Rio Grande Tree-Ring Monsoon Workshop

New Mexico State University
Las Cruces, NM

September 19, 2013

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Welcome and Introductions

New Mexico State University

Laboratory of Tree-Ring Research
The University of Arizona

Climate Assessment for the Southwest

The information and research presented here are the result of the efforts of many people and a variety of funding sources (I’ll get back to this)
Today’s Agenda

• Tree-ring workshops background
• Tree Rings 101 in brief: using tree rings to reconstruct past climate, applications
• Reconstruction of the Rio Grande/Otowi, lower Rio Grande monsoon precipitation
• Comparison of records of past streamflow and monsoon precipitation over past centuries; current conditions in context
• Some words on the Rio Conchos watershed reconstruction
• Discussion, questions, comments, and suggestions for next steps

THIS IS INFORMAL!
PLEASE FEEL FREE TO ASK QUESTIONS AND MAKE COMMENTS
Workshop #1: Tree-Ring Reconstructions of Hydroclimatic Variability in the Rio Grande Basin, NM, November 2, 2007

The goal of this workshop was to expand and improve the usability of tree-ring based reconstructions for drought planning and resource management in the Rio Grande basin.


We convened a follow-up workshop to deliver new reconstructions for the Otowi gage, and create TreeFlow web page for New Mexico to feature Rio Grande region reconstructions.


The purpose of this workshop was to provide information about how tree-rings document not only past streamflow but monsoon precipitation in the Middle Rio Grande region.

Purpose of this workshop

- Provide you with information about tree-ring reconstructions for Rio Grande flow, lower Rio Grande monsoon, and Rio Conchos precipitation
- Learn from you how this information could be made more useful for planning and management
Rio Grande water year streamflow (Otowi gage, Del Norte gage)

Lowe Rio Grande June-July total precipitation

Rio Conchos basin October-July total precipitation
Part 1.

Overview of Tree Rings and Climate Reconstruction

- how trees record climate
- how reconstructions past climate and hydrology are developed
- uncertainty in reconstructions
- kinds of information from reconstructions
How tree rings record climate information
The formation of annual growth rings

- New wood forms in the vascular cambium, underneath the bark
- Earlywood + latewood = growth ring
- In temperate climates, growth ring = *annual ring*
- Ring widths vary according the factor which is most limiting to growth, typically climate in the southwestern U.S.
What trees are the best recorders of precipitation?

Typically (but not always), trees that are limited by moisture, growing on open, well-drained sites, with thin soils

Douglas-fir  Pinyon pine  Ponderosa pine
The moisture signal recorded by trees in the Southwest is particularly strong Here, the ring widths from one tree are closely correlated to the western Colorado precipitation \((r = 0.78)\) from 1930-2002
Annual tree growth of some tree species is associated with winter snowpack in Colorado and New Mexico.

Since snow is the major source of water for the Rio Grande headwaters, it is possible to use tree rings to reconstruct past streamflow.
How does this work?

Ring widths and streamflow both integrate the effects of precipitation (especially winter snowpack) and evapotranspiration, as mediated by the soil, over the course of the water year.
How climate reconstructions are developed: field work to statistical model
1. Field Collections

An increment borer is used to sample cores from about 20 trees at a site.
2. Sample Preparation

Cores are mounted and sanded, then dated, and measured
3. Detrending the measured series

- Ring-width series typically have a declining trend with time because of tree geometry.
- These biological trends are not related to climate so are removed.
- Raw ring series are detrended with straight line, exponential curve, or spline.
- These standardized series are compiled into the site chronology.
4. Compiling the Tree-Ring Chronology from the measurements from many trees

Van Bibber, CO
(ponderosa)
30 series from 15 trees

Chronology = basic unit of tree-ring data, “building block” for the climate reconstruction
Tree-ring chronologies in North America > 200 years
Colored triangle are moisture sensitive chronologies

