Tree-Ring Records as Indicators of Air-Sea Interaction in the Northeast Pacific Sector

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Abstract: Climate conditions in land areas of the Pacific Northwest are strongly influenced by atmosphere/ocean variability, including fluctuations in the Aleutian Low, Pacific-North American (PNA) atmospheric circulation modes, and the El Niño-Southern Oscillation (ENSO). It thus seems likely that climatically sensitive tree-ring data from these coastal land areas would likewise reflect such climatic parameters. In this paper, tree-ring width and maximum latewood density chronologies from northwestern Washington State and near Vancouver Island, British Columbia, are compared to surface air temperature and precipitation from nearby coastal and near-coastal land stations and to monthly sea surface temperature (SST) and sea level pressure (SLP) data from the northeast Pacific sector. Results show much promise for eventual reconstruction of these parameters, potentially extending available instrumental records for the northeastern Pacific by several hundred years or more.

Introduction

Atmosphere-ocean interactions play an extremely important role in the climatic variability over western North America. Linkages have been demonstrated between northeast Pacific SLP and SST and other indicators of atmosphere/ocean interaction (such as the Aleutian Low Index and PNA) and climate over land (Walsh and Richman 1981; Namias *et al* 1988; Trenberth 1990; Leathers *et al* 1991). The role of the northeastern Pacific sector in large-scale climatic dynamics, including teleconnections with ENSO events, has also been well documented (Andrade and Sellers 1988; Cayan 1980; Emery and Hamilton 1985; Namias *et al* 1988; Niebauer 1988; Ropelewski and Halpert 1986).

In this paper we explore relationships between tree-ring width and maximum latewood density chronologies from the Pacific Northwest and climatic data from coastal/near-coastal land stations, as well as SST and SLP records from the northeastern Pacific sector. Previous researchers have used tree rings to model and reconstruct air/ocean parameters, including sea surface temperatures (Douglas 1980; Lough 1986), sea level pressure (Blasing and Fritts 1975) and ENSO events (Lough and Fritts 1985, 1989; Michaelson *et al* 1987). In their reconstructions, Lough and Fritts (1985, 1989) employed a grid of 65 chronologies representing a variety of species over a wide geographic area of western North America. We use an approach more similar to those of Douglas (1980) and Michaelson *et al* (1987), in which a small subset of tree-ring chronologies, found to be the most sensitive to specific variables of interest, were

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retained for final analysis. Our study represents one of the first attempts to relate North American maximum latewood density data (in addition to ring widths) to features of atmosphere/ocean circulation such as SLP and SST.

