Modeling North Pacific Temperature and Pressure Changes from Coastal Tree-Ring Chronologies

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ABSTRACT: Climate modeling using coastal tree-ring chronologies has yielded the first summer temperature reconstructions for coastal stations along the Gulf of Alaska and the Pacific Northwest. These land temperature reconstructions are strongly correlated with nearby sea surface temperatures, indicating large-scale ocean-atmospheric influences. Significant progress has also been made in modeling winter land temperatures and sea surface temperatures from coastal and shipboard stations. In addition to temperature, the pressure variability center over the central North Pacific Ocean (PAC), which is related to the strength and location of the Aleutian Low pressure system, could be extended using coastal tree rings.

Introduction

Temperature and pressure fluctuations in the Northeastern Pacific sector are important for understanding global climate and its prediction (Cayan 1980; Namias *et al* 1988; Trenberth and Hurrell 1994) as well as for their impact on major fishery resources (Mysak 1986; Francis and Sibley 1991). Few physical or biological time series from the Gulf of Alaska and the Pacific Northwest extend over more than several decades, an insufficient interval to evaluate long-term climate variability (Roden 1989). Coastal tree-ring width and density records provide some of the best proxies for year-to-year climate change and can extend existing records by several centuries or more. Tree-rings from coastal and near coastal sites along the Northeastern Pacific are influenced by and can be used to reconstruct large-scale oceanic and atmospheric temperature changes (Blasing and Fritts 1975, 1976; Xiangding and Lough 1987).

Whereas a relatively dense network of tree-ring records for climatic reconstruction exists for western North American interior forest sites (Chapter 1, Cook and Kairiukstis 1990), few studies have used coastal trees to reconstruct oceanic and climatic variations for the Northeastern Pacific sector. Climatic conditions along coastal regions can differ considerably from those at interior sites. How climate changes in these transitional zones between the continental and oceanic environment is crucial for understanding Earth's climate system. Goals of this paper are:

- To analyze the climate signal in Northeastern Pacific ring-width and maximum latewood density chronologies.
- To present summer temperature reconstructions and evaluate the linkages between sea surface and land temperatures as recorded in tree rings.
- To examine the winter climate signal in the tree-ring time series.

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Previous Dendroclimatic Studies in the Northeastern Pacific Sector

Previous researchers have used tree-ring chronologies from western North America to model temperature and pressure variations in the North Pacific sector (Blasing and Fritts 1975, 1976; Douglas 1980). For example, Blasing and Fritts (1975) identified 10 patterns of summer tree growth from 21 ring-width chronologies in western Canada and interior and Arctic Alaska. No coastal chronologies were included in these analyses. A more extensive network of 49 ring-width chronologies in western North America was employed to reconstruct winter climatic anomalies for the North Pacific sector and western North America (Blasing and Fritts 1976). Reconstruction of Pacific sea level pressure variations was the subject of a study by Xiangding and Lough (1987), who estimated summer sea level pressure using tree-ring chronologies from North America combined with documentary records of precipitation from China.

Tree-ring chronologies from near-coastal and interior regions have been used in various temperature reconstructions for the Northeastern Pacific sector. Graumlich and Brubaker (1986) reconstructed mean annual temperatures for Longmire, Washington, from a set of ring-width chronologies in the Cascade Range. More recently, Schweingruber *et al* (1993) presented new tree-ring chronologies from a major sampling transect across North America. Analysis of this dataset by Briffa *et al* (1992) included growing season temperature reconstructions for the Alaska-Yukon region and the Pacific Northwest. Using only chronologies from coastal and near-coastal sites, Buckley *et al* (1992) investigated the temperature and precipitation response of tree-ring records from the Pacific Northwest. In this study, density chronologies were found to be more sensitive indicators of year-to-year temperature variations than the companion ring-width series. Additionally, links between the tree-ring records and sea surface temperatures and sea level pressure suggested that the chronologies had the potential to reconstruct large-scale atmospheric phenomena such as changes in the Aleutian Low pressure system. Their tree-ring dataset included some of the same tree-ring chronologies presented in this analysis. This paper uses an approach similar to that of Buckley *et al* (1992), employing climatically sensitive chronologies to reconstruct coastal climate variations for regions in the Northeastern Pacific sector.

Tree-Ring and Meteorological Data

New tree-ring data from the Gulf of Alaska, together with existing collections from British Columbia, Alaska, Washington, and California, make up the primary database for modeling studies in coastal regions of the Northeastern Pacific (Figure 1; Table 1). Maximum latewood density chronologies for Alaska, Washington, and Vancouver Island were processed in Switzerland by F. Schweingruber at the Swiss Federal Institute of Forestry Research as part of a collection of 69 tree-ring sites sampled in northern North America during 1984 and 1989 (Schweingruber *et al*, 1993). Final chronologies were developed from their raw data at the Tree Ring Laboratory of Lamont-Doherty Earth Observatory, using standard dendrochronological techniques (Fritts 1976; Cook and Kairiukstis 1990). Additional chronologies were obtained through the International Tree-Ring Database of the University of Arizona.

