## Introduction

Mann, Bradly, 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).



Figure 2: The top curve is meteorological data for the northern hemisphere and the bottom curve in Mann, Bradly, and Hughes (1999) 1,000-year temperature reconstruction as published in the 2001 IPCC report



Figure 3: The red line is the 1,100 tree-ring reconstruction for the northern hemisphere from Wilson et al. (2016), while the lower graph shows how this is compared to other climate reconstructions

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

#### 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<sup>2</sup> value (r<sup>2</sup> = 0.25, p < 0.001) and</li> 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 ated by Colline Maluban

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  | 41, 41, 41, 40, 59, 59, 59, 59, 59, 59, 59, 59, 59, 59  | 600 1<br>600 1<br>.57<br>.42<br>.58<br>.46<br>.79<br>.40<br>.40<br>.40  | .18<br>.29<br>.19<br>.19<br>.19<br>.19<br>.19<br>.19<br>.19<br>.19<br>.19<br>.1   | 098 02<br>049 02<br>   
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   | 1275 1<br>1404 1<br>-48<br>-58<br>-58<br>-72<br>-49<br>-46<br>-68<br>-68<br>-68<br>-68<br>-68<br>-68<br>-68<br>-68<br>-68<br>-6  | 440 142<br>440 142<br>30 .20 .2<br>.30 .2<br>.31 .4<br>.34 .2<br>.34 .2<br>.40 .4<br>.40 .4<br>.40 .4<br>.40 .4  
   
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Figure 5: C a. I ra ed 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 grided 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<sup>2</sup> = 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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Vilaba	CastaAto-Overo 7	NOPU	ARCE107	Argenting	South America	1562	122	1 0.591	0.308	22	291	167	-
Allen .	Bins Tier	PHAS.	41/51 025	Australia	Anatolia	1102	195	4 0.617	4.64	87	2010	134	_
Munda	Day Harbady	4040	ADCEVIS	Amentina	South America	1414	200	6 0.000	0.177	- 6	200.0	173	-
Mundo	Lago Rucachorgi	ARAR	ARGE123	Argenting	South America	1947	200	6 0.503	0.125	- 40	21.0	174	
Vilaba	Rio Maero	AUCH	ARCESTS	Argenting	South America	1589	122	1 0.573	0.274	15	24.5	194	(
Riceg	North_Egmont_Recollection_2	LOI	NEW2061	New Zealand	Austalia	1625	122	0 0.591	0.232	- 63	252.1	100	(
Vilaba	Datancia Pulmari	ARAR	ARCED54	Argenting	South America	1589	120	9 0,509	0.232	25	252.6	172	-
Riceg	Raha_Saddle	LIS	NEW2070	New Zealand	Austalia	1500	122	6 0.503	0.347	- 40	201	172	(
Maba	RÃ-o Horqueta 2	FICU	ARG2030	Argentina	South America	574	122	D 0.443	0.278	24	6336	Low Throughout	
Maba	RA-q J'rim	FICU	ARGEOST	Argentina	South America	555	122	6 0.458	0.253	- 17	570.7	Low Throughout	
Soninsegna	Ro_Cane_Chubul	FICU	ARGEDIS	Argentina	South America	441	123	4 0.518	0.23	42	522.3	150	
Lamarche	Beyond_Burn	A10U	AUSLOOG	Autola	Australia	1225	127	5 0.622	0.173	- 41	405.1	115	
vilaba	La Dipeninza	FICU	ARGE092	Argentina	South America	-342	122	5 0.567	0.255	- 58	452.3	Low Throughout	
Xong	Hauhungatahi_Site_C_Tongarins	LB	NEW2374	New Zealard	Austalia	1213	122	2 0.471	0.263	25	395.4	Low Throughout	
Lamarche	Lake, Newdegrie	A10J	AUSLOD	Autola	Austalia	1285	123	4 0.503	0.217	35	372.8	100	
Dunwidde	Mangawhero R.B.	DACO	NEW2311	New Zealard	Australia	1454	127	5 0.590	0.195	38	255.5	150	
Luneose	United	- 18	new 2013	INER Zealand	AUSTRIA	1546	123	o 0.545	0.245	- 29	365.5	140	
Lamarche	Unenque yenuen	AGAR	ATL:4005	Argentina	DOUTH ATTRICE	401	123	• 0.525	0.207	- 50	209.8	150	
LATINCIA	U ABPD	AU01	UNIL002	5.518	DOUTH ATTRACTS	1211	127	2 0.641	0.254	65	206.5	540	
Lamarche	jitanua	ANNR.	ATL:4004	Argentina	DOUTH ATTRACTS	311	123	• 0.533	0.201	- 28	223.4	155	
Luneose	Takapan	- 18	new2018	new Jealand	AUSTRIA	1255	123	0 0.513	0.219	-46	218.5	150	
LATINCIA	LOOKIN Spur_Hoad	PTRS	AUSC 214	Autola	AUSTRIA	1573	127	ceso c	0.385	- 30	217.6	159	
LATECOS	DZ_FRONTS	PTRS	AUSCERS	Autola	Autoria	1507	123	• 0.569	0.545	- 1	215.9	row issonation	

