 10.8, 9.8 - 9.4, 8.5 - 7.5, 6.2, 5.2 - 4.5, 2.5 -1.3, and 0.47 - 0 kyr BP. Periods of stability in the South Atlantic-Gulf Coast CPF include: 9.2, 6.1 - 5.3, 4.4, 1.9 - 1.8, and 0.96 kyr BP. All basins had above average probability for fluvial activity approximately 6,200 years BP.

The sensitivity analysis determined that in the Southeastern U.S. fluvial activity temporal variability is primarily a result of local factors such as hurricanes or land-use. However, fluvial geomorphology studies have demonstrated a relationship between climate and floods (Knox, 2000; Munoz and Dee, 2017). Figure 7 and Figure 8 include three major climate periods overlaid with each southeastern river basin chronology. The HCO was the warmest period during the Holocene with the Northern Hemisphere experiencing average global temperature of 1.6 °C ±0.8 greater than present temperatures (Kaufman et al., 2004). In the southeastern fluvial chronologies, all basins were actively depositing for less than 37% percent of the HCO period (Figure 8). The Tennessee basin and Lower Mississippi basin were actively depositing during 20% of the period (Figure 8). Notably, each basin appears to indicate an event or events approximate 5,300 yrs BP with no other activity clusters (Figure 7). The Tennessee basin stability chronology includes a period of high probability of stability in the region before and after the 5,300 yr BP fluvial activity cluster. Development of stable environments are consistent with paleoecological reconstructions in Canada and the northeastern U.S. (Kaufman et al., 2004).

In North America over the last 2,000 years, MCA was characterized by relative warmer conditions; while the LIA was characterized by relative cooling (Mann et al., 2009a). During the MCA, Lower Mississippi fluvial activity was the dominate fluvial state in the region (Figure 8).
Conversely, the Tennessee and South Atlantic-Gulf Coast basins show no fluvial activity but also did not indicate stability and therefore, this trend is more likely related to lack of data. During the LIA, each basin has at least one high probability event in the latter half of the period (Figure 7). The South Atlantic-Gulf Coast activity chronology is particularly active (88% of period) during the LIA, which is consistent with the Atlantic paleohurricane record (Mann et al., 2009b).
**Figure 7.** Activity chronologies (black line/ positive values) and stability chronologies (grey lines/ negative values) for each major river basin in the Southeastern U.S. Peaks filled in with color represent above-average likelihood of either activity or stability. Light gray bars indicate climate periods: Holocene Climatic Optimum (6,000 – 4,200 yrs BP), Medieval Climate Anomaly (MCA; 1050 – 650 yrs BP), Little Ice Age (LIA; 500 – 100 yrs BP).
Figure 8. Spatial variability of fluvial activity during major climate periods of the Holocene.
4. DISCUSSION

4.1 Chronology Validation

Several methods of validating fluvial activity and stability chronologies demonstrate the efficacy of the CPF curves for estimating the timing and likelihood of a certain fluvial state. This validation is important because the CPF method can have under-represented time periods or poorly represented locations because of spatial variability of studies performed or where sediments are preserved. For the FADSU chronology, stability episodes generally do not overlap with fluvial activity periods, suggesting that the interpretation of sedimentary context used to assign dates to activity or stability episodes was consistent across basins (Figure 7). There are some instances of overlapping above-average activity and stability in the same basin, however, such as in the Lower Mississippi basin from 6,300 to 6,100 yrs BP, and in the Tennessee Basin 7,400 yrs BP (Figure 7). There are three possible causes for this discrepancy. First, these exceptions could be artifacts of the radiocarbon calibration process, rather than actual opposing states of fluvial activity (Chiverrell et al., 2011). Second, the fluvial activity event may not have occurred basin-wide; therefore, other parts of the basin remained stable. Third, the number of radiocarbon dates in the dataset is not yet above the statistical threshold (n> 500) deemed “reliable”, or not liable to change (Williams, 2012). No fluvial radiocarbon database to date is large enough to claim reliability (Jones et al., 2015) and as such, it is possible that with the addition of more radiocarbon dates these discrepancies would be resolved. For the most part, the stability versus fluvial activity chronologies complement each other and provide validation of the CPF method.
Historical accounts of flooding in the southeast provide an opportunity to validate that the chronology correctly identifies increased probability of fluvial activity for known floods. The Tennessee and South Atlantic-Gulf Coast Basins show a general increase in fluvial activity through the 1800’s, which is consistent with Knox (2000) but are not easily identified as single events in their chronologies. Conversely, the Lower Mississippi basin fluvial activity chronology has the most pronounced signals of historical flooding events (Figure 8). Hernando Desoto documented a 40-day long flood, most commonly referred to as the Desoto Flood, in the Lower Mississippi in 1543 CE (Hoyt and Langbein, 1955). This event is captured in the Lower Mississippi River chronology but plots as a lower-than-average probability for basin-wide fluvial activity (Figure 9). Hoyt and Langbein (1955) identified historic accounts of basin-wide fluvial activity on the Lower Mississippi in 1734 CE, 1809 CE, 1825 CE, and 1927 CE. The Lower Mississippi fluvial chronology captures many of these events (Figure 9). The 1927 flood, referred to as the Great Mississippi Flood, is pronounced (visible peak) in the chronology. The extreme floods that one expects should be in the sedimentary record are represented in the chronology, which demonstrates the efficacy of this method.
4.2 Comparison to Other Proxies

