Determination of Sweetgum Tree Circumferential Periodicity due to Evapotranspiration and Environmental Conditions

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ABSTRACT: For a five week period meteorological and atmospheric field research was conducted in an urban forested location within the Atlanta, GA metropolitan area. Previous research by Bogatkevich (2004) suggests a correlation between precipitation amounts and radial tree growth on the diurnal scale. This project was designed to examine the relationship between the boundary layer and evapotranspiration occurring within the forest canopy. The study also investigated links between the environmental conditions and the biological responses, both on diurnal and longer-term scales, by observing changes of the tree circumference of Sweetgum (*Liquidambar styraciflua*), a species native to the mid-Atlantic region. These environmental conditions include insolation flux, soil water content, atmospheric temperature and relative humidity. Biological responses include fluctuations in vascular sap flow and periodic opening and closing of stomatal pores. Various numerical techniques were employed, including Fourier transforms and natural spline curve fitting to determine the periodicity of change in the tree circumference record.

INTRODUCTION

Evapotranspiration is a combination of two processes: evaporation and transpiration. Evaporation releases water from the ground and from the exposed surfaces of vegetation. Both processes contribute directly to atmospheric water vapor; transpiration, however, releases water from within the vegetation via the stomatal pores. If the volume of water transpired by a single tree can be accurately calculated, the results can be used to parameterize a theoretical forest of similar trees. In the absence of fog or clouds, insolation has an evident diurnal pattern with its instantaneous value dependent upon solar zenith angle and on the ratio of the actual distance with the mean distance of the earth to the sun (Arya, 33). As surface insolation increases there is a rise in the net energy balance. This rise causes an increase in the air temperature which in turn results in an increase in the rate of evapotranspiration by reducing the relative humidity. Evapotranspiration is greatest during periods of high insolation. It can therefore be theorized that at the point in the day when insolation is at its greatest, a tree's water loss rate is greatest.

Jake Peters, a hydrologist with the U.S. Geological Survey in Atlanta, has conducted research correlating evapotranspiration to stream height fluctuations (2004). He has observed diurnal cycles and fluctuations in stream flow patterns. Peters believes that they are related to the uptake of water by trees and vary with the rates of evapotranspiration. Rostislav V. Bogatkevich, of the National Academy of Sciences in Belarus, measured daily radial growths peaking at 6:30 and 18:30. The radial growths were between 3mm and 4mm on a Blue Spruce with a trunk diameter of 160 mm at height of 15 meters above the ground. This is equivalent to changes of approximately 18mm to 24mm on a tree with a circumference of 480mm, or 0.7 inches to 0.9 inches on trees with a circumference of 18.9 inches (2002). However, Bogatkevich's observations focused on radial growth, the accompanying results focused on diurnal radial changes. Students in the previous years' Research Experience for Undergraduates (REU) at Clark Atlanta University (CAU) recorded similar changes in measurements over a 3 week period during drought conditions in the summers of 2002 and saturated conditions in 2003. With more water available, the daily changes in circumference were expected to be significantly larger. Expectations were to record drops in tree circumferences at or closely following the diurnal period of maximum insolation. By linking circumference changes with stream height and meteorological site observations, the intention was to develop a model (using Forward Fourier Transforms and natural spline curve fitting) to predict the periodicity of radial tree fluctuations in response to changing environmental conditions.

Figure 1. Hourly tree measurement

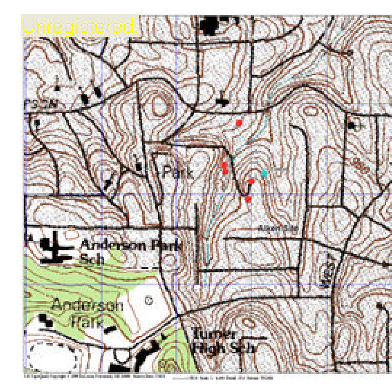


Figure 2. Topographical map of the Aiken Site location based on GPS measurements. Red dots are the location of trees. The blue dot shows the location of the control site.