Species
- JUOC
- JUSC
- JUVI
- PIAZ
- PIED
- PIMO
- PIPO
- PSMA
- PSME
- QUDG
- TADI
- TAMU
- other
5. Generating the climate reconstruction

Tree Ring Chronologies (predictors) → Statistical Calibration: regression (most common approach) → Reconstruction Model

Observed Climate (e.g. precipitation) (predictand) → Reconstruction Model

Climate reconstruction → Model validation

based on Meko (2005)
Requirements for observed climate or hydrology records

- **Length** – minimum 40 years for robust calibration with tree-ring data

- **Quality** – screened for station moves, changes in instrumentation, natural or estimated natural flows.
  - Gridded climate data are now commonly used
Requirements for tree-ring chronologies

- **Moisture sensitive species** – primarily Douglas-fir, ponderosa pine, pinyon pine

- **Location** – from a region that is **climatically linked** to the region of interest

- **Length tradeoff**: fewer chronologies available further back in time (and in recent years, to some extent)
Reconstruction modeling strategies

- Linear or multiple linear regression are most common
  - one common version of linear regression is principle components regression
- Other approaches are possible (e.g., quantile regression, neural networks, non-parametric methods)
6. Model validation and skill assessment

- Are regression assumptions satisfied?
- How does the model validate on data not used to calibrate the model?
- How does the reconstruction compare to the gage record?

Regression model explains 81% of the variance in the gage record.
7. The model is then applied to the full-length chronologies to produce a record of past climate variability

Reconstruction of Colorado River at Lees Ferry, 1490-1997

Woodhouse et al. 2006
Sources of Uncertainty in Climate Reconstructions

• Trees are imperfect recorders of climate.

• The reconstruction model never explains 100% of the variance in the observed record.

• Climate or hydrology data may contain errors.

• A variety of decisions are made in the reconstruction process, all of which can have an effect on the final reconstruction.

• BOTTOM LINE: A reconstruction is a *best estimate* of past climate, and each annual point represents the central tendency of a range of plausible values, given the uncertainty.
An Example: Colorado River at Lees Ferry Streamflow Reconstructions, 1977-2007

Differences are due to a variety of factors:

- calibration data used
- selection of tree-ring data
- treatment of tree-ring data (e.g., detrending)
- statistical methods for model calibration
What tree-ring reconstructions provide:

• context for assessing instrumental climate or gage record over a longer time frame

• a way to evaluate recent drought events in terms of natural variability over past centuries

• a framework for understanding the range of drought characteristics (intensity, duration, magnitude) that has occurred

• insights on low-frequency (scale of decades to half century) variability

• an understanding of the rich sequences of wet and dry years that have occurred over past centuries
TreeFlow web pages: A resource for water managers

- tree-ring basics
- reconstruction and gage data
- workshop presentations
- applications examples
- references

http://treeflow.info/
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http://treeflow.info/

Basin Map

The map below shows the streamflow reconstructions currently available for the Rio Grande Basin. Select a gage to view the page for that reconstruction. Select an adjacent basin to visit the TreeFlow homepage for that basin. A list of the reconstructions available for the basin is presented below the map.

Rio Grande Basin Reconstructions

<table>
<thead>
<tr>
<th>Streamflow Reconstruction Page</th>
<th>Period</th>
<th>Data File</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rio Grande near Del Norte, CO</td>
<td>1508-2002</td>
<td>riograndedelnorte.txt</td>
</tr>
<tr>
<td>Saguache Creek near Saguache, CO</td>
<td>1520-2000</td>
<td>saguache.txt</td>
</tr>
<tr>
<td>Alamosa River above Terrace Res., CO</td>
<td>1932-2002</td>
<td>alamosa.txt</td>
</tr>
<tr>
<td>Conejos River near Mogote, CO</td>
<td>1508-2002</td>
<td>conejos.txt</td>
</tr>
<tr>
<td>Rio Grande at Otowi, NM (NRCS flows)</td>
<td>1460-2002</td>
<td>riograndetonirncs.txt</td>
</tr>
<tr>
<td>Rio Grande at Otowi, NM (Natural flows)</td>
<td>1460-2002</td>
<td>riograndetoninatural.txt</td>
</tr>
<tr>
<td>Santa Fe River near Santa Fe, NM (Short)</td>
<td>1502-2007</td>
<td>santafeshort-santafelong.xls</td>
</tr>
<tr>
<td>Santa Fe River near Santa Fe, NM (Long)</td>
<td>1305-2007</td>
<td>santafeshort-santafelong.xls</td>
</tr>
</tbody>
</table>