Climate and Tree-Ring Data

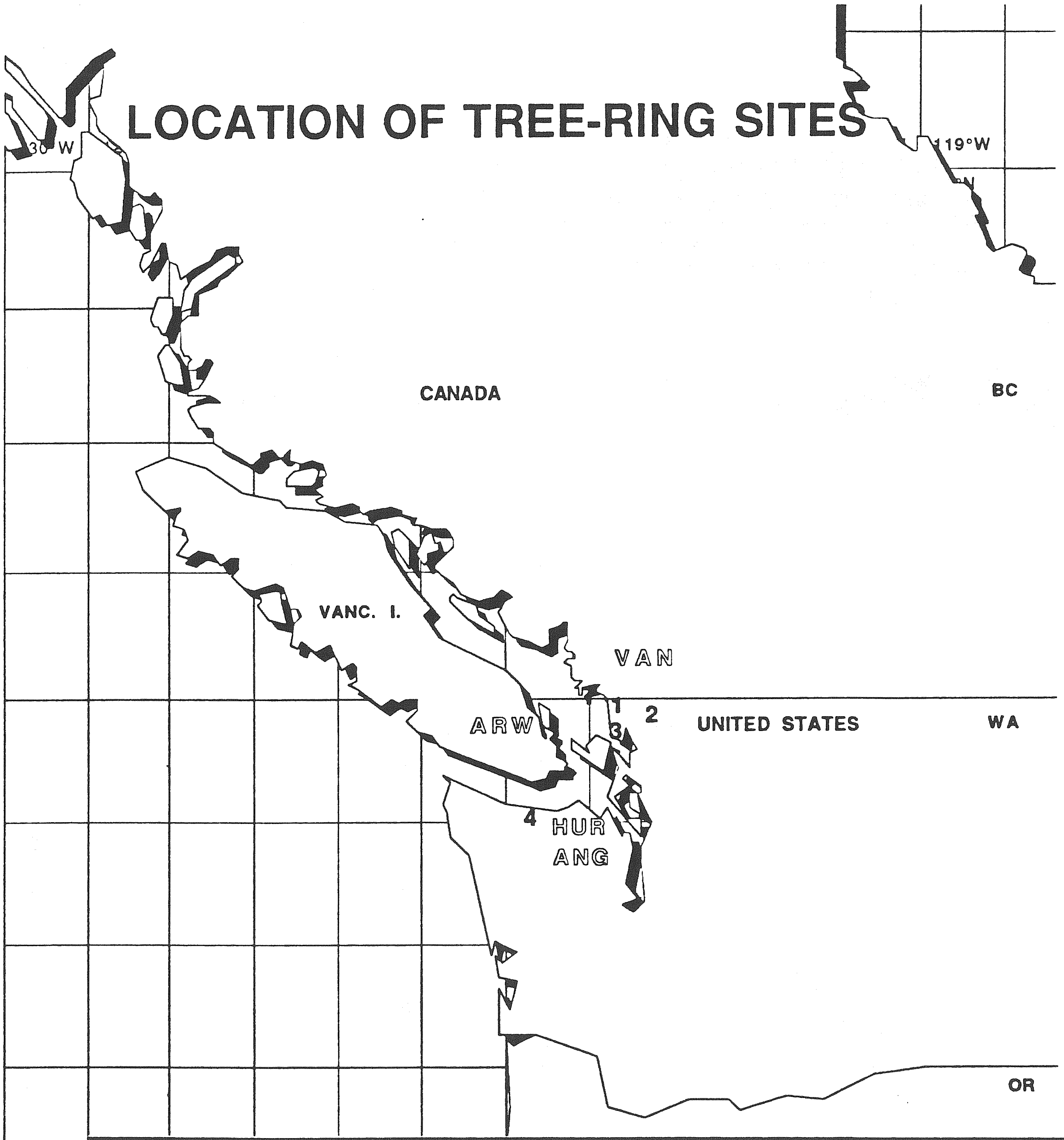
Four sets of climatically sensitive, maritime tree-ring chronologies of both ring width and maximum latewood density from sites in northwestern Washington State and southwestern British Columbia were selected for this study (Figure 1). Three tree species are represented: *Pseudotsuga menziesii* (Douglas fir), *Abies amabilis* (Pacific silver fir), and *Tsuga mertensiana* (mountain hemlock). The raw data were processed in Switzerland and supplied to us by Dr. Fritz Schweingruber of the Swiss Federal Institute of Forestry Research. Final chronologies (Figure 2) were developed from the raw data at the Tree-Ring Laboratory at Lamont-Doherty Geological Observatory, using standard dendrochronological techniques (Fritts 1976; Cook and Kairiukstis 1990). The common period of the eight chronologies is 1750 to 1983.

The tree-ring data were first compared to monthly temperature and precipitation instrumental records from nearby individual land climate stations, obtained from the Historical Climate Network. After screening all available nearby stations, four were averaged into a regional series: Blaine, Bellingham, Clearbrook, and Port Angeles — all in northwestern Washington (Figure 1). A monthly SST dataset for the northeastern Pacific, at 5x5 degree grid resolution and extending from 1947 to 1990, was supplied to us by Dr. D. Cayan of Scripps Institute of Oceanography. Monthly sea level pressure data, also at 5x5 degree grid resolution (available from 1899 to 1980), was obtained from Dr. K. Trenberth of the National Center for Atmospheric Research.

Response of Tree Growth to Land Climate

The climatic response of the density and ring-width series was evaluated using simple correlation and linear regression analyses. Correlations were determined between the ring width and maximum latewood density chronologies and the regionally averaged monthly temperature and total precipitation data for a 17-month dendroclimatic year (beginning in June of the year prior to growth and extending to October of the growth year) for the common period from 1903 to 1983 (Figure 3).