PROCEDURE

The observation site is located approximately six kilometers west of the center of Atlanta at an elevation of 250 meters above sea level at coordinates 33° 45.695" N 84° 26.812" W. While still within the city of Atlanta, the site is a forested area with two small creeks off of a main road. The soil is generally a red clay loam that is typical of that area of Georgia. During periods of high water flow and rainfall, the creeks fill with sediment-laden water due to the dense surrounding vegetation. Erosion is clearly evident in both creeks as exposed roots mark the former location of the banks. Constant erosion of sediment created a small waterfall about 20 meters downstream of the gauge that often shifted and caused a readjustment of stream levels after a storm. Climatologically, the temperatures of the Georgia Piedmont region during the summer months fall within the low 30°C range with precipitation averaging about 0.127m (Climatology)

Six Sweetgum trees were studied for evidence of circumferential change cycles. Three of the trees are located along the creek and three are significantly uphill away from the creek and the water table (figure 2). Sweetgums are large deciduous trees that are clearly identifiable by their distinctive seedpods and five-lobed leaves. This species is widespread throughout the Southeast and grown naturally as far north as Connecticut.

Hourly measurements were taken continuously (when possible) during a period between June 15, 2004 and July 16, 2004. These observations included tree circumferences (figure 1), stream height, air temperature, wet bulb temperature, soil temperatures, fractional cloud cover, and precipitation. Fractional cloud cover was visually estimated every hour by the observer on duty while other observations were made with various analog instruments. Every minute dataloggers sampled air temperature, humidity, air pressure, soil temperature and moisture profiles, insolation, net radiation, and soil matric potential. Hourly surface observations were taken from METAR archives of the ASOS station at Brown Field/Fulton County Airport, (KFTY). Upper air sounding data was taken from Falcon Field / Peachtree City (KFFC, 72215).

Trees were recorded in the same order during each observation to ensure that the measurements were taken as close to the same hourly time as possible. Eight team members rotated through three shifts per day, each taking eight hourly measurements. Missed observations were entered in as blank cells in the database.

The height of tree measurements were marked using four nails on each tree above which the steel tape measurements were made. Inconsistencies in bark surface did contribute to some measurement errors. In order to calculate the standard deviation seven of the eight of observers measured three times each of the six trees resulting in an average standard deviation of 0.090 inches; the deviation for the stream was 0.078 inches. Due to inconsistencies in the gathering of rainfall data, the stream height measurements were used as a proxy for determining significant precipitation events (figure 3a).