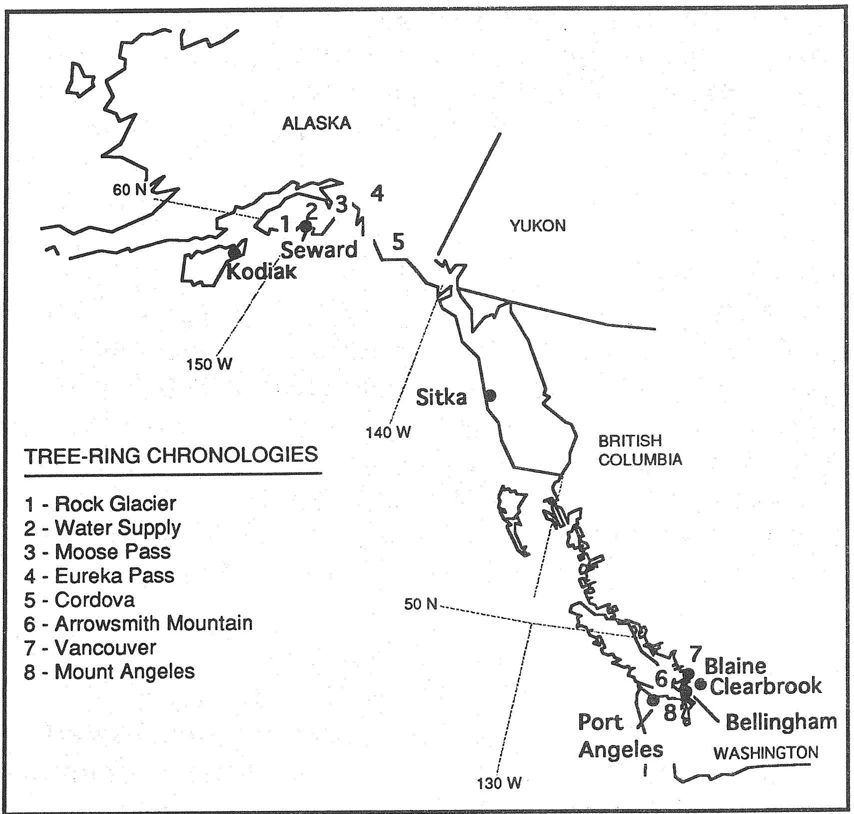

Figure 1. MAP SHOWING LOCATION OF TREE-RING CHRONOLOGIES AND METEOROLOGICAL STATIONS USED IN SUMMER TEMPERATURE RECONSTRUCTIONS FOR THE GULF OF ALASKA AND THE PACIFIC NORTHWEST

Table 1
TREE-RING SITES USED IN MODELING NORTHEAST PACIFIC CLIMATE.

Tree Ring Site	Species	Interval	Elevation (meters)	Latitude / Longitude
ALASKA				
Cordova (CV)	TSME	1192-1992	428	61°20' N / 145°40' W
Eureka Summit (ES)	PCGL	1654-1983	960	61°50' N / 147°20' W
Moose Pass (MP)	PCSI	1732-1983	100	61°20' N / 149°35' W
Nichawak Mountain (NK)	PCSI	1762-1992	320	60°15' N / 144°00' W
Rock Glacier (RGL)	TSME	1530-1991	420	61°04' N / 148°00' W
Water Supply (WS)	TSME	1727-1989	305	61°05' N / 149°36' W
CALIFORNIA				
Snow White Ridge (SNO)	PIPO	1557-1980	1731	38°08' N / 120°03' W
NEVADA				
Pete's Summit (PSU)	PIMO	1439-1982	2347	39°11' N / 116°47' W
WASHINGTON				
Arrowsmith Mountain (ARW)	TSME	1629-1983	1020	49°09' N / 125°14' W
Frying Pan Creek (FPC)	PSME	1286-1980	1170	46°53' N / 121°37' W
Mount Angeles (ANG)	PSME	1750-1983	1360	47°58' N / 123°26' W
Vancouver (VAN)	TSME	1413-1983	1110	49°20' N / 123°20' W

PCGL = *Picea glauca*
PCSI = *Picea sitchensis*
PIMO = *Pinus cembroides*
PIPO = *Pinus ponderosa*
PSME = *Pseudotsuga menziesii*
TSME = *Tsuga mertensiana*

Individual average monthly temperature series for meteorological stations at Sitka, Seward, and Kodiak, along the Gulf of Alaska, and from the coastal stations of Blaine, Bellingham, Clearbrook, and Port Angeles, all in northwestern Washington, were obtained from the Historical Climate Network. Regional average temperature series for the last 80 years were computed for the Gulf of Alaska (GOA) and for Washington stations in the Pacific Northwest (PNW). In addition to the land temperature series, a 5°X5° monthly sea surface temperature dataset for the Northeast Pacific (1947 to 1990) was obtained from Dr. Dan Cayan of Scripps Institution of Oceanography. Tree-ring data were also compared with the PAC teleconnection index series of Rogers (1990). The PAC index is the North-Central Pacific low-frequency variability pattern that is related to the strength of the Aleutian Low pressure system. A strong low is associated with a high index value and a weaker low with a smaller index value. Sea surface temperatures recorded at the coastal station of Amphitrite Point, British Columbia, were provided by D. Ware.