Other Hydroclimatic Reconstructions developed for, or including, the Rio Grande Basin:

- Summer (JJA) Palmer Drought Severity Index (PDSI), covering most of North America on a 2.5-degree grid
- Cool season (Nov-Mar) precipitation for each climate division in New Mexico and Arizona, extending back 1000 years (Ni et al. 2002)
- Annual (June-June) precipitation for northwestern New Mexico, extending back 2100 years (Grissino-Mayer 1996)
Part 2.

Streamflow Reconstruction for the Rio Grande at Otowi
Streamflow Reconstruction for Rio Grande at Otowi, NM

The reconstruction model was calibrating using the average of 17 tree-ring chronologies (GREEN TRIANGLES)
Streamflow Reconstruction for Rio Grande at Otowi, NM

Reconstruction explains 74% of the variance in the gage record.
Rio Grande, Otowi reconstructed natural streamflow
Water Year 1450-2002
and natural flow estimate for gage, 1958-2007
(10-yr moving average)

<table>
<thead>
<tr>
<th>5 Driest Decades</th>
<th>5 Wettest Decades</th>
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<tr>
<td>1576-1585</td>
<td>1978-1987</td>
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<td>1772-1781</td>
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<tr>
<td>1623-1632</td>
<td>1610-1619</td>
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<td>1874-1883</td>
<td>1912-1921</td>
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<td>1893-1902</td>
<td>1831-1840</td>
</tr>
<tr>
<td><strong>1950-1959</strong></td>
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</tbody>
</table>
Rio Grande, Otowi Reconstruction, Statistical Characteristics by Century
Drought Duration and Frequency, Otowi
Drought is defined as a single year or set of consecutive years below the long-term median

![Graph showing drought duration and frequency](image)
Part 3.

Lower Rio Grande monsoon reconstruction: a slightly different approach
Circulation shifts between June and July result in a ridge of high pressure over the southwestern U.S., and advection of moisture into the region.
The US Southwest has a bimodal precipitation regime: winter rain/snow and summer monsoon.

This precipitation regime is reflected in the sub-annual ring widths increments, called earlywood (EW) and latewood (LW) in several southwestern tree species.
Earlywood & Latewood

**Earlywood**
- Lighter color
- Less Dense
  (Larger cells/thinner walls)
- Conducts water & nutrients

**Latewood**
- Darker color
- More Dense
  (Smaller cells/thicker walls)
- Provides structural stability
Earlywood & Latewood

1874

LW
Dry Summer

EW
Wet Winter
Earlywood & Latewood

<table>
<thead>
<tr>
<th>Year</th>
<th>EW</th>
<th>LW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1873</td>
<td>EW</td>
<td>LW (Dry Summer)</td>
</tr>
<tr>
<td>1874</td>
<td>LW (Wet Winter)</td>
<td>EW (Dry Summer)</td>
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</tbody>
</table>
Earlywood & Latewood
## Earlywood & Latewood

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<thead>
<tr>
<th>Year</th>
<th>LW</th>
<th>EW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1874</td>
<td>Dry Summer</td>
<td>Wet Winter</td>
</tr>
<tr>
<td>1873</td>
<td>Dry Summer</td>
<td>Wet Winter</td>
</tr>
<tr>
<td>1872</td>
<td>Wet Summer</td>
<td>Wet Winter</td>
</tr>
<tr>
<td>1871</td>
<td>Wet Summer</td>
<td>Dry Winter</td>
</tr>
</tbody>
</table>
Earlywood & Latewood

