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Sedimentary Environments and Paleoecology of Proterozoic and Cambrian "Avalonian" Strata in the United States
Mark McMenamin (Mount Holyoke College) and Jack Beuthin (U of Pittsburgh, Johnstown)
Students: Evan Anderson, Anna Lavarreda, Ken O'Donnell, Walter Persons, Jessica Williams

Development and Analysis of Millennial-Scale Tree Ring Records from Glacier Bay National Park and Preserve, Alaska (Glacier Bay)
Greg Wiles (The College of Wooster)
Students: Erica Erlanger, Alex Trutko, Adam Plourde

The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
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Keck Geology Consortium: Projects 2007-2008
Short Contributions – Alaska

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RECONSTRUCTION OF SITKA, ALASKA TEMPERATURES (1569-1991) BASED ON EIGHT GULF OF ALASKA TREE-RING CHRONOLOGIES

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INTRODUCTION

The majority of climate instrumental records from coastal and near-coastal sites along the Northeast Pacific Rim span less than 100 years. Tree-rings provide a means to extend these records back several centuries to millennia and thus, a range of natural climate variability can be better defined. Climate fluctuations in this area correspond well with the Pacific Decadal Oscillation (PDO), an interdecadal pattern of climate variability most visible in the North Pacific Ocean (Mantua, 2002). During the winter and spring months, the climate of the North Pacific is greatly influenced by the strength and position of the Aleutian low pressure cell (Overland et al., 1999).

Tree-rings provide high resolution, long-term thermal records for the North Pacific region. The coastal mountain ranges that surround Glacier Bay (58°28' N, 135°56' W), located in the southeastern Gulf of Alaska (GOA), are ideal sites for tree-ring sampling at elevational tree-line, where trees are known to be particularly sensitive to temperature (Cook and Kairiukstis, 1990).

The instrumental record from Sitka, Alaska (57°03' N, 135°19' W) spans from AD 1832-1991 and is the longest record of temperature and precipitation in the North Pacific. Scientists have incorporated the Sitka instrumental data into studies on reconstructing sea surface temperatures (Overland et al., 2000) and coastal land temperatures (Wilson et al., 2007). The purpose of this Keck project was to develop a reconstruction of the Sitka, Alaska temperature record based on 8 tree-ring chronologies from the GOA.

METHODS

Cores were extracted from old-growth mountain hemlocks in Glacier Bay National Park using increment borers. Sample preparation and tree-core analyses were performed at the College of Wooster Tree-Ring Lab in Wooster, Ohio. Each core was mounted, sanded, and dated using methods outlined by Stokes and Smiley (1996). Raw tree-ring measurements, measured to the nearest 0.001 mm, from all cores at an individual site, were cross-dated with each other in COFECHA using standard procedures (Holmes, 1983; Grissino-Mayer, 2001). The raw ring-width data was then standardized using negative exponential growth functions using ARSTAN software (Cook, 1985). Six additional standardized chronologies were added to samples collected in 2006 and 2007 and distilled into principal components in PCREG software, which models climate from tree-rings using principal component regression analysis (Table 1). The model was assessed with calibration and verification statistics. The reconstruction and climate files created after each run of PCREG were used to plot the Sitka temperature reconstruction in degrees Celsius.

DATA

The coastal area temperatures of Sitka, Alaska were reconstructed from AD 1569-1991 (Fig. 1). The temperature model retained the first PC for regression, which represents variations in temperature. Precipitation was not modeled due to weak correlations between the instrumental record and ring-widths. Averaged temperatures (February-August) of the present year of growth correlate with the first principal component scores at the 0.05 significance level. Three models of reconstructed temperatures were created to examine the use of several different calibration periods. The full calibration model (AD 1900-1991) explains 40% of the variance in temperature (Table 2). The period from AD 1832-1899 was not included in the full calibration model, as there are missing years of data intermittently from AD 1832-1855 and only 6 continuous years of data between AD 1876 and 1900. The full calibration interval was split in half to calibrate and verify the model results. The reconstruction that encompasses the first half of this interval (AD 1900-1944) explains 44% of the variance (Table 2). The reconstruction that comprises the second half of this interval (AD 1945 - 1991) explains 29% of the variance (Table 2). Missing temperature data between AD 1870 and 1899 were estimated using ring-widths in the regression model (Fig. 2).