Summer Temperature Reconstructions

The temperature signal in the tree-ring time series was evaluated by simple correlations between the series and the 17-month dendroclimatic year (June of the previous year through October of the growth year; Figure 2) of the regional average temperature series from PNW and GOA. The GOA ring-width data correlated positively with all months; strongest correlations were for the growing season, March through September. Density chronologies along the gulf showed a negative relationship with previous July through November mean temperatures and a positive correlation with temperatures from March through September. Chronologies of maximum latewood density from Washington State are also positively correlated with temperature during April through September. Based on these results, we decided to use the tree-ring data to model temperatures averaged over the April-September season.

Principal components regression techniques (Chapter 4, Cook and Kairiukstis 1990) were employed to reconstruct summer temperatures. Tree-ring data for the current year (t) were used to predict summer temperatures. The GOA model is based on three ring-width time series and two maximum latewood density chronologies, which have a similar response to growing season temperatures (Figure 2a, b). The PNW model uses the three latewood density chronologies (Figure 2c). Both the tree-ring and temperature data were prewhitened prior to modeling to remove the persistence in the series (Box and Jenkins 1970). In each case, most of the variance was explained in the first eigenvector, and only the first eigenvector of the principal component analysis was retained for regression.

Model verification was performed by halving each temperature series, with each half verified using the calibration of the other. For the PNW

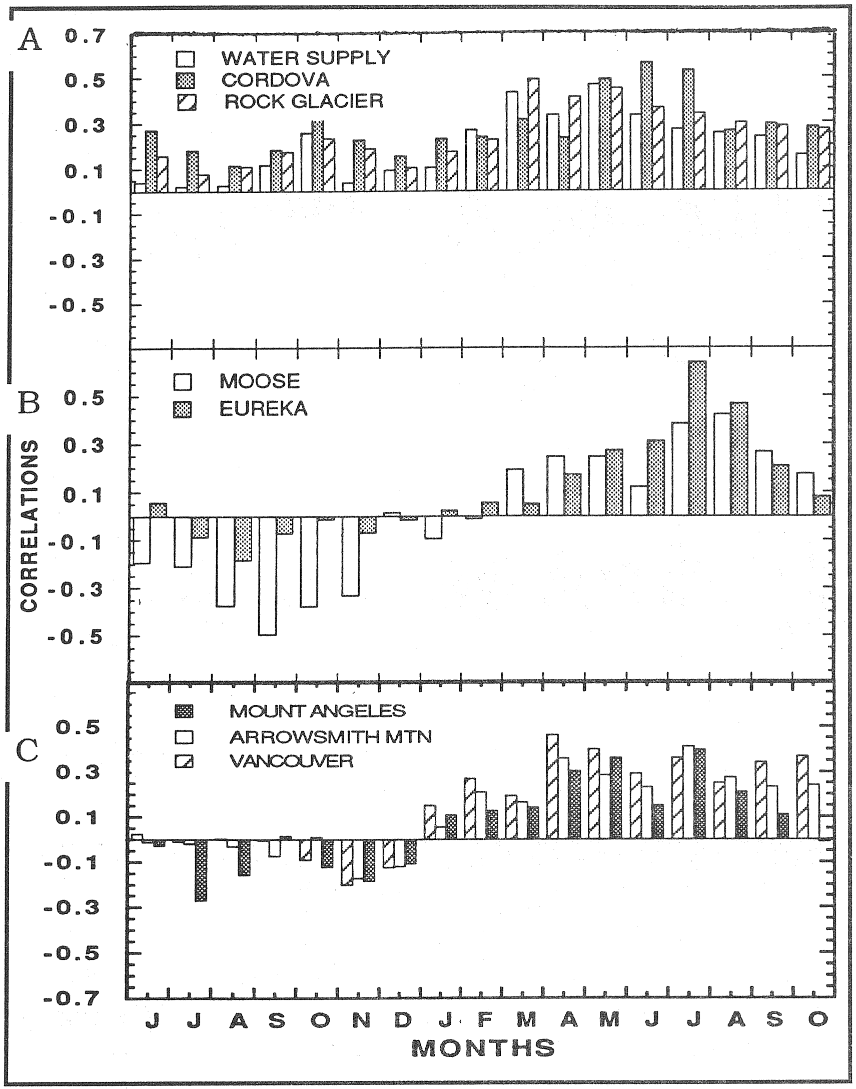

Figure 2. HISTOGRAM SHOWING CORRELATIONS BETWEEN A MONTHLY SERIES OF REGIONAL AVERAGE TEMPERATURES AND: (A) RING WIDTH SERIES, (B) TREE-RING DENSITY CHRONOLOGIES FROM THE GULF OF ALASKA, AND (C) DENSITY CHRONOLOGIES FROM NORTHWEST WASHINGTON