(Griffin et al. 2011 *Tree-Ring Research*)
Earlywood & Latewood

(Giffin et al. 2011 *Tree-Ring Research*)
Earlywood & Latewood

![Earlywood & Latewood example](image)

### Correlation Chart

- **Oct-Apr**
- **Jul-Aug**

**p < 0.05**

- **TW**
- **EW**
- **LW**
- **LW_a**

(Griffin et al. 2011 *Tree-Ring Research*)
Earlywood & Latewood

(Griffin et al. 2011 *Tree-Ring Research*)
Monsoon Project* Chronology Network

*A National Science Foundation-funded project just completed. For more information, see: http://monsoon.ltrr.arizona.edu/
Location of Lower Rio Grande Monsoon Region and Chronologies used for June-July Precipitation Reconstruction.
Lower Rio Grande Region average monthly precipitation (based on 1896-2010)

The monsoon reconstruction is based on June-July total, ~ 55% of the June-August total
With this reconstruction, we are getting early and mid-monsoon precipitation -- not the entire season.

However, June + July is fairly representative of June-August precipitation (correlation between JJ and JJA = 0.76)
Monsoon Reconstruction (June-July) for the Lower Rio Grande Region, 1896-2008

Reconstruction model explains 53% of the variance in the precipitation record.
Monsoon Reconstruction (June-July) for the Lower Rio Grande Region, 1659-2008

Annual values (gray line) and 10-year running average (blue line)
Monsoon Reconstruction (June-July, 10yr moving average)
Wettest and Driest Decades (non-overlapping)

<table>
<thead>
<tr>
<th>5 Driest Decades</th>
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<tr>
<td>1664-1673</td>
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Lower Rio Grande June-July Drought Duration and Frequency

Drought is defined as a single year or set of consecutive years below the long-term median.

2 events:
- 1900-1906
- 2001-2007

But 2006 only 0.001" Below the median
Rio Grande Reconstructions

Annual values (gray line) and 10-year running average (red or blue line)
Rio Grande Reconstructions

Annual values (gray line) and 10-year running average (blue line)

EXAMPLES of PERIODS with WET AND DRY CONDITIONS in both seasons
Rio Grande Reconstructions
Annual values (gray line) and 10-year running average (blue line)
EXAMPLES of PERIODS with OPPOSITE CONDITIONS in the 2 seasons

Lower RG Monsoon

% average

WET
DRY
Trending
DRY

Rio Grande flow

% average

DRY-ish
DRY
DRY
WET

year

1650 1700 1750 1800 1850 1900 1950 2000
Part 4.

Analysis of Monsoon and Rio Grande Streamflow Reconstructions

- Are summer droughts longer than winter (i.e., from streamflow) droughts?
- How closely are Rio Grande water year streamflow and monsoon precipitation related?
- How often do low flows and dry monsoons occur in the same year?
- How does the recent sequence of wet and dry years compare to sequences of years over the past centuries?
Drought Duration and Frequency, Otowi Flow and Monsoon Precipitation, 1659-2002

Drought is defined as a single year or set of consecutive years below the long-term median.
Comparison of Rio Grande Otowi Water Year Flow and June-July Precipitation

1659-2002 (monsoon to 2008)
smoothed with a 20-year moving average

Note: On an annual basis, Otowi flow and June-July precipitation are uncorrelated (observed record, $r = -0.03$; reconstruction, $r = 0.13$, 1958-2002), and just barely significant for the full reconstruction, $r = 0.14$ ($p < 0.01$)
Concurrence of dry periods* in Rio Grande headwaters flow and Monsoon precipitation

Series were filtered with a 5-year running mean. Only periods with values in the 30th and 15th percentiles are shown. The percentiles are inverted to emphasize drought severity.
Numbers of years with shared and opposite wet and dry conditions by 50-year periods