site, species, location, and chronology statistics. The bold shows the chosen chronologies



Figure 8: This is a picture of the program R, in which I can translate tree-ring width to temperature for econstruction (Graphic created by Leif Speer



curve, and the output when that curve is applied. B) the standardization curves for each core, C) the running r-bar and EPS showing a cut off around 750 CE, D) the final chronologies with sample dept



Figure 9: Southern hemisphere temperature A) Land and ocean annual temperature from meteorological ns by NOAA, B) my 1500-year southern hemisphere temperature reconstruction (Graphic cre





corr Aug Ave 19 Chron index

Figure 10: Map from KNMI Climate Explorer, showing he correspondence between our tree ring data and temperature records for the globe (Graphic created by Leif Speer).

Figure 11: Map from KNMI Climate Explorer showing explicitly ocean surface correspondence between our tree ring data (Graphic created by Leif Speer



Hemisphere temperature reconstruction

comparing 1500-1550 CE to 1962-2011 CE (Graphic created by Leif Speer).

Figure 13: Regression analysis showing the reconstruction model and the verification and calibration statistics (Graphic created by Leif Speer).

## Conclusion

The results of this reconstruction certainly show a large positive trend in temperature in the past century compared to the previous 1,400 years shown. Also as hypothesized, the southern hemisphere shows a smaller increase in temperature than the northern hemisphere. We have high significance in our graph. There is a phase shift from 1955 to 1975 to warmer temperature regime, after which the temperature stay warm but somewhat level out

## Acknowledgements

Thank you to my dad and mom for their help with this project. Dr. Rob Wilson and his colleagues, Dr. Michael Mann, Dr. Raymond Bradley, and Dr. Malcolm Hughes for paving the way for this reconstruction. Dr. Shantos Shaw wrote the R script and Dr. Narayan Gaire and Sanjaya Bhandari shared the R script with me, Collins Malubeni created the ITRDB map for his thesis and allowed me to use it in my presentation. The researchers who contributed to the ITRDB from which I retrieved the chronologies, and all others who, directly or indirectly, worked to make this project happen.

Cook F.B. 1986 U manual for program ABSTAN Trae-ring chr olmes, R.L., Adams, R.K. and Fritts, H.C., 1986. Tree-ring chronologie with procedures used in the chronology developmentwork includir

procedures uses in ..... 1. Bradley, R. & Hughes, M. Global-scale ter <sup>1</sup> and Van Oldenborgh, G.J., 2013. KNMI Cli ouet, V. and Van 69(1), pp.3-13. text (), pup-1-a. text (), pup-1-a. Soon, R. K.J. Anchukaitis, K. Briffa, U. Büntgen, E.R. Cook, R.D. D'Arrigo, N. Davi, J. Esper, D. Frank, B. Gunnarson, G. Hegeri, S. Helama, S. Klesse, P.J. Krusic, H. Linderholm, V. Myglan, T. J. Osborn, Z. Peng, M. Rydval, L. Schneider, A. Schurer, G. Wiles and E. Zorita, Last millennium Northern