reconstruction, about 39% of the variance for 1905 to 1983 is explained after adjusting for degrees of freedom lost in regression (ar^2). When the period 1905-1944 was used in calibration and the verification was 1945-1983, the adjusted variance explained was 31%, with a reduction of error (RE) of 0.33 and a Spearman correlation of 0.56. The reduction of error is a method of test significance (Gordon and LeDuc 1981) where any value above zero indicates significant predictive success. When the calibration (1945-1983) and verification (1905-1944) intervals were reversed, the variance explained was 46%, with an RE of 0.47 and a Spearman correlation of 0.64.

Somewhat better results were obtained for the Gulf of Alaska model, with 47% of the variance explained for the full period of 1909 to 1983. The calibration interval of 1909 to 1945 yielded an adjusted r-square of 0.40, an RE of 0.42, and a Spearman correlation coefficient of 0.51 for the later verification period. When these intervals were reversed, 56% of the temperature variance was explained, with an RE of 0.56 and a Spearman coefficient of 0.70. Figure 3 presents the two well-verified, summer temperature reconstructions for the Gulf of Alaska and the Pacific Northwest.

No summer temperature reconstructions have been available for the Gulf of Alaska prior to current study. Some features of the Yukon and Alaska regional summer temperature reconstruction (Briffa *et al* 1992) are consistent with the GOA reconstruction, including warming in the 1820s and cooling in the 1810s, 1860s, and 1890s (Figure 3a). They identified the summer of 1810 as the coldest over their Alaska -Yukon study region, as was found in our record of GOA summer temperatures. Historical 19th century temperature data for Sitka, Alaska (compiled by Roden [1989]), are consistent with the GOA temperature reconstruction, with extended cold periods during 1857-1863 and warm intervals during 1864-1870.

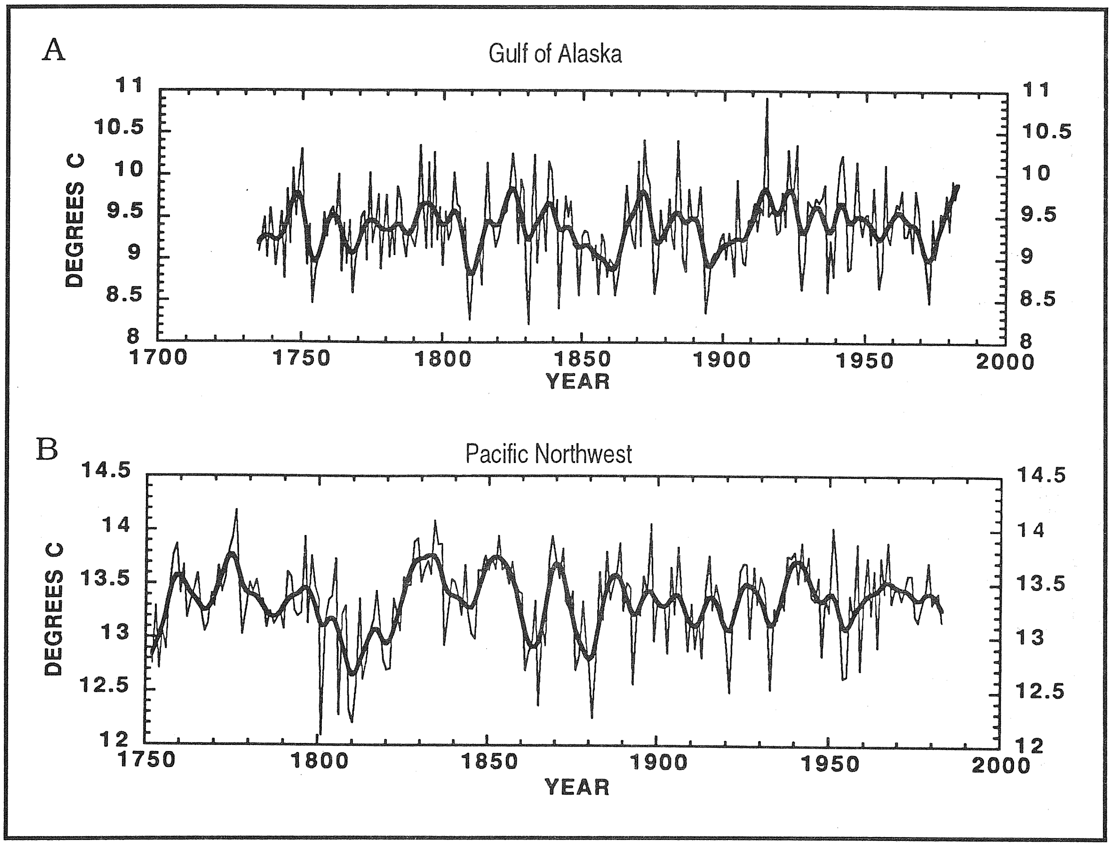

Figure 3. SUMMER TEMPERATURE RECONSTRUCTIONS FOR THE GULF OF ALASKA AND THE PACIFIC NORTHWEST
Smoothed reconstructions lines represent a 10-year cubic smoothing spline (Cook and Peters 1981).

