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Original article

Winter in the Ouchitas—A severe winter storm signature in *Pinus echinata* in the Ouachita Mountains of Oklahoma and Arkansas, USA

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ABSTRACT

Each year severe winter storms (≈ice storms) damage trees throughout the southern USA. Arkansas and Oklahoma have a history of severe winter storms. To extend that history back beyond the reach of written records, a distinctive tree ring pattern or signature is needed. Storm-caused breakage, branch loss and bending stress provide that signature. We found a severe storm signature in shortleaf pine (*Pinus echinata*). We used three published site chronologies, a set of five new site chronologies from a growth-and-yield study conducted by Oklahoma State University and the unpublished Shortleaf Canyon chronology from a master's thesis at the University of Arkansas. Our method is based on two ring width values for the first and second growing seasons after the storm standardized to the ring widths of the seven growing seasons after the storm. Concordance between storm years predicted by tree ring patterns and actual storm years was tested using Cohen's Kappa. Concern about confounding of ice storm signals by droughts led us to test concordance between severe storms and drought in July, August and September; results were inconclusive but stand as a warning that these two phenomena cannot be distinguished with certainty in the tree ring record. Damaging severe storms occurred in about 2.8% of all years. Two out of three storms identified as "severe" produced glaze icing.

1. Introduction

Severe winter storms, including both snow and ice storms, are some of the most important causes of forest disturbance (Bragg et al., 2003). The December 2000 ice storms in Arkansas damaged or destroyed 82,100 ha of *Pinus echinata* (Burner and Ares, 2003) and heavily damaged stands in LeFlore and McCurtain Counties in Oklahoma.

To plan investments, planting and harvesting schedules, forest managers need to know how frequently these storms occur in individual stands and how damaging they might be. Climatologists and meteorologists need dates and severity data when studying past climates and weather patterns and to correct precipitation and drought severity chronologies for the occurrence of large storms. Because severe winter storms are infrequent, data collection must either await their happening or be done using tree ring proxies.

Ice storms occur most frequently in eastern North America where warm, moist air masses from the Gulf of Mexico ride up over frigid air masses from Canada, setting up inversion layers (Gay and Davis, 1993). Snow forms at the top of the warm layer, falls into warmer air below and melts. Raindrops become super-chilled when they fall into the cold layer near the ground, freezing in a phase-change reaction when striking an object, such as a power line or twig (Michaels, 1991).

Glaze icing events are quite patchy in rugged topography (Millward et al., 2010). Damaged areas are usually oriented southwest-to-northeast (Lecomte et al., 1998) and can be as narrow as 15 km and as wide as 250 km (Lemon, 1961).

Severe winter storms affect the width of tree rings (Travis et al., 1989; Lafon and Speer, 2002), presumably through loss of photosynthetic capacity and the need to use stored carbohydrate to repair

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damage. Studies in Georgia and South Carolina (Travis et al., 1989) found ice damage accounted for 10-19% of ring width variance in *Pinus taeda* beyond 25–39% explained by temperature and precipitation. *P. taeda* damaged in an ice storm had reduced ring width five years after the storm (Belanger et al., 1996). Lack of a well-defined storm signal made reconstruction of storm chronologies from tree ring series difficult.

The term "ice storm" means specifically, a storm that produced glaze icing. "Severe winter storm" includes ice storms, but may also include snow, graupel, freezing rain, sleet and frequently all of them. There is no clear divide between "ice storms" and other storms and no clear divide between "large" and "small" storms.

In this study we (1) determine that there is a signal in tree rings that is associated with severe winter storms, (2) describe that signal, and (3) use it to construct sample histories of winter storms at specific sites. Our method uses ring widths standardized to the seven growing seasons following a suspected severe storm. This signal allows researchers to characterize long term variations in weather patterns at a landscape scale and permits climate, specifically severe winter storms, to be studied at finer scales and farther back in time than other records allow (Phipps, 1982).

2. Methods

In 1985 Oklahoma State University (OSU), in cooperation with the USDA Forest Service, established a growth-and-yield study of shortleaf pine (*P. echinata* Mill.) on the Ouachita National Forest in eastern Oklahoma and western Arkansas. Eighteen plots (0.08 ha) from a previous study were updated and 189 new plots installed. Tree diameters and heights were re-measured at approximately five-year intervals. In December 2000, two major ice storms (December 12–13 and December 25–27) caused severe damage to many trees and plots. These are referred to collectively as "the Christmas 2000 ice storm." An opportunity arose to study effects of severe storm damage on trees and stands with known growth histories.