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Mt_Read_Update	LGFR	AUSLOSS	Australita	Australia	-2145	2909	0.571	0.195	289	533.1	-300	
RA-o_Alerce	FICU	ARCESS	Argentina	South America	864	1991	0.543	0.240	75	453.9	300	-
Mt. Read	ATSE	AUSLOIS	Australia	Austalia	254	2011	0.534	0.237	50	47.9	1220	-
Crade Mountain Update	ATSE	AUSLOH1	Australia	Austalia	245	2905	0.568	0.212	115	4012	1150	-
M. Field Update	ATCU	AUSLOND	Australia	Austalia	1025	2905	0.572	0.94	23	61.6	1150	-
Rip Alerca	FICU	ARCE144	Argenting	South America	826	2011	0.502	0.254	213	47.1	1100	
Cradia Muschain 1 200 Year Lindate	ATTE	AUSI 050	Asstalls	Acatralia	302	2005	0.590	0.302	217	105.7	500	-
the first	1.00	amazor .	Name Taxabased	Australia	4.000	4354	4.012	4.333	-	2011	4500	
Carden Star	100	ABCELLS.	Annual and	Fault America	1400	2001	0.000	4.343	-	2013	4700	
and the second second	100		Augurana .	And a state of the					- 104	201.1	1400	
Assessment and a congerve	1.00	NEW2073	NEW 215510	Acessia	1332	1332	6.563	6.135	- 24	200.2	1620	
MCKBy_Creek	ATCO	AUGLUUS	Alterna	Acarsina	1309	2009	6.500		113	206.5	1460	
University reconstroom	1.00	NEW2063	New 218810	ACESSIC	1140	1332	6.304	0.256		203.7	1400	
Cerro De Cuanaco	ADUR	ARGEBUS	Argentina	South America	1497	1391	63/6		- 22	215.0	1800	
cavanae_sx	ANGAR	ARLETIN	Asgenona	South America	1590	2000	6.350	0.197	2/	313.5	1630	
Scott's_Peak_Road	PHAS	AUSL001	Australita	Australia	1519	1225	0.630	0.300	52	306.3	1570	
Paso_Do_Las_Nubes_4	NOPU	ARGEETS	Argentina	South America	1529	1221	0.645	0.205	- 20	204.5	1500	
Haubungstahl_Site_A_Tongariro	LIDE	NEW2072	New Zealand	Austalla	1511	1992	0.538	0.215	-6	203.4	1600	
Mintani	LIDE	NEW2066	New Zealand	Australia	1421	1331	0.534	0.255	51	295.5	1530	
Takapari_Recollection	LIDE	NEW2062	New Zealand	Australia	1255	1992	0.582	0.221	62	297.6	1550	- 1
Tyonna_TNE	PHAS	AUSLO43	Australita	Australia	1525	2012	0.503	0.37	140	295.5	1500	- 1
Paso Del Arco	ARAR	ARCE113	Argenting	South America	1264	2006	0.538	0.227	26	294.8	1720	-
Paso De Las Nubes 1	NOPU	ARCEUSE	Argenting	South America	1546	1221	0.503	0.32	28	292.5	1620	-
Relotia Falla	PHAS	AUSLO25	Australia	Austalia	1240	2007	0.590	0.64	- 60	292.3	1400	-
CastaAto Overo 6	NOPU	ARCE106	Argenting	South America	1529	1221	0.651	0.338	24	202.5	1590	-
Natural Day	AUCH	ABCENTS	Assessing	South America	1927	1997	0.055	- 61	28	264.4	1000	-
El Cantinala	ALCH	ADCRETE	America	South America	1401	1989	0.702	0.174	- 10	274.7	1400	-
Core Water	1.00	-	Name Taxabased	Australia	4.000	4354		6.343		2010	4000	-
Bushing Commen	1.00	100000	Name Taxabased	Australia	100	4354	6.011	0.000		7744	4500	- 1