Name	Code	Lat. (N)	Long. (W)	Species	Number of Cores/Trees	Period
Ellsworth Glacier$_a$	EL	60 05	148 58	Mountain hemlock	20/17	1543-1991
Rock Glacier$_a$	RG	60 04	148 50	Mountain hemlock	20/16	1514-1992
Wolverine Glacier$_a$	WV	60 22	148 54	Mountain hemlock	21/18	1247-1991
Cordova Eyak Mountain$_a$	CV	60 36	145 40	Mountain hemlock	29/21	1345-2001
Verstovia	VC	57 03	135 16	Mountain hemlock		1387-1996
Miners Well	MW	60 00	141 41	Mountain hemlock		1428-1995
Excursion Ridge$_a$	EX	58 26	135 35	Mountain hemlock	80/44	1517-2006
Beartrack Mountain$_a$	BT	58 37	135 52	Mountain hemlock	27/20	1569-2005

a indicates tree line sites

Calibration	Verification	r^2	r	N	p
Eight-chronology reconstruction					
1900-1991	1832-1899	0.4	0.63	91	<0.0001
1900-1944	1832-1899; 1945-1991	0.44	0.66	91	<0.0001
1945-1991	1832-1944	0.29	0.54	91	<0.0001

r^2=variance explained; r=correlation coefficient

Table 2: Calibration and verification statistics for the Sitka temperature reconstruction

The average temperature throughout the reconstructed period (AD 1569-1991) is 7.5°C. The maximum and minimum values reached throughout the 422 years of reconstructed temperature were 9.3°C in AD 1723 and 5.5°C in AD 1698, respectively. The duration of temperature intervals is not consistent and varies from a single year (the AD 1847 to 1848 temperature spike) to over a decade (the temperature spike from AD 1680-1698). Clusters of several periods of higher or lower temperatures are observed in the reconstruction and occur on longer, multi-decadal time scales (Fig. 1). The duration of these multiple decades of warmer or cooler temperatures becomes more obvious from AD 1780 through 1991. Five warm periods were identified: AD

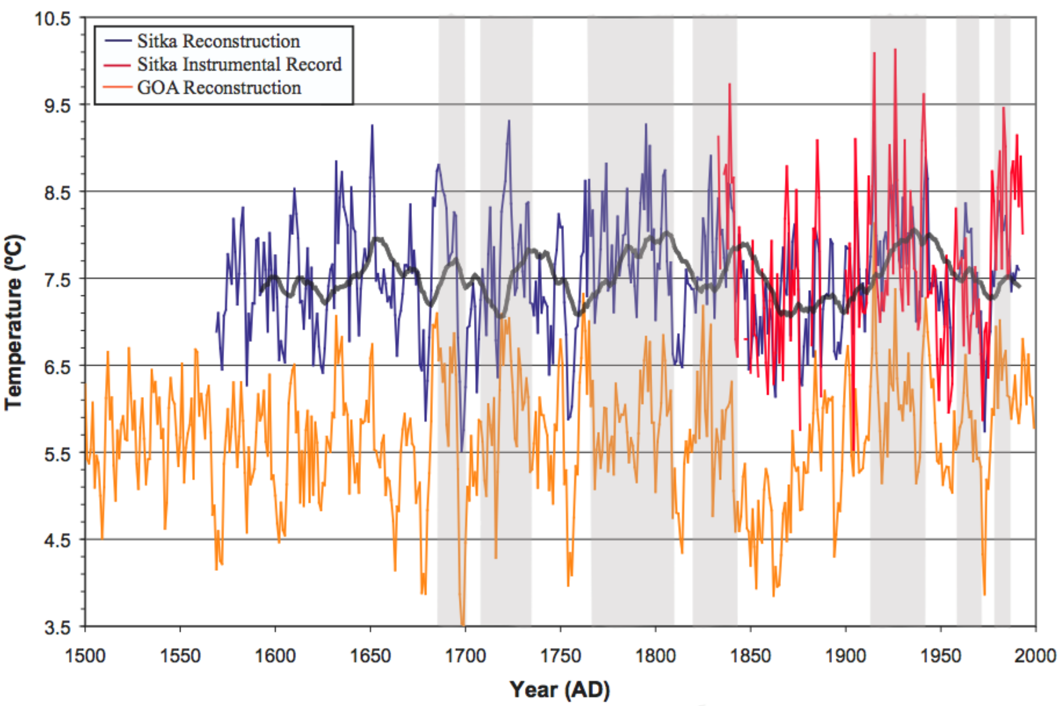

Figure 1: February-August Sitka temperature reconstruction based on 8 Gulf of Alaska ring-width chronologies (blue line). Calibration of the reconstruction was performed over the interval AD 1900-1991 (red line). A comparison of GOA (January-September) temperature reconstruction from AD 713-1999 (orange line) developed by Wilson et al. (2007) shows strong agreement with the reconstruction presented in this study. Shaded intervals indicate positive PDO periods, based on Mantua et al., (1997), Biondi et al., (2001), and Wilson et al., (2007).

