

## Introduction

Mann, Bradley, and Hughes (1999) made the first northern hemisphere temperature reconstruction from tree rings, ice cores, corals, and other proxy records. Their study was used in the 2001 IPCC report, where it was dubbed the "hockey stick curve" (Figure 2). Wilson et al. (2016) created their own northern hemisphere temperature reconstruction from just tree rings that dealt with several statistical issues that people had criticized in the original study and found the same extreme increase in temperature in the last century (Figure 3). Until now, no similar reconstruction has been done in the southern hemisphere because of the scarcity of chronologies. I hypothesize that a southern hemisphere tree-ring reconstruction of temperature will show a similar hockey stick curve but with less increase in temperature.



Figure 1: Collecting tree cores at Crown Hill Cemetery, Indianapolis, Indiana. I had the opportunity to go out and collect cores with the dendrochronology graduate class of Indiana State University. (Photo taken by James H. Speer).

# Does a Dendroclimatic Reconstruction of the Southern Hemisphere Show the "Hockey Stick Curve"?

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## Methods

- Gathered the metadata from the 275 chronologies that have been contributed to the International Tree-Ring Databank (ITRDB) (Zhao et al. 2019) in the southern hemisphere and entering them in an Excel spreadsheet (Figure 4).
- Downloaded the raw ring-width chronologies from the ITRDB
- Checked the quality of their dating with the program COFECHA (Holmes et al. 1986, Figure 5).
- Chose the best chronologies based on length (greater than 250 years) and good dating
- Resulted in 41 chronologies representing South American, Tasmania, and New Zealand (Figure 6).
- Standardized each chronology with an age-dependent spline in the program ARSTAN (Cook 1986), which takes out age-related growth trends and provides an Expressed Population Signal (EPS, Figure 7).
- Ran the standard chronology from these 41 series in a correlation matrix against NOAA land and sea southern hemisphere temperature going back to 1850.
- Resulted in 19 chronologies which I used in a Principal Component Analysis (PCA) where SPSS creates a 19-dimensional Eigencloud.
- Used a score of one for inclusion of an Eigenvector in the model.
- The Eigenvectors unfortunately ended with a poor  $r^2$  value ( $r^2 = 0.25$ ,  $p < 0.001$ ) and sorted the different chronologies into their regions, so I ended up running a simple average of all 19 chronologies.

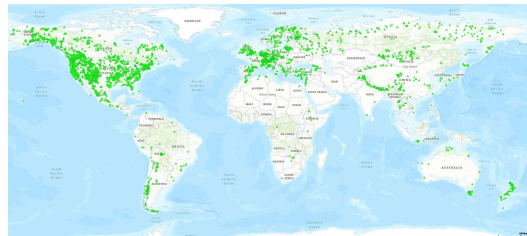


Figure 4: Tree-ring chronologies in the International Tree-Ring Databank (ITRDB). Notice the lower number of chronologies in the southern hemisphere (Graphic created by Collins Malubeni).

Researcher	Site	Chronology	Country	Continents	Start Year	End Year	Series	Interconnection	Standardization	Statistical	Mean	r <sup>2</sup>	df	Length of
Wentworth	McAlister	FR01	FR00001	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR02	FR00002	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR03	FR00003	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR04	FR00004	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR05	FR00005	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR06	FR00006	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
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Wentworth	McAlister	FR08	FR00008	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
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Wentworth	McAlister	FR15	FR00015	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR16	FR00016	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR17	FR00017	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR18	FR00018	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR19	FR00019	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR20	FR00020	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR21	FR00021	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR22	FR00022	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR23	FR00023	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR24	FR00024	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR25	FR00025	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR26	FR00026	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR27	FR00027	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR28	FR00028	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR29	FR00029	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR30	FR00030	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR31	FR00031	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR32	FR00032	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR33	FR00033	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR34	FR00034	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR35	FR00035	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR36	FR00036	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR37	FR00037	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR38	FR00038	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR39	FR00039	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR40	FR00040	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	
Wentworth	McAlister	FR41	FR00041	Argentina	South America	1987	1992	1987-1992	0.99	0.99	0.99	0.99	1987-1992	

Figure 5: COFECHA output showing the dating quality of the tree-ring chronology 119 from Argentina. I ran and examined 275 of these outputs in the process of choosing the best chronologies (Graphic Created by Leif Speer).

- The average of all 19 chronologies resulted in a longer chronology from 500 CE to 2011 CE with at least three chronologies represented.
- Ran R Studio to run script in R for a calibration and verification process with alternating halves of the NOAA temperature data set (Figure 8).
- Provided validation statistics of the Coefficient of Efficiency (CE) and Reduction of Error (RE).
- Ran a regression analysis in Excel that graphically displays the model that was produced in R.
- R was able to create a model that reconstructed temperature for the past 1,500 years by comparing the tree-ring data to the meteorological data.
- Developed a spatial response to our chronologies in KNMI Climate Explorer (Trouet and Van Oldenborgh 2013) with temperature data from Hadley CRU TS Land and Sea Temperature data gridded at one degree latitude and longitude.
- Conducted a T-test in Excel to see if there was a statistically significant change in temperature.
- Chose 1500-1549 as the base line, and then 1968-2011 (my most current data) for the recent comparison.

## Results

Despite discrepancies and difficulties from lack of data in certain regions, I supported my hypothesis and demonstrated that the southern hemisphere also exhibits a hockey stick curve (Figure 9). I developed an extremely strong model that explains the majority of southern hemisphere temperature curve ( $r^2 = 0.74$ ,  $p < 0.1$ ), and extends back to 500 CE. My southern hemisphere reconstruction has a significant correlation with land and sea temperature data, with higher than 0.6 correlation in the Indian, Atlantic, and Southern oceans. (Figures 10 and 11). According to the reconstruction, on average, the southern hemisphere has experience 0.42 degrees Celsius of warming since 1910 (Figure 12 and 13).

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