The mean annual temperature reconstruction for Longmire, Washington, based on ring-width data from high elevations (Graumlich and Brubaker 1986) shows cool intervals in the early 1800s and the 1880s, consistent with the PNW reconstruction. However, the Graumlich and Brubaker reconstruction exhibits warming in the latter part of the 20th century; the coastal PNW series does not show this change (Figure 3b).

The density chronologies used in the summer temperature reconstruction of Briffa *et al* (1992) for the Pacific Northwest and British Columbia (their BCPNW) include the three density chronologies used in our PNW reconstruction. As expected, most primary features in the two reconstructions are similar. However, the cool interval centered around 1860 AD is not apparent in the Briffa *et al* (1992) reconstruction. This cool period is a significant interval in the coastal reconstruction and is also noted as a major cool interval from coastal temperature time series (Roden 1989).

The good correspondence with independent historical data from coastal temperature instrumental records and the broad agreement with published reconstructions based on tree-ring data suggest that the two summer temperature reconstructions are reliable records of temperature change along the Pacific Northeastern coastal areas.

Tree Growth and Sea Surface Temperatures

The next step in the analyses was to explore links between tree growth, land surface temperatures, and sea surface temperatures. Land surface and sea surface temperature records from the Gulf of Alaska are strongly correlated for April through September, with the strongest correlations at 55°N latitude, 150°W longitude (Figure 4). PCA scores from the five tree-ring chronologies show a similar correlation pattern, with the strongest correlation also at 55°N, 150°W (Figure 5).

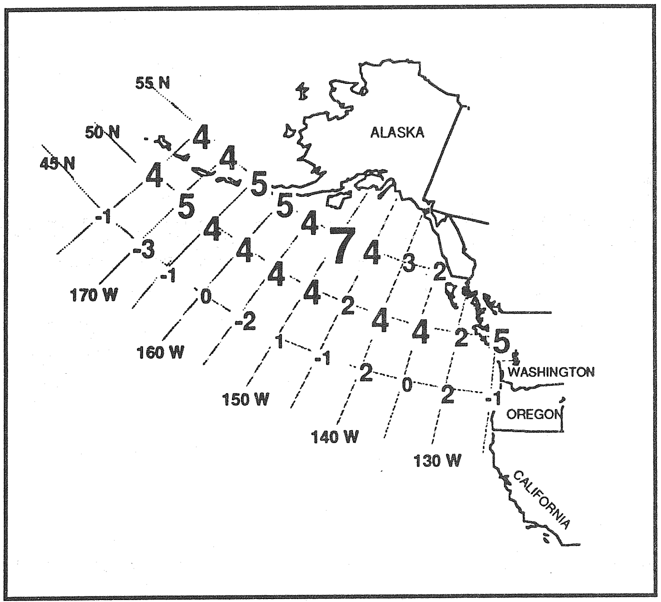

Figure 4. CORRELATION FIELDS SHOWING RELATIONSHIP BETWEEN LAND TEMPERATURE AND SEA SURFACE TEMPERATURE FOR THE GULF OF ALASKA

Magnitude of Correlation:

0	.00 - .09	4	.40 - .49
1	.10 - .19	5	.50 - .59
2	.20 - .29	6	.60 - .69
3	.30 - .39	7	.70 - .79

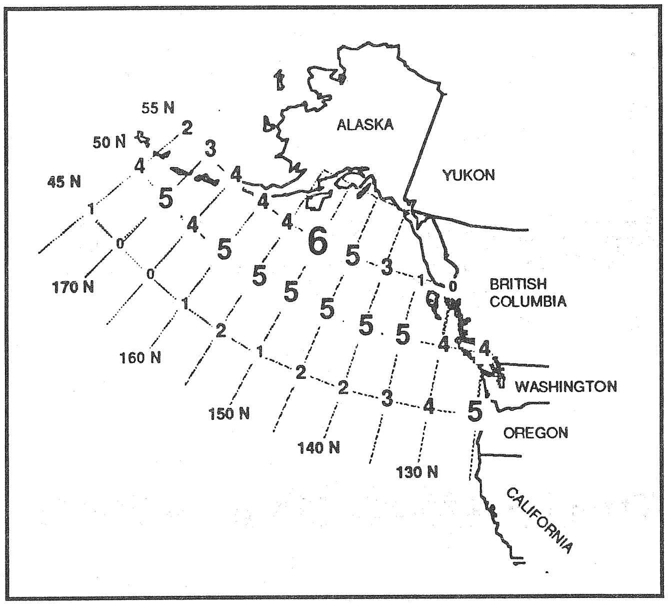

Figure 5. CORRELATION FIELDS SHOWING RELATIONSHIP BETWEEN TREE RING PCA SCORES AND SEA SURFACE TEMPERATURE FOR THE GULF OF ALASKA