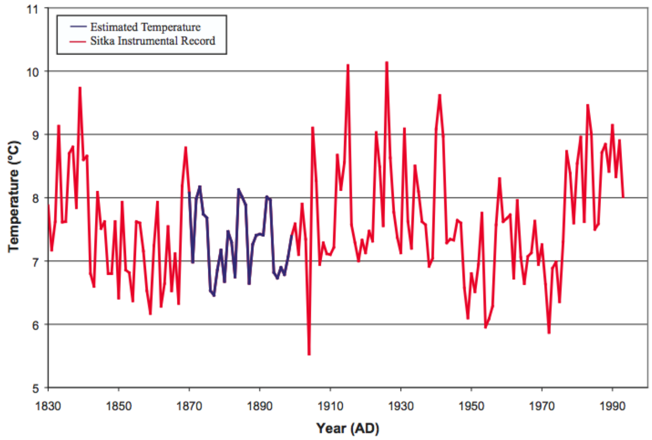

Figure 2: The complete Sitka temperature record from AD 1832 to 1991. Temperature was estimated for the missing period (blue line) from AD 1870-1899 with ring-widths inserted into a manually-generated regression equation

1680-1698, AD 1761-1809, AD 1816-1847, AD 1913-1937, AD 1959-1967, and AD 1977-1988. Cooler periods are short-lived compared to warmer periods, and it is difficult in some cases to differentiate between a cool event and a cool period. The longest sustained cooling occurred from AD 1869-1910. The other instances of cooler temperatures are generally brief in extent, persisting 2-9 years.

The correlation between the predicted and actual temperature values is 0.63 and the p-value is <0.0001, using an overlapping period of N=91 years. The Sitka temperature record (Fig. 1) correlates well with the duration of consistently warmer or cooler temperatures, although maxima and minima in the temperature record are typically larger in amplitude by 0.1°C-1.3°C in contrast to the reconstructed values. The reconstructed and temperature records begin to diverge around AD 1985; Sitka temperature continues to rise while the reconstructed values do not match this rise. Data beyond 1991 is not currently available, so it is difficult to determine how trends in the estimated temperature and actual data could have changed over the past 17 years. The timing of temperature intervals between the reconstructed records is not perceptibly different. Differences in amplitudes between the actual and predicted temperature records are greatest in the AD 1945-1991 calibration model. Inconsistencies between the actual and estimated values appear in the last decade of the reconstruction, as temperatures rise from the 1970's through to 1991. In comparison, the estimated values begin to show a decrease around 1984 and remain relatively constant through 1991.

DISCUSSION

The reconstruction underestimates maximum and minimum temperatures in the instrumental record, perhaps due to biological constraints on ring-growth during times of extreme temperatures (Fritts, 1976). Based on comparisons between the instrumental record and the reconstructed values, it can be inferred that additional peaks and lows in temperature occurred before AD 1832 that are not accurately expressed in the reconstruction. Estimated temperatures may therefore have been more extreme before AD 1832 than is apparent in the model, especially from the 1500's through the 1800's, an interval that coincides with a portion of the Little Ice Age (LIA). Three of the coolest years of temperature in the Sitka reconstruction occurred during the 17th century at AD 1679, AD 1698, and AD 1699. This coincides with glacial advances during the 17th century in Prince William Sound inferred by Wiles et al. (1999) from subfossil logs. From AD 1849-1898, estimated temperature values are 0.5°C below-average, which also coincide with moraine-building events in Prince William Sound from AD 1874-1895. These events mark the maximum observable extent of six of the glaciers studied by Wiles et al. (1999) during the LIA.

Decadal-scale fluctuations appear to correspond well with known 20th century shifts in the Pacific Decadal Oscillation (PDO), which represents interdecadal sea-surface temperature variability in the North Pacific Basin. PDO is the prominent mode of variability in the Gulf of Alaska, although its signal is difficult to detect in climate proxy records prior to the mid 1850's, as its strength diminishes (Biondi et al., 2001; Gedalof and Smith, 2001). Interdecadal shifts in the instrumental temperature record are apparent around AD 1923, AD 1947, and AD 1977, as noted by Mantua et al. (1997). PDO oscillations in the reconstruction are less pronounced, as maxima and minima in the instrumental record are generally more extreme and therefore exhibit PDO trends more clearly. Biondi et al. (2001) noted weak PDO signals from the late 1700 to mid-1800's. From the beginning of the Sitka reconstruction in AD 1569 to the late 17th century, there are no obvious shifts in PDO, and thus, this could be construed as a period of weaker Pacific Decadal Variability.