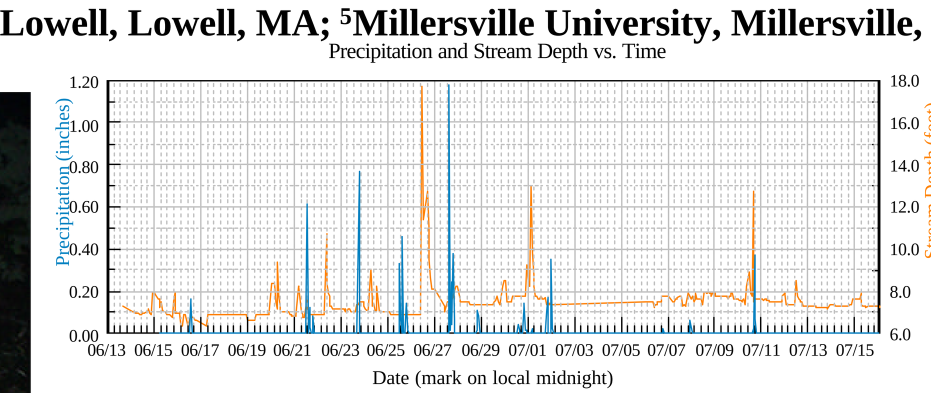


Figure 3a

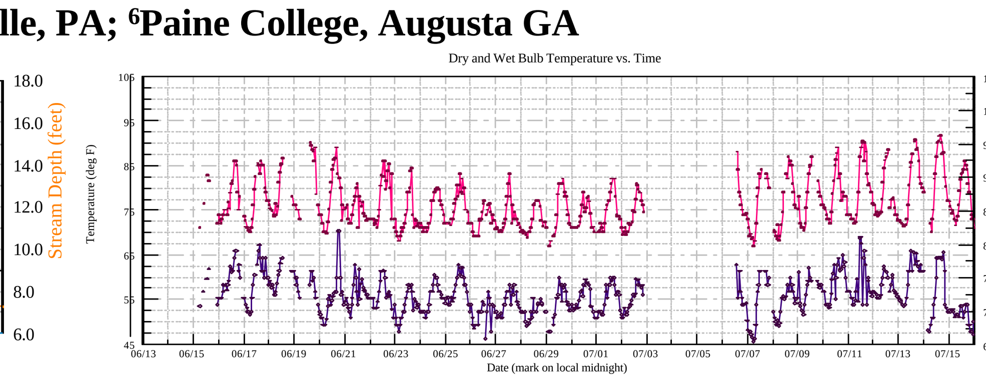


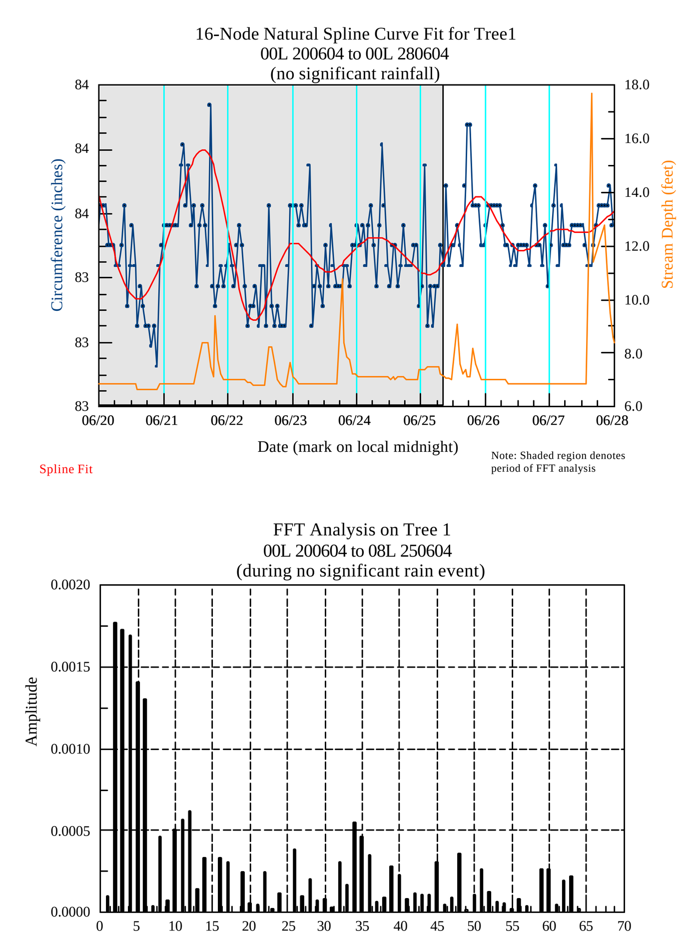
Figure 3b

DISCUSSION

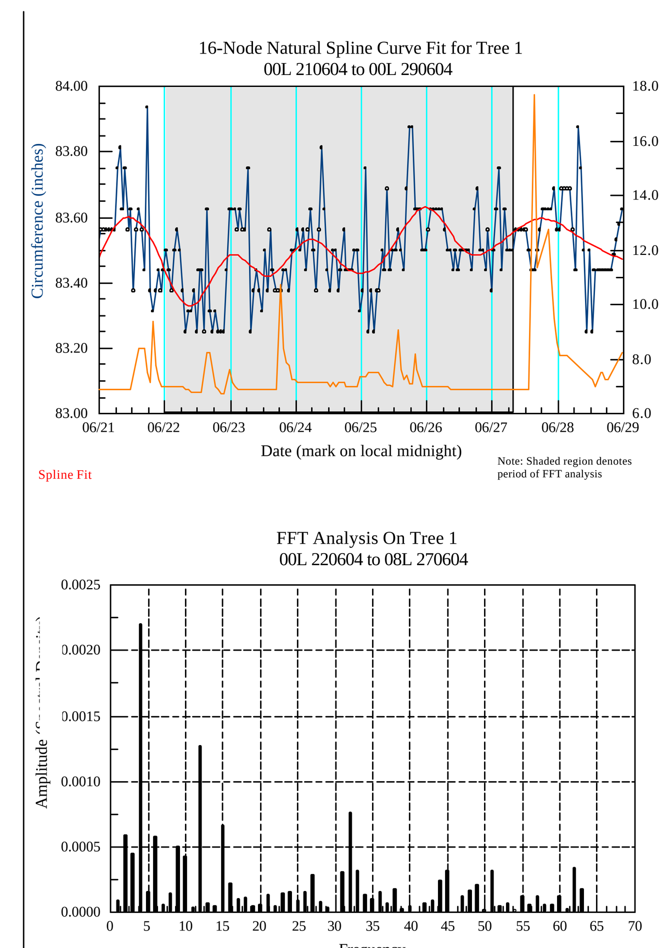
Environmentally, daytime high temperatures were generally around 30°C (~86°F, figure 3b) with dew points rarely moving from the low 20°C (~68°F) range, thus complicating evapotranspiration rates. Thunderstorms were common during the afternoon and evening hours hence not only making observations dangerous due to lightening but also generating sudden rises in the stream height. A year-long dry-spell was broken in the course of the month of observations. Heavy rain transformed the predominantly clay soil into a slurry mud. After about a week of rain the soil, had become saturated causing all new rain thereafter to be discharged as runoff. Wet conditions were common throughout the field work with drier weather returning at the end of the study.