Magnitude of Correlation:

0	.00 - .09	4	.40 - .49
1	.10 - .19	5	.50 - .59
2	.20 - .29	6	.60 - .69
3	.30 - .39	7	.70 - .79

The average land temperature record from northwestern Washington is highly correlated with sea surface temperatures from offshore British Columbia to southern California (Figure 6). The PNW temperature reconstruction correlates most strongly with sea surface temperature at 45°N latitude and 135°W longitude, with correlations dropping off dramatically away from this point (Figure 7). These linkages of tree growth, land temperatures, and sea surface temperatures suggest that tree growth is strongly affected by and provides information about nearby ocean temperatures.

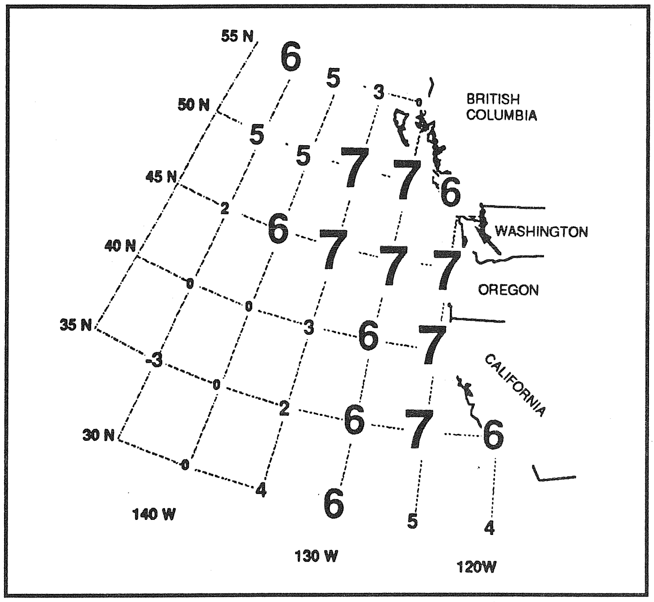

Figure 6. CORRELATION FIELDS SHOWING RELATIONSHIP BETWEEN LAND TEMPERATURE AND SEA SURFACE TEMPERATURE FOR THE PACIFIC NORTHWEST

Magnitude of Correlation:				
	0	.00 - .09	4	.40 - .49
	1	.10 - .19	5	.50 - .59
	2	.20 - .29	6	.60 - .69
	3	.30 - .39	7	.70 - .79

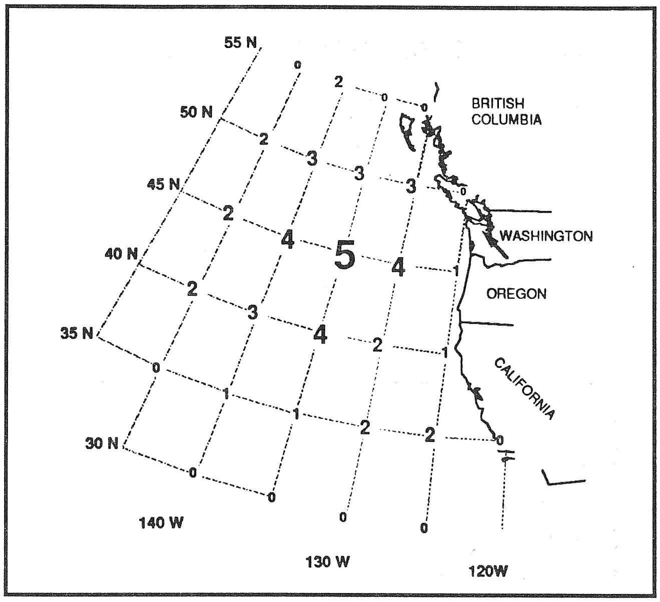

Figure 7. CORRELATION FIELDS SHOWING RELATIONSHIP BETWEEN TREE RING PCA SCORES AND SEA SURFACE TEMPERATURE FOR THE PACIFIC NORTHWEST

Magnitude of Correlation:				
	0	.00 - .09	4	.40 - .49
	1	.10 - .19	5	.50 - .59
	2	.20 - .29	6	.60 - .69
	3	.30 - .39	7	.70 - .79

Tree Growth and Winter Climate

Chronologies used to model winter temperature at the Amphitrite Point lighthouse shore station were ring-width time series from northern California (SNO), Washington State (FPC), Vancouver Island (ANG), and the Gulf of Alaska (NK). Tree-ring widths show a strong positive correlation with winter temperatures (Figure 8). Both the average winter (December-February) temperature series and the tree-ring data were prewhitened prior to PCA regression. The four ring-width chronologies together explain 41% of the variance in winter temperature for the full 44-year calibration period (Figure 9).