Wilson et al. (2007) similarly reconstructed spring/summer temperature variability in the Gulf of Alaska over the past 1,300 years, using living mountain hemlock chronologies and subfossil wood. The reconstruction developed by Wilson et al. (2007), henceforth referred to as the GOA reconstruction, exhibits average temperatures that are approximately 1.8°C lower (5.84°C compared to 7.61°C) than the temperature model presented in this study, due to the different climate window reconstructed in the GOA model (January-September; Fig. 1). However, five out of eight hemlock chronologies used in the Sitka reconstruction are common to both studies, so parallels between the two models are to be expected. The timing of temperature variations and unusually warm or cool intervals are similarly exhibited in both the Sitka and GOA reconstructions. PDO shifts apparent in the Sitka reconstruction agree well with deduced shifts in the GOA reconstruction from AD 1840 through to the present. Prior to this date, the Sitka reconstruction matches well with the GOA reconstruction developed from subfossil logs, which show higher resolution PDO shifts before AD 1840 that are not captured in the GOA hemlock reconstruction. From AD 1718-1840, several PDO shifts are recorded in the sub-fossil wood reconstruction: AD 1718-1734 and AD 1734-1761. The Sitka reconstruction presented in this study also captures these shifts, as well as several others absent from the GOA reconstruction: AD 1761-1806, AD 1807-1826, and AD 1826-1842.

A spring/summer temperature reconstruction developed by Wiles et al. (1998) also incorporated four tree-ring chronologies used in this study (Table 1) and explains 35% of the variance in temperature. The reconstruction presented in this study is an improvement of the former model, as the full calibration model explains 40% of the variance. Wiles et al. (1998) inferred warming over the last 90 years from increased ring-widths compared to the past three centuries.

There are no obvious warming trends in the Sitka reconstruction; it is possible that this signal is too weak compared to the overriding trends in PDO. To further explore this trend in the recent part of the record, residual values derived from regression estimates for the AD 1900-1991 calibration models were examined. Residual values represent the difference between actual and estimated temperature. Since AD 1960, there has been an abrupt increase in the residual values that continues through the end of the reconstruction at AD 1991, which indicates that trees in the GOA may have been systematically underestimating Sitka temperature (Fig. 3).

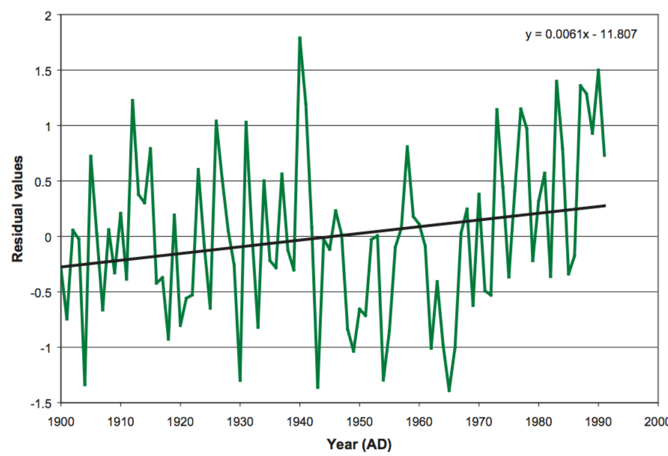

Figure 3: Residual values calculated from regression estimates for the AD 1900-1991 calibration model. The regression estimate indicates model accuracy by comparing temperature data with the estimated temperature values (derived from the model) from AD 1900-1991. Linear trendline is shown in black.

The inconsistencies between the estimated and instrumental temperature values are not definitive evidence for recent global warming, but could be due to the phenomenon of divergence that has been observed in northern latitude forests in recent years (Briffa et al. 1998). D'Arrigo et al. (2008) summarizes this phenomenon and possible sources. Divergence represents a reduction in sensitivity to climate and decreased tree-ring widths relative to increasing temperatures observed during the past few decades. A variety of climatic variables and stresses could be responsible for divergence, including recent warming and soil moisture. Warming in some regions of Alaska has caused a decrease in precipitation and a resulting increase in moisture stress on trees (Jacoby and D'Arrigo, 1995). In the GOA, temperature, rather than precipitation, is the limiting factor on tree-ring growth (Jacoby and D'Arrigo, 1989), and the lack of correlations between precipitation and the tree-rings noted in this study also agrees with this notion. However, a decrease in precipitation in the interior and northern portion of Alaska, as noted in Jacoby and D'Arrigo (1995), could confound the sensitivity of trees to temperature if moisture were to become a limiting factor in growth. Therefore, warming may be a signal that is indirectly expressed in recent decades within the reconstruction. In conclusion, the presented reconstruction provides inadequate data for making definitive inferences on recent global warming trends, as the instrumental record only extends to AD 1991. Nevertheless, the GOA reconstruction by Wiles et al. (1998) demonstrates that warming in the past century can be evaluated using records from this region.

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