Wet and dry years are those in the highest and lowest third of values, respectively.
Sequences of wet/dry/moderate monsoon precipitation and Rio Grande flow years

Shared wet

Shared dry

Opposite conditions (though both periods close to average @ 102%)

Recent conditions

ORANGE = DRIEST 1/3
BLUE - WETTEST 1/3
WHITE = MIDDLE 1/3
Current conditions in a long-term context
2012 and 2013 Streamflow and Monsoon Conditions

Streamflow forecasts for spring and summer

Precipitation totals for June-July-August
Water stored in Elephant Butte Reservoir (1915-2010) as a percent of its full capacity of 2.195 million acre-feet at the beginning of the water year on October 1.

Elephant Butte and Caballo Storage, August 28, 2013

Looking at averages over 10-15 year periods: While never the lowest, 21st century Rio Grande flow ranks in 2nd or 3rd lowest of 13-14 yr periods (period ending 1963 and/or 1964 has lower flow)

In terms of driest 10 to 15 year periods, the 21st century trails periods in the 1900s, late 1930s-40s, and 1950s, coming in at the 37th driest of all 11-yr periods (other length periods rank wetter)

*Very similar results for June-July-August
While we cannot make direct comparisons of conditions beyond the reconstruction (2008 for monsoon, 2002 for flow), an assessment of the instrumental records allow us to compare the driest/lowest flows in the 20th century with the reconstructions.

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**Rio Grande/Otowi Flow, 1450-2002**

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**Lower Rio Grande June-July precipitation, 1659-2008***

In the gaged Rio Grande flows, the decade of 2002-2011 ranks 7th behind the 1950s (for Del Norte gage).

*note: June-July reconstruction is shorter than flow reconstruction; does not get the late 16th century, which is a dry monsoon in AZ.

In the instrumental record, the 21st century decades trails decades in the early 1900s, late 1930s-40s, and 1950s, coming in at the 45th driest of all 10-yr periods.

*note: June-July reconstruction is shorter than flow reconstruction; does not get the late 16th century, which is a dry monsoon in AZ. 

*note: June-July reconstruction is shorter than flow reconstruction; does not get the late 16th century, which is a dry monsoon in AZ.
Rio Grande Flow and Rio Conchos Precipitation Reconstructions

Woodhouse et al. 2012, *Climate Research*
Comparison of total water year precipitation and Oct-July precipitation*, Mexico Division 5, Rio Conchos basin

*Because of the information we could extract from the tree-ring data available, we could only reconstruct Oct-July total precipitation.
Comparison of total water year precipitation, Oct-July precipitation, and Rio Grande headwaters water year flow.

Correlations:
Water year precipitation and RG water year flow, $r = 0.080$
Oct-July precipitation and RG water year flow, $r = 0.111$
Comparison of observed (light line) and reconstructed (dark line) Rio Grande streamflow and Rio Conchos precipitation
Reconstructed Rio Grande streamflow and Rio Conchos watershed October-July total precipitation, 1649-1993
(smoothed with a 20-year filter)

Yellow shading indicates periods when values in both reconstructions are below average.
Summary

• By analyzing total, earlywood and latewood widths from tree rings, it is possible to reconstruct streamflow, cool season, and monsoon (at least for a portion of the season) precipitation.

• When Rio Grande streamflow and monsoon are compared, there is no relationship between the two on year-to-year time scales (both in observed and reconstruction data), but perhaps some coherence at longer times scales.

• The occurrence of years with shared flow/monsoon conditions and opposite conditions is variable over time.

• Recent conditions in Rio Grande flow and lower Rio Grande monsoon precipitation have yet exceeded the severity of the 20th century; reconstructions suggest longer, more severe droughts are possible.