The two major drainage basins contributing to the Lower Mississippi are the Upper Mississippi and Ohio basins. The Upper Mississippi paleofloods are well-studied relative to rivers in the Eastern U.S. The Lower Mississippi activity chronology matches periods of large paleofloods in the Upper Mississippi (Knox, 1985) 5,500 – 5,000 yrs BP and 2,500 years BP. Knox (1985) identified three periods of smaller magnitude floods in the Upper Mississippi basin between 8,000 - 6,500, 4,500 – 3,000, and 2,000 – 1,200 yrs BP. The Lower Mississippi chronology demonstrates increased fluvial activity between 4,400 and 3,200 yrs BP but this period was also one of the few periods when basin-wide stability and activity are simultaneous. Based on Knox (1985) findings, small floods may have also occurred across the basin in the Lower Mississippi with no single, basin-wide flood resulting in signals of both activity and stability.
The CPF method is best suited for determining flood frequency over thousands of years. Thus, CPF Chronologies will not often identify a flood in its exact year but rather a short range, such as Desoto Flood and 1927 Floods in Figure 9, which in terms of a 11,500 chronology is a relatively short time period. Dendrochronology in the southeast cannot provide the same temporal length as sedimentary archives, but recently developed tree-ring chronologies provide high temporal resolution, absolute dating of flood occurrence in the Lower Mississippi River basin (Therrell and Bialecki, 2015). The CPF peaks of the Lower Mississippi chronology do not correlate well with the absolute dates of the tree-rings; however, considering the limitations associated with using radiocarbon ages (i.e., probable peaks), the regional events are in the ballpark of the absolute dates. Interestingly, events captured in the dendrochronology record that are not represented in the chronology, i.e. around 1900 A.D., are followed by the 1927 flood which is the flood of record on the Lower Mississippi River. The sedimentary record is vulnerable to scour and the relative size of the 1927 flood may have eroded the smaller preceding floods.
Figure 10. A comparison of the Lower Mississippi fluvial chronology (black) from this study to a flood record reconstructed from tree-ring data (grey bars) modified from Therrell and Bialecki (2015). An increase in percent injured tree means a greater number of sampled trees show cellular damage associated with floods.

4.3 Possible Mechanisms for Large Events

Historically, extreme flood events in the Southeastern U.S. occur because of large convectional or frontal storms and land falling hurricanes (O’Connor and Costa, 2003). Large convectional and frontal storms cannot be discretely recognized in the paleorecord presented here. Land falling hurricanes however, leave over-wash deposits in the sedimentary record, which are utilized for developing paleohurricane records along the coasts (Wallace and Anderson, 2010). Lui and Fearn (1993) applied this method to a core in Lake Shelby, Alabama. Based on an approximately 4,000-year record, hurricanes that were category 4 or 5 occurred 3.5-3.3, 2.8, 2.2, 1.3, and 0.7 kyr BP (Lui and Fearn, 1993; Figure 11). Comparison of the paleohurricane record with all three southeastern chronologies suggests that hurricane land fall may explain some fluvial activity in the Lower Mississippi and the South Atlantic-Gulf Coast chronologies (Figure 10). The Tennessee Basin chronology, however, has no temporal overlap
with reconstructed hurricane chronologies, suggesting that alluvial deposition preserved in this basin may not be coincident with land falling hurricanes over the last 4,000 years. In the Lower Mississippi basin, three of the five hurricanes correspond with increase in fluvial activity. The hurricane that occurred 700 years ago, has the most pronounced increase in fluvial activity (40%) in the Lower Mississippi, suggesting that it may have resulted in fluvial deposition in more locations across the basin than the other hurricanes. In the South Atlantic-Gulf Coast, two out of five hurricanes corresponded with fluvial activity. Again, one of the hurricanes (1,300 yrs BP) has a more pronounced increase in fluvial activity (55%) in the basin. These reconstructed hurricanes, excluding the 3.5 - 3.3 kyr BP range, occur in either the Lower Mississippi (2.9 and 0.7 kyr BP) or the South Atlantic-Gulf Coast (2.2 and 1.3 kyr BP) but not in both during the same event.