A diurnal cycle of expansion and shrinkage was expected to appear in the tree circumference data. However, the data contained discontinuities and was slightly erratic, necessitating numerical techniques for extracting any periodicity in the data. A natural spline-curve was fitted to the tree circumference plot in order to render an extrapolated sinusoidal waveform, shown here for Tree 1 (Control Site, above the water table; figures 4a and 4c) and Tree 4 (directly above the water table; figures 5a and 5c). These spline curves utilized a fit which minimized the sum of squared deviations between data points. This technique allowed for a rapid check for any deviations from a purely diurnal pattern evident in the measurements.

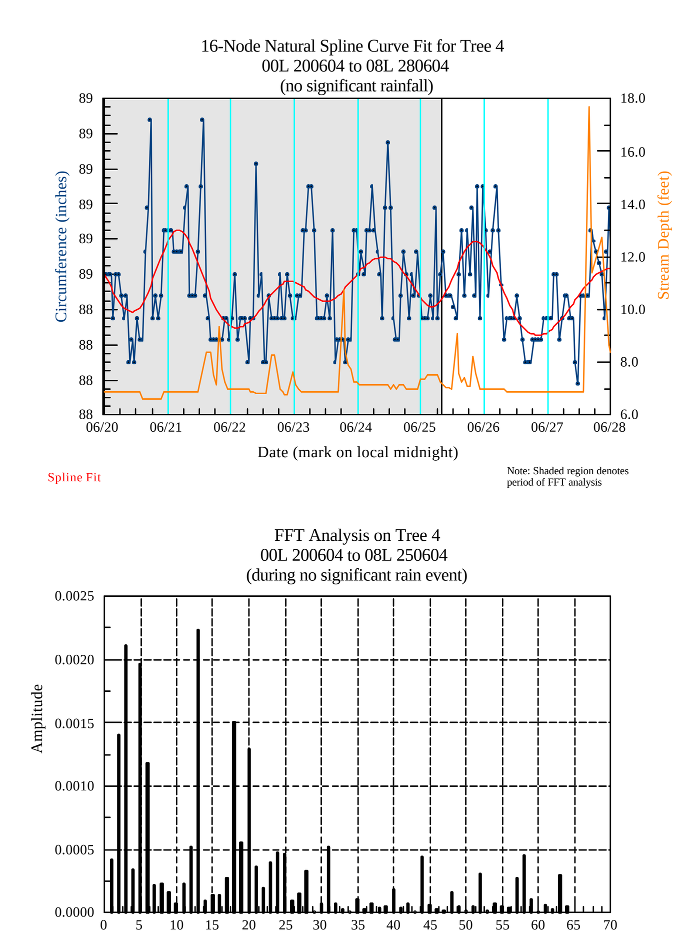
For analysis the time period from 20z June 24th to 20z July 2nd was selected due to the initial relatively dry pattern interrupted by the later segment characterized by more severe and frequent precipitation events. The two trees were selected due to their respective position in relation to the water table as well as two time periods for each tree. The spline curve plots for the initial time period for both trees reveals a near diurnal pattern in Tree 1 whereas the period for Tree 4 is more attenuated, due in part to the saturated soils near the stream banks which dampened the effect of precipitation and circumferential fluctuations.