The maximum latewood density chronologies show a much more consistent response to land climate, across both site and species, than does ring width. For all four density series, there is a strikingly clear, positive correlation between tree growth and growing season (April through August) temperatures and a corresponding negative correlation with late growing season (June through August) precipitation. Although the ring



TREE RING SITES	TREE RING SPECIES	TIME SPAN	ELEVATION	LATITUDE	LONGITUDE
ARROWSMITH MTN	Tsuga Mertensiana	1629-1983	1020 M	49 09 N	125 14 W
ARW					
HURRICANE RIDGE	Abies Amabilis	1698-1983	1560 M	47 57 N	123 28 W
HUR					
MOUNT ANGELES	Pseudotsuga Men.	1750-1983	1360 M	47 58 N	123 26 W
ANG					
VANCOUVER	Tsuga Mertensiana	1413-1983	1110 M	49 20 N	123 20 W
VAN					

Figure 1. Map showing tree-ring sites in Washington state and British Columbia. Locations of climate stations are marked by numbers: 1=Blaine, 2=Clearbrook, 3=Bellingham, and 4=Port Angeles.

width/climate relationships agree qualitatively with those of latewood density, the ring width data also show a tendency for a response to growing season climate of the prior year (a negative response to temperature and a positive response to precipitation). In addition, variability in response is greater between species and between sites for ring width (see Figure 3). Thus the ring width and density data provide different types of climatic information, and both contribute to our understanding of the tree growth response to climate at these sites.