Russine_comer	1.00	NEW COUS	NEW 215510	Acessia	14/3	1201	6222	0.000	73	2/4.1	1600	
Wate of Jackson	ATCO	AUGLORS	ALIFFAIL	Acarsiia	13/6	2204	6.540	6.00	- 65	2/33	1530	
Laka Mackenzie	ATCO	AUGLORZ	Alterate	Acarsiia	1200	2000	6.508	6.21/	- 22	2/2.1	1310	
Castakin Overe s	NUPU	ARLE 100	Argentina	South America	15/2	1331	6.941	0.324	- 25	2/21	1630	
CBEBATE-OVERS_/	NUPU	ARGE 107	Asgenona	South America	1964	1221	6.391	0.300	22	2013	16-0	
Bue Ter	PHAS	AUSLODS	Australita	Australia	1152	1254	0.617	0.51	82	2015	1340	
Pino_Hachado	ARAR	ARGE115	Argentina	South America	1424	2906	0.555	0.177	-6	250.8	1720	
Lago_Rucachorol	ARAR	ARGE123	Argentina	South America	1647	2906	0.503	0.195	- 40	21.6	1740	
Rio_Mnero	AUCH	ARCESTS	Argentina	South America	1589	1221	0.673	0.274	16	24.5	1940	
North_Egmont_Recollection_2	LIDE	NEW2061	New Zealand	Australia	1625	1220	0.591	0.232	65	252.1	1600	
Datancia Pulmari	ARAR	ARCED54	Argenting	South America	1502	1202	0.509	0.222	28	252.0	1720	- 1
Rahu Saddle	LIDE	NEW2070	New Zealand	Australia	1500	1221	0.503	0.247	40	20.3	1720	
RA-o Horoueta 2	FICU	ARG8220	Argentina	South America	574	1252	0.440	0.278	24	653.0 Low Through	haut	
RA-o Frim	FICU	ANGEOS7	Argentina	South America	855	1201	0.458	0.250	- 17	570.7 Low Through	tuor	
Ro Care Clubal	FICU	ARGEIDI	Argenting	South America	441	1274	0.518	0.23	-42	522.2	1500	
Devand Burn	ATOJ.	AUSLING	Autola	Austalia	1228	1875	0.522	0.172	-41	495.1	1150	
La Esperanza	FICU	ARG2022	Argenting	South America	-342	1885	0.567	0.255	- 55	422 Los Trout	bad	
Heuhanostahi Site C Tonzatro	LB	NEW2374	New Zealand	Austalia	1213	1892	0.471	0.263	2	395.4 Low Through	bout	
Into Newtowie	4701	405001	Antala	Acaballa	1205	1274	0.501	0.212		172.8	1000	
Managhers P.S.	0400	NEW/2011	New Tenland	Acaballa	1454	1235	0.590	0.195	- 10	755.0	1500	
Dears	100	NEW 2111	New Tenland	Australia	1345	1235	0.646	0.345	- 10	345.0	1400	
Owners Selver	4040	4057006	America	South America	411	1234	0.575	0.202	- 10	172.8	1400	
W. Adapte	100	Chill 003	Chile .	Fact Income	4444	4375	0.000	0.184		204.4	100	
Reference -	-001	107002	Annual and	Frank Lenning	-211	1014	0.001	0.204		202.4	180	
Tuburgal	1000	ACCREDING NO.	Num Textured	Australia	311	10.75	0.6130	0.201	- 20	20.0	1400	
(mapper		1000022318	Tene Learns	Passand	1200	1874	walls.	0.278	- 40	210.0	1.000	
LOOKAY_Spur_Hose	PTRO	AUSLIN	Autoria	ALITSIS	15/3	TAID	0.093	0.385	- 30	317.6	1390	
24, 790878	PTRS	AUDICERS	Autolia	AUTOR	1507	TAN	0.509	0.546		JID V LOW Through	10LZ	
Urade_Mounden	ATSE	w056.002	Autola	AL87313	1198	CAT	u 399	u 207	- 39	311.5	19/0	
Penan Rose	PHAS	AUSLOIS	Australia	Austalia	1290	1275	0.549	0.305	- 34	307.2	1990	

(Graphic created by Leif Speer)