• Conditions in the Rio Conchos and the Rio Grande headwaters are largely uncorrelated, but drought have been synchronize in both regions in the past.
Tree rings and multiseason drought variability in the lower Rio Grande Basin, USA

C. A. Woodhouse,1,2 D. M. Mcdo,2 D. Griffin,2,1,3 and C. L. Castro3

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2 School of Geography and Development, University of Arizona, Tucson, Arizona, USA
3 University of New Mexico, Albuquerque, New Mexico, USA


1. Upper and Lower Rio Grande Basin Drought

[Text continues...]
New Mexico Earth Matters

Winter 2013

Tree-ring Insights on New Mexico’s Monsoon and Rio Grande Stream Flow

Recent drought conditions have caught the attention of many people, and a question commonly asked is: How bad is this drought? Is it the driest series of monsoon years, and are these the lowest flows the Rio Grande has ever experienced? Are these drought conditions an indication of climate change, or just part of the natural variability of the climate system? How often are winters with low mean followed by dry monsoon? Cage record of rainfall and stream flow for this region are little more than 100 years in the best cases. Do these records fully capture the range of conditions that could occur under natural climate variability?

It is possible to extend instrumental records back in time using historic or geologic evidence from sources such as tree rings, corals, ice cores, and sediments from the bottoms of lakes and oceans, all of which can reflect climate variations in their rings or layers. Data from these sources, called paleoclimate proxy data, provide information about past climate, before the time of modern climate measurements. Tree rings have been especially useful for documenting variations in rainfall, drought, and stream flow in New Mexico, because the growth rings in several tree species that grow in this state are limited by moisture. These species include Douglas fir and ponderosa pine. A small ring in these trees indicates dry conditions and a wide ring indicates wet conditions. Because tree rings grow annually, there is a ring width value for each year, and because the widths correspond to growth-limiting moisture, the series of widths can be used as a proxy for climate extending back the length of the tree’s life. Here in the Southwest, it is common to find trees 300–500 years old, and many as old as 600–700 years.

In order to create a tree-ring width record, about 25–35 trees at a single site are sampled with an increment borer, which is used to extract a pencil-width cylinder of wood from the tree. These tree cores are glued into core mounts, sanded to a flat surface, and each ring is assigned a calendar year date. Dating is accomplished using a method called cross-dating, which is anchored by the ring next to the back—the year the tree was sampled— and matching the ring-width patterns between trees. The patterns are extremely consistent among moisture-sensitive trees across a climatic region, and this pattern-matching technique is used to create each and every ring is correctly dated. Dated rings are then measured, the measurements are adjusted to account for difference in ages of trees sampled, and then averaged together to create a tree-ring chronology for that site.

In New Mexico, detailed information about both the summer monsoon rainfall and the cool season precipitation that is largely responsible for Rio Grande peak runoff can be obtained from tree rings. It has long been recognized that annual growth rings have two parts: a light-colored part formed in the first part of the growing season, called the earlywood, and a dark part formed near the end of the growing season, called the latewood. Although it has been customary to measure the entire ring, if measurements are made of the earlywood and latewood widths separately, scientists have found that, throughout much of the southwestern U.S., earlywood widths correspond to cool season precipitation and the latewood widths correspond to monsoon season precipitation.

Rio Grande, Climate Division 5 (shaded red), Otowi gage (blue square), and tree-ring chronologies used in monsoon reconstruction (red triangles).
Other related documents and data

Documents & Data

This page hosts documents related to the Monsoon Project:

- **Publications and data** from peer-reviewed research.
- **Articles** aimed at non-technical audiences.
- **Workshop** descriptions and presentations.
- **Posters** presented at professional conferences.

http://monsoon.ltrr.arizona.edu/documents.html
Questions?

Some of mine:

• How important is the monsoon in the Rio Grande basin?

• What management issues/questions does it impact?

• Is an understanding of variability on the seasonal scale helpful?

• Is there anything we can do to make this information/data more useful to you?
Acknowledgements

• **PIs and Contributors for Rio Grande and North American Monsoon Projects:**

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