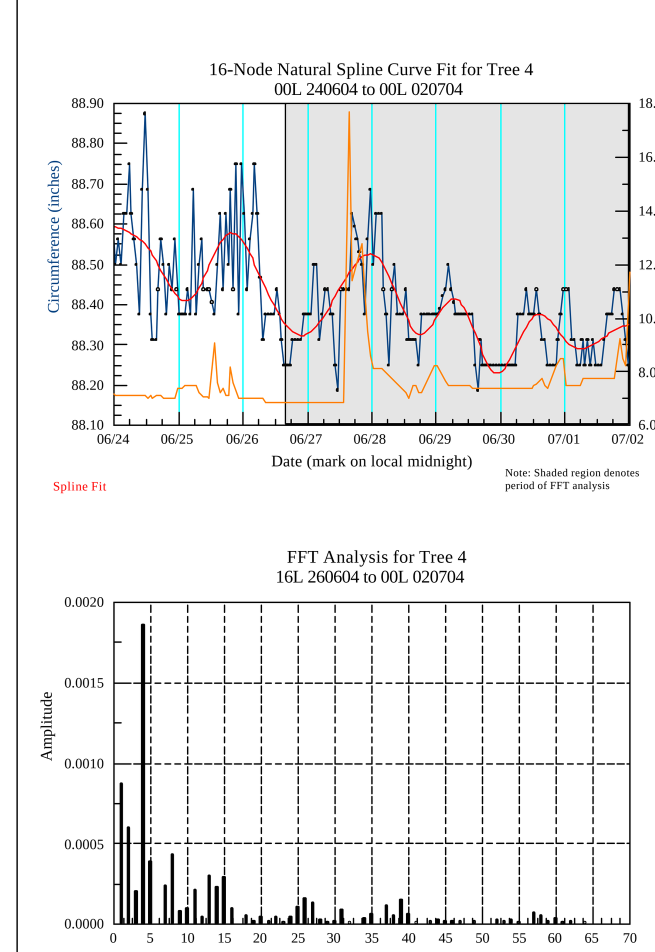
Figures 4a-b.



Figures 4c-d.



Figures 5 a-b.



Figures 5c-d.

In order to distinguish the spectral densities of the frequencies embedded in the data, a Fourier decomposition was used on the same trees (figures 4b,d ad 5b,d). When calculating the Fast Fourier Transforms (FFT), an interval of five and one-third days was selected for examination (128 hourly points). The FFT plots are actually a subset of the sixteen-node spline plots as shown by the shaded areas in the spline plots. The FFT plots for the non-significant preciitation span (figures 4b and 5b) reveal little in the way of explicit evidence for any dominant periodicity, although in both plots frequency 5 (128÷5=25.6, which coincides closest with the diurnal frequency) is quite prominent. In examining the spline plots for the rain events (figures 4d and 5d) it was apparent there were only 4 periodic cycles even though it was thought that there would be approximately five cycles during the examination interval (which was true for all but one of the trees). The FFT plots further prove a concentrating of the frequency of the periodicity around 4-5 which implies periods of between 25.6 and 32 hours. Figures 4d and 5d coincided with four precipitation events, two of which were the most severe during the field study. The relationship between major precipitation events and the tree circumference spline appears to reveal a reaction delay of approximately three to six hours. This delay was attributed to rainwater soaking into the ground. It was then postulated that this delay would dampen the diurnal cycle sought from this analysis by the stated three to six hours at least, thus accounting for the expansion in the cycle noted in the Fourier Transforms.

CONCLUSIONS

During this field study, it was originally assumed that the trees would exhibit diurnal fluctuations in their circumference due to the dynamic interaction with the environment. It was shown that above-average precipitation during this time frame lead to a dampening effect in the trees' natural circumferential fluctuations. These fluctuations imply that the biological functions are sensitive to variances in precipitation (even during saturated times) in conjunction with temperature and insolation changes which thus merits further study. Diurnal cycles in tree circumference seem to be masked by environmental changes of slightly greater time scales. Fourier analysis clearly shows these environmental cycles as evident in distinct, non-diurnal frequencies.

FURTHER RESEARCH

The biological processes behind the cycles observed during this period still require additional investigation using the data at hand. Water vapor exchange through the stomal pores and nutrient flow (including water) through the xylem to the leaves are both specific processes that should be examined. Synoptic scale weather patterns have yet to be examined for correlations to the environmental conditions. Insolation and advective fluxes should also be more closely examined for correlations to evapotranspiration rates and environmental conditions.

REFERENCES

Arya, S. Pal, 2001. *Introduction to Micrometeorology*. 2d ed. Academic Press, 33 pp.

Bogatkevich, Rostislav, cited 2004. The Diagrams of a Tree Radial Growth in a Condition of Water Deficiency. [Available online at http://rostik8.narod.ru/index-3.html.]

Georgia State Climate Office, cited 2004. Climatology of the Georgia Piedmont. [Available online at http://climate.engr.uga.edu/pubs/piedmont.pdf.]

Peters, Jake, 2004. Personal Email to Dr. Randal Mandock

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