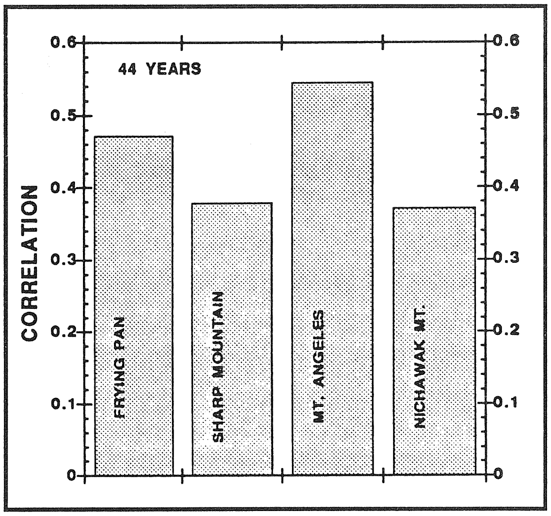

Figure 8. CORRELATIONS OF TREE-RING TIME SERIES AND 44 YEARS OF OBSERVED WINTER SEA SURFACE TEMPERATURE FROM AMPHITRITE POINT, VANCOUVER ISLAND

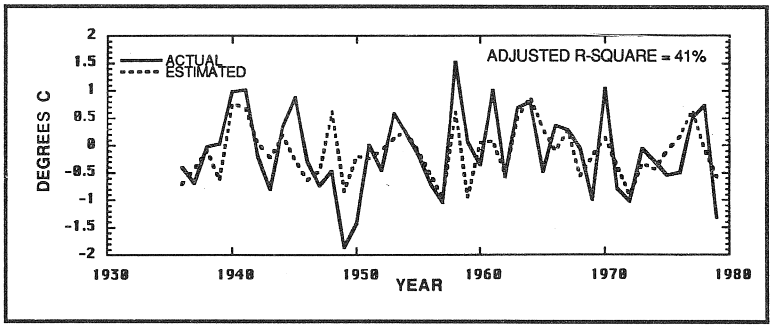

Figure 9. ACTUAL VERSUS ESTIMATED TEMPERATURE VALUES BASED ON THE FOUR CHRONOLOGIES IN FIGURE 8.

Ring-width data are also strongly correlated with shipboard winter sea surface temperatures. The Frying Pan Creek ring-width chronology (Table 1; Graumlich 1985), included in the analysis above, shows strong correlations with winter sea surface temperatures, with the center of correlation just off the northwest Washington coast at 50°N latitude and 130°W longitude (Figure 10).