Eighty-seven plots from the study were already measured for an update when the Christmas 2000 ice storm struck. The measurement protocols were re-designed to include ice damage data and the remaining plots measured, creating two groups of plots for the 2000/2001 update: those measured before the storms and those measured after them. After the 2006 update, a study of ice-caused damage was initiated. Plot measurements included pre-storm total height for all trees and height at the break for trees with broken trunks.

Tree ring data was obtained from OSU study sites at Caddo Gap, Cold Springs, Knoppers Ford, Sand Lick and Story, the Shortleaf Canyon Chronology (Cerny, 2009; Stevenson et al., 2014a,b) and the Hot Springs (Stahle et al., 1982), Lake Winona (Stahle, 1980) and McCurtain County (Stahle et al., 1982) chronologies (Fig. 1). Data was cross-dated, then intercorrelation was determined using COFECHA (Grissino-Mayer, 2001). This produced a set of nine site chronologies which we truncated to include only years with at least eight observations. Spans thus produced were: Caddo Gap: 1947–2008 (62 years); Cold Springs: 1945–2008 (64 years); Knoppers Ford: 1929–2007 (74 years); Sand Lick: 1943–2007 (65 years); Story: 1924–2007 (84 years); Shortleaf Canyon: 1868–2008 (131 years); Hot Springs: 1777–1982 (206 years); Lake Winona: 1745–1980 (236 years) and McCurtain County: 1749–1982 (234 years). We further truncated chronologies to include only years after 1884 (Fig. 2) due to the unreliable nature of earlier records.

Climatological Data (NCDC, 2011a) records are lists of daily and monthly temperatures and precipitation with occasional notes on ice accumulation, sleet and snow. There were 31 stations that

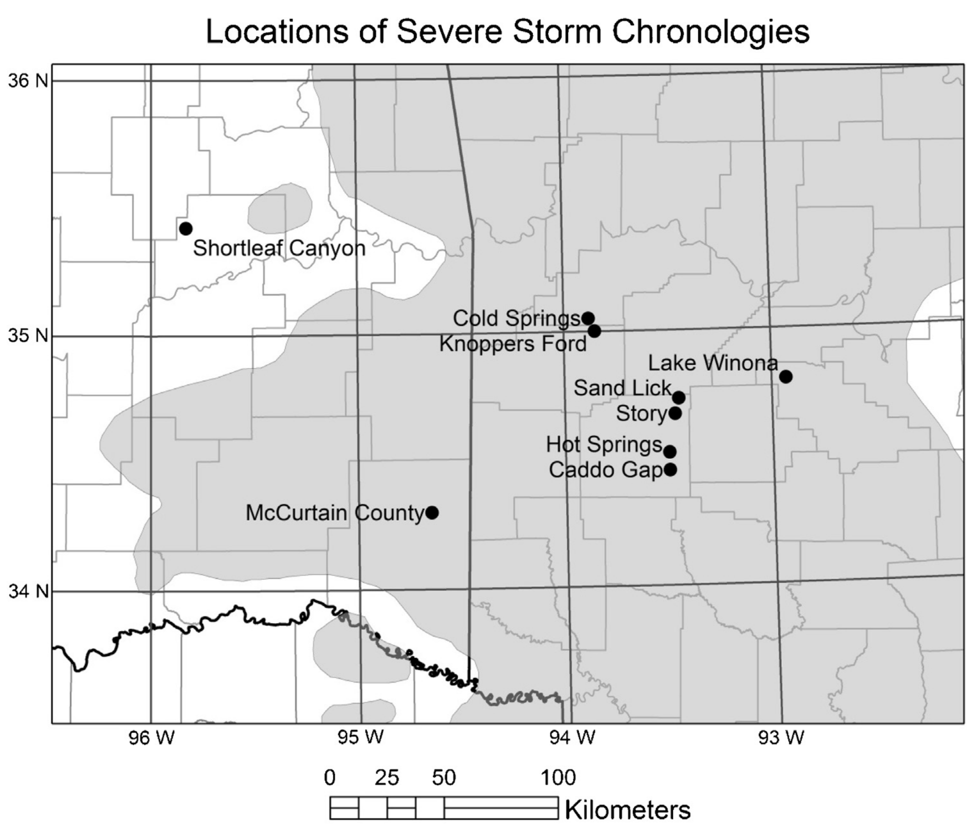

Fig. 1. Severe storm study sites. Map includes five Ouachita site chronologies, the Shortleaf Canyon chronology and three older site chronologies from the NCDC. Shaded area indicates the natural range of *P. echinata*. Shortleaf Canyon is one of five outlier stands that lie west of *P. echinata*'s principle range. Map data from ArcGIS.