Little is known about the tracks of paleohurricanes once they have made landfall because of the lack of regional, multi-proxy comparison. Based on the fact that all reconstructed hurricanes from Lui and Fearn (1993) made landfall at or near the Alabama Gulf Coast and the location of sites contributing to each basins chronology (see Figure 5). The spatial pattern of hurricane associated fluvial activity in the chronology suggesting the 1,300 yr BP hurricane tracked eastward towards the South Atlantic-Gulf Coast and the 700 yr BP hurricane tracked westward towards the Lower Mississippi basin.
Figure 11. Comparison of the Lower Mississippi basin (black), the Tennessee basin (black dotted line), and the South Atlantic-Gulf Coast basin (dark grey) to the paleohurricane record (light grey vertical bars) reconstructed by Lui and Fearn (1993).

Comparing the Southeastern fluvial activity chronologies to hurricanes also revealed that many peaks of increased fluvial activity do not correspond with reconstructed hurricanes (Figure 11). These periods of fluvial activity have alternative mechanisms, but there is currently no paleoclimate record to discern other types of runoff-generating events that resulted in flooding. To date, paleohurricane records for the region extend only a few thousand years. It is possible that hurricanes are a dominant mechanism for large events at other periods in the chronologies. However, based solely on available data, hurricanes do not appear to be the dominant mechanism of basin-wide fluvial activity in any of the southeastern basins.

4.4 Future Directions and Research Questions

Fluvial chronologies for the Southeastern U.S. provide extensive insight into where fluvial deposition has occurred and how frequently. Magnitude, however, is not represented by the CPF chronologies. Now that frequency of basin-wide fluvial activity events in the southeast is well-constrained, a direct reconstruction of the magnitude of these events should be completed to provide a full understanding of flood hazard in the Southeastern U.S. For example, all three
basins indicate fluvial activity around 6,200 yrs BP. This event could represent three scenarios: (1) three basin-specific events that happened to occur in the same year, (2) a wet period that caused aggradation, or (3) a single event that covered all three basins and created fluvial activity across the entire southeast. If the latter is true, this type of event must be known for flood hazard planning purposes. Current proxy records for the southeast are not long enough to interpret these periods of fluvial activity. Therefore, targeted investigation of the magnitude and mechanism of these periods of fluvial activity is warranted.

Based on the observed trends between the Lower Mississippi and South Atlantic-Gulf Coast fluvial activity chronologies and paleohurricane records (Figure 11) further questions exist regarding the application of this multi-proxy approach for understanding the connection of fluvial activity and paleohurricanes in the Southeastern U.S.

Finally, the FADSU is the first iteration of a fluvial radiocarbon database for the Southeastern U.S. The database will be maintained at the University of Alabama for public use, and will be expanded as new literature becomes available.
5. CONCLUSIONS

Three 11,500-yr fluvial chronologies were developed and validated for the Lower Mississippi, the Tennessee, and the South Atlantic-Gulf Coast Basins. These chronologies provide several pieces of important spatio-temporal insights into periods of fluvial activity in the Southeastern U.S.: (1) the three basins have significantly different chronologies, suggesting either meta-analysis limitations or local basin factors are effecting river sensitivity to activity-causing events, (2) the fluvial activity chronologies appear consistent with known historic floods and events documented in the available paleorecords and historical accounts; (3) paleohurricane records corresponded with two high probability fluvial activity dates, but do not appear to be a driver of fluvial activity in the Tennessee Basin, and are not the sole driver of fluvial activity in any basin; and (4) by comparing marine and fluvial chronologies it may be possible to reconstruct hurricane tracks inland. This method is best utilized as a big picture of fluvial activity over several millennia. While further research into the magnitude of events represented in these fluvial activity chronologies is still needed, this work contributes to a better understanding flood hazard in the Southeastern U.S.
REFERENCES


Harden, T.M., O’Connor, J.E., Driscoll, D.G., and Stamm, J.F., (2011), Flood-frequency analyses from paleoflood investigations for Spring, Rapid, Boxelder, and Elk Creeks,