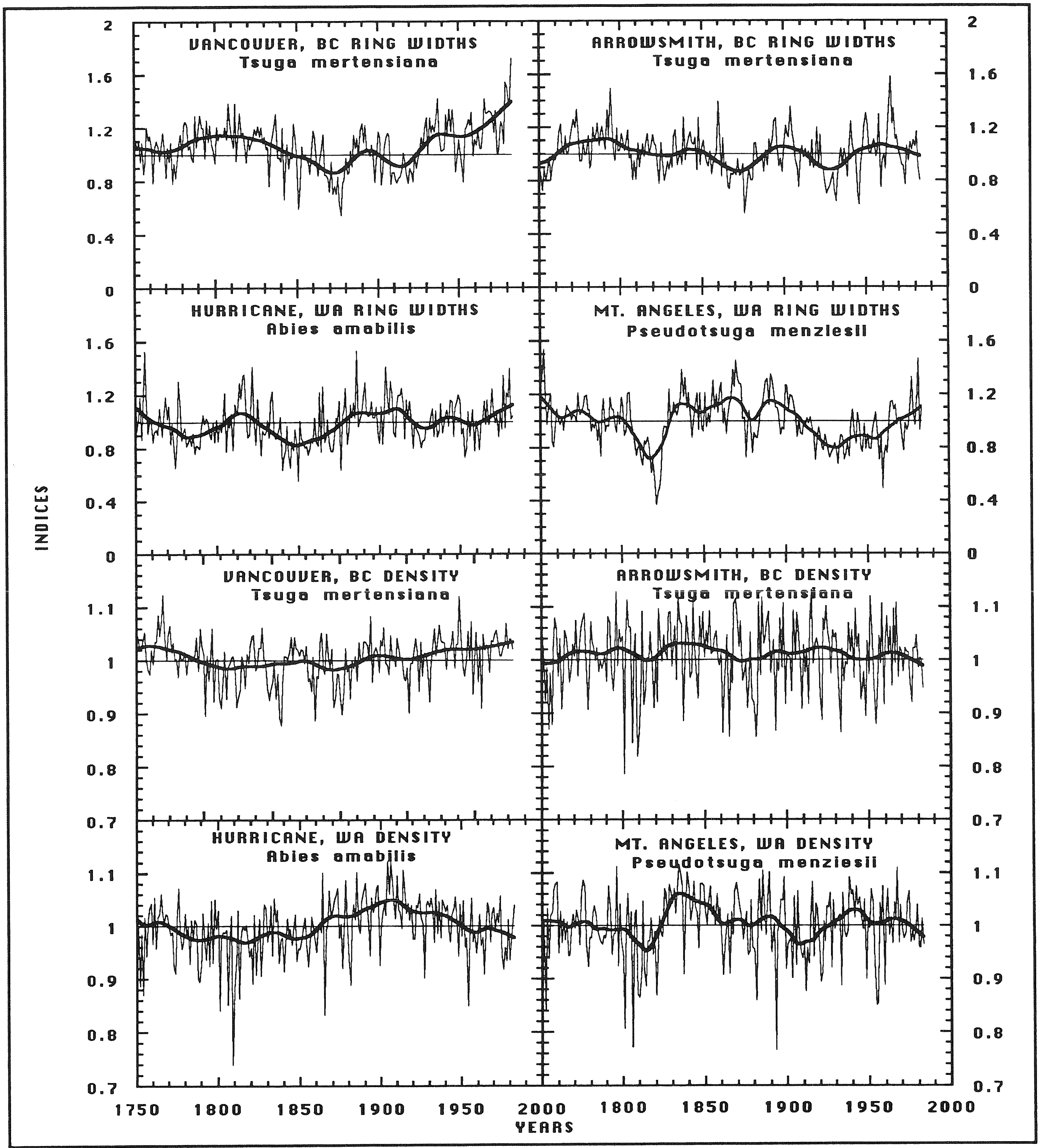


Figure 2. Plots of ring width and density indices from each of the four sites. Shown is the common period of all sites from 1750 to 1983.