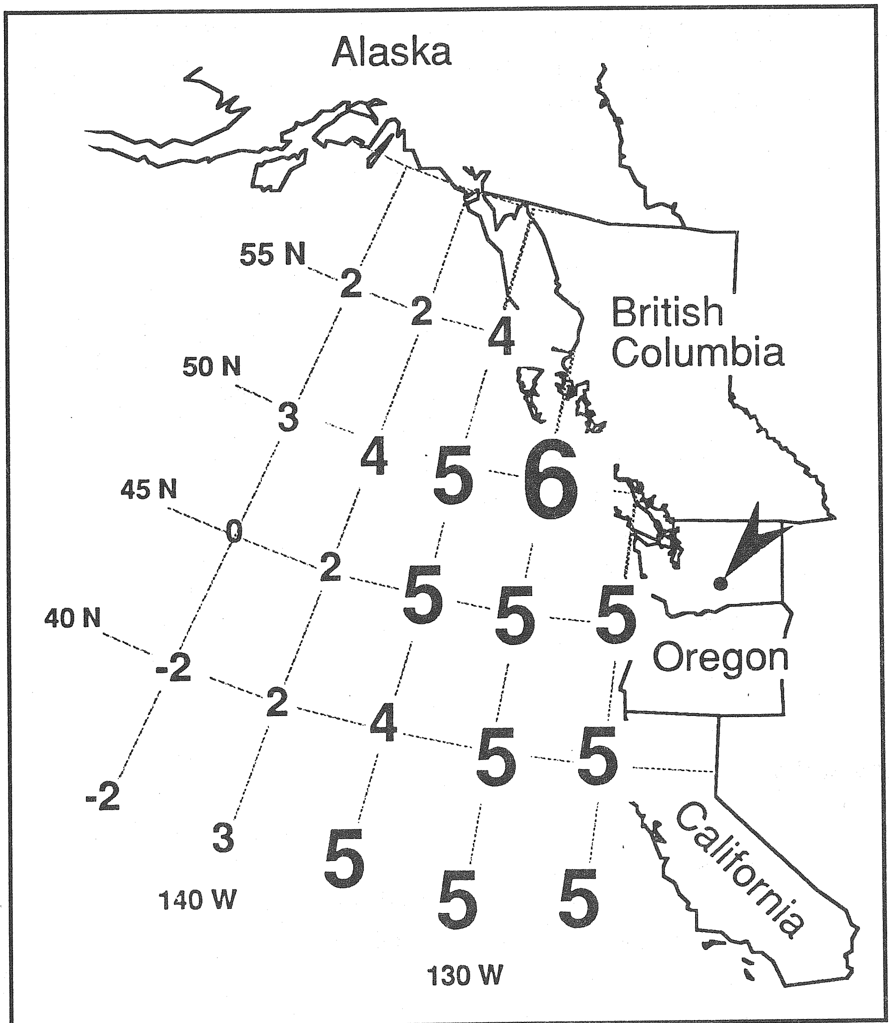

Figure 10. CORRELATIONS OF THE FRYING PAN CREEK RING-WIDTH CHRONOLOGY (Table 1) AND WINTER SEA SURFACE TEMPERATURE VALUES

Magnitude of Correlation:	0	.00 - .09	4	.40 - .49
	1	.10 - .19	5	.50 - .59
	2	.20 - .29	6	.60 - .69
	3	.30 - .39	7	.70 - .79

In addition to the potential of tree-ring data in coastal regions for reconstructing temperature changes, pressure variability is also recorded in the tree-ring record. The Aleutian Low is a major feature influencing circulation in the Northeast Pacific, especially during the winter (Namias *et al* 1988; Emery and Hamilton 1985). Modeling the Aleutian Low with tree rings using the Aleutian Low index was explored by Buckley *et al* (1992). Here we compare three ring-width chronologies with the PAC index of Rogers (1990). A strong Aleutian Low (higher PAC index) is associated with a near-shore climate influenced by warm subtropical water. During times of weaker lows (lower PAC index), cooler waters dominate as northward flow of warmer waters is inhibited. The strength of this low pressure system is most pronounced during winter and spring. Thus the climatic link between trees and pressure variations is that warmer temperatures are associated with a strong Aleutian Low that is, in turn, favorable for tree growth.

The average of winter and spring (December-May) PAC values were used in modeling. In correlations for the RGL Alaskan chronology (0.45) and the California series (SNO, 0.39), the PAC is negatively correlated with the Nevada chronology (PTS, –0.36). After prewhitening, these three chronologies together explain 38% of the variance in the PAC for an 81-year calibration period (Figure 11).

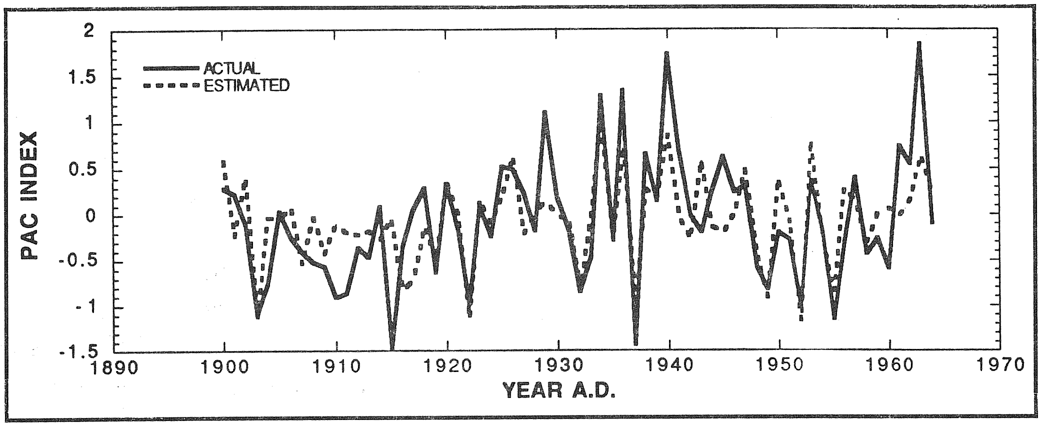

Figure 11. ACTUAL VERSUS ESTIMATED PAC VALUES FOR SPRING AND WINTER
Three ring-width series together account for 38% of the variance over the 81-year calibration period.

Conclusions

Summer temperature reconstructions presented here are the first temperature series from the Pacific Northeast sector that are based only on coastal and near-coastal tree-ring sites. These well-verified models based on ring-width and maximum latewood density chronologies provided the strongest records of temperature change in our analyses. In addition to the tree rings as a record of land temperature change, tree ring comparisons with sea surface temperatures suggest that tree growth variations reflect oceanic as well as atmospheric conditions.

Ring-width chronologies from the Northeast Pacific can provide information related to winter temperature and pressure change in the region. Updating existing chronologies and adding new chronologies could lead to rigorous reconstruction of land temperatures as well as sea surface temperatures from coastal stations (such as Amphitrite Point) in addition to sea surface temperature records from ship observations.

The relationship between tree growth and sea level pressure variability patterns such as the PAC suggests that tree rings can potentially extend the record of sea level pressure changes in the Northeast Pacific. Continued sampling in subarctic coastal areas will yield greater coverage for improved pressure reconstructions.

Acknowledgments

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