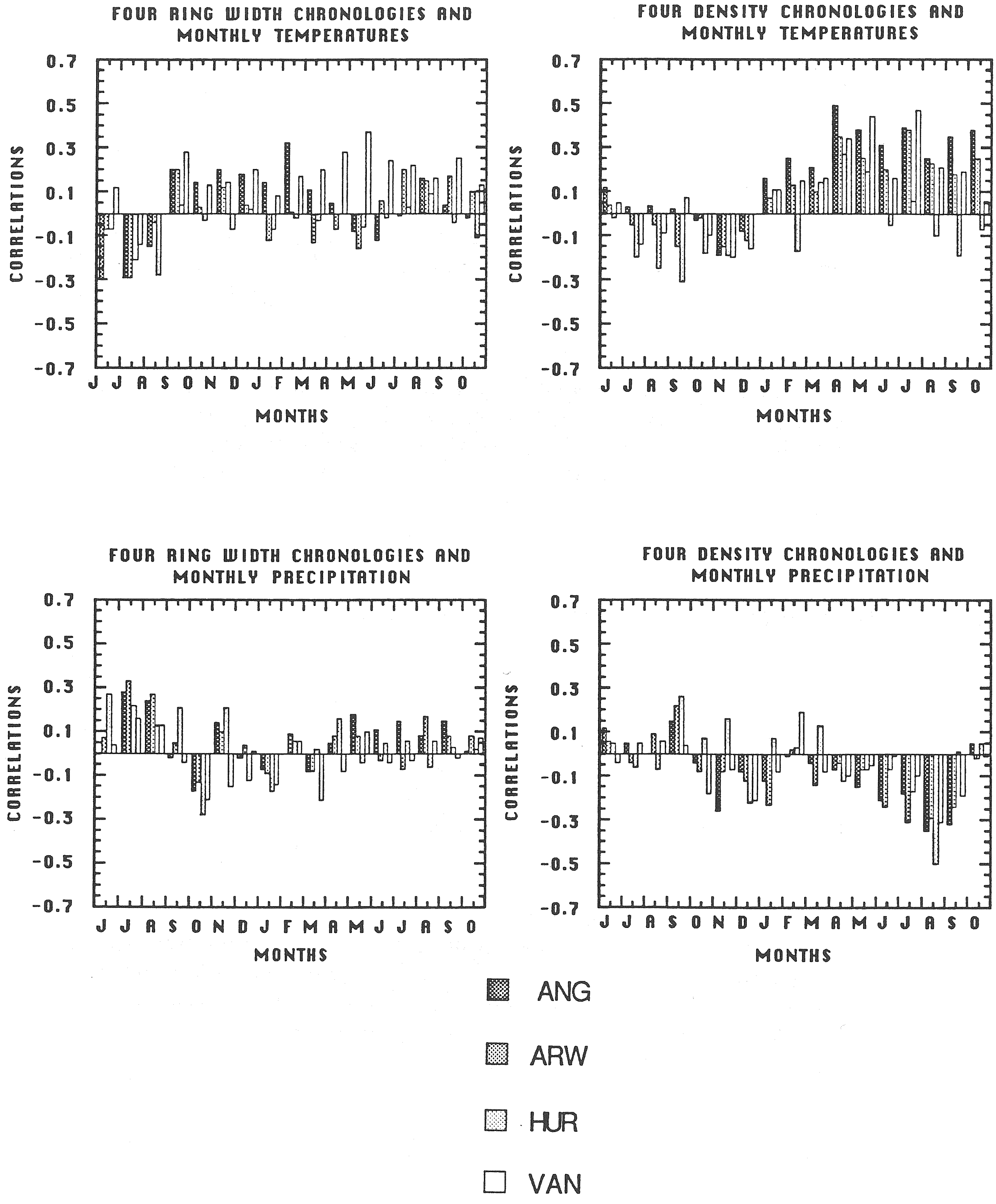


Figure 3. Bar graphs of correlations between tree growth and climate for ring width and maximum latewood density. Note the more uniform cross-species response of the density series for both temperature and precipitation and the greater prior season response for ring width. The most significant values are the positive correlation of density with spring temperature and the negative correlation of density with summer precipitation.

Land/Ocean Climate Linkages in the Northeast Pacific Sector

Previous research has determined that relationships exist between climate over the Pacific Ocean and western North America (Walsh and Richman 1981; Douglas *et al* 1982; Andrade and Sellers 1988; Emery and Hamilton 1985; Namias *et al* 1988). We analyzed the relationship between land instrumental records and northeast Pacific SST and SLP for a series of grid points ranging from 35 to 55 degrees North and 125 to 150 degrees West. The regionally-averaged land temperatures were compared with SSTs for four seasons: fall (OND), winter (JFM), spring (AMJ), and summer (JAS). The strongest correlations (positive) were found in spring and summer (Figure 4). A striking geographic pattern was found, with those SST gridpoints nearest to shore having the strongest correlations with land climate. The somewhat weaker correlations in summer might be explained by the increasing role of radiative heating and cooling of the continent during the region's dry season and also of the late-seasonal changes in circulation over the Pacific with the migration of the sun's declination, the westward displacement of the Aleutian Low, and the northward displacement of the Subtropical High.

Tree Growth and Sea Surface Temperatures

The four sets of chronologies (ring width and density data for each site) were compared to SST data for the same gridpoints as those previously compared to land temperatures (Figure 5). Overall the strongest correlations were found with summer SST. Maximum latewood density demonstrated a significant, positive correlation with summer SST, with the highest correlation at the gridpoint 45N/135W. The strength of the correlations decrease rapidly from this gridpoint in all directions, as shown in Figure 5. The ring-width chronologies show a moderately strong correlation with a zone away from shore centered on 45N, 140W, while the near-shore gridpoints show a weak, negative correlation. While the most significant gridpoint was five degrees farther west than that for density, the ring-width correlations were still strongly positive for 45N/135W. It was, therefore, determined that the strongest relationship overall is between summer SSTs for 45N/135W, and combined maximum latewood density and ring width data.

Summer SST at gridpoint 45N/135W was estimated using two density chronologies and one ring-width chronology (which showed the strongest correlations) as predictors in linear regression analysis for the common period from 1947 to 1983 (Figure 6). Agreement is good between the recorded and estimated SSTs, with 42% variance explained (adjusted for degrees of freedom). However, the relationship appears to break down in the late 1960s and into the 1970s.

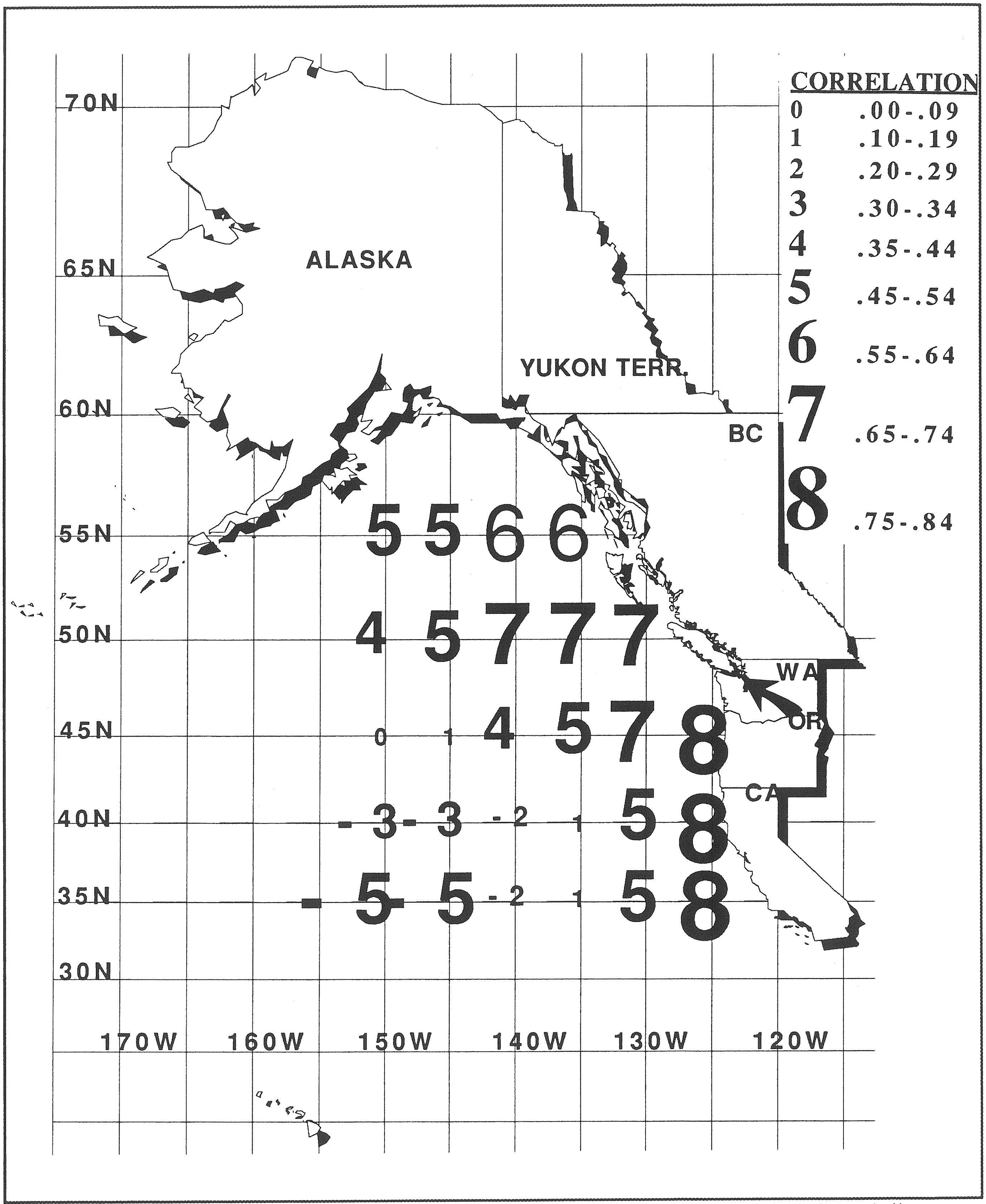


Figure 4. Map showing areal correlation between regional spring temperature (AMJ) for the selected climate stations (indicated by the arrow) with sea surface temperatures for the same period. Note the very strong correlations with SST along the coast and northwestward into the Gulf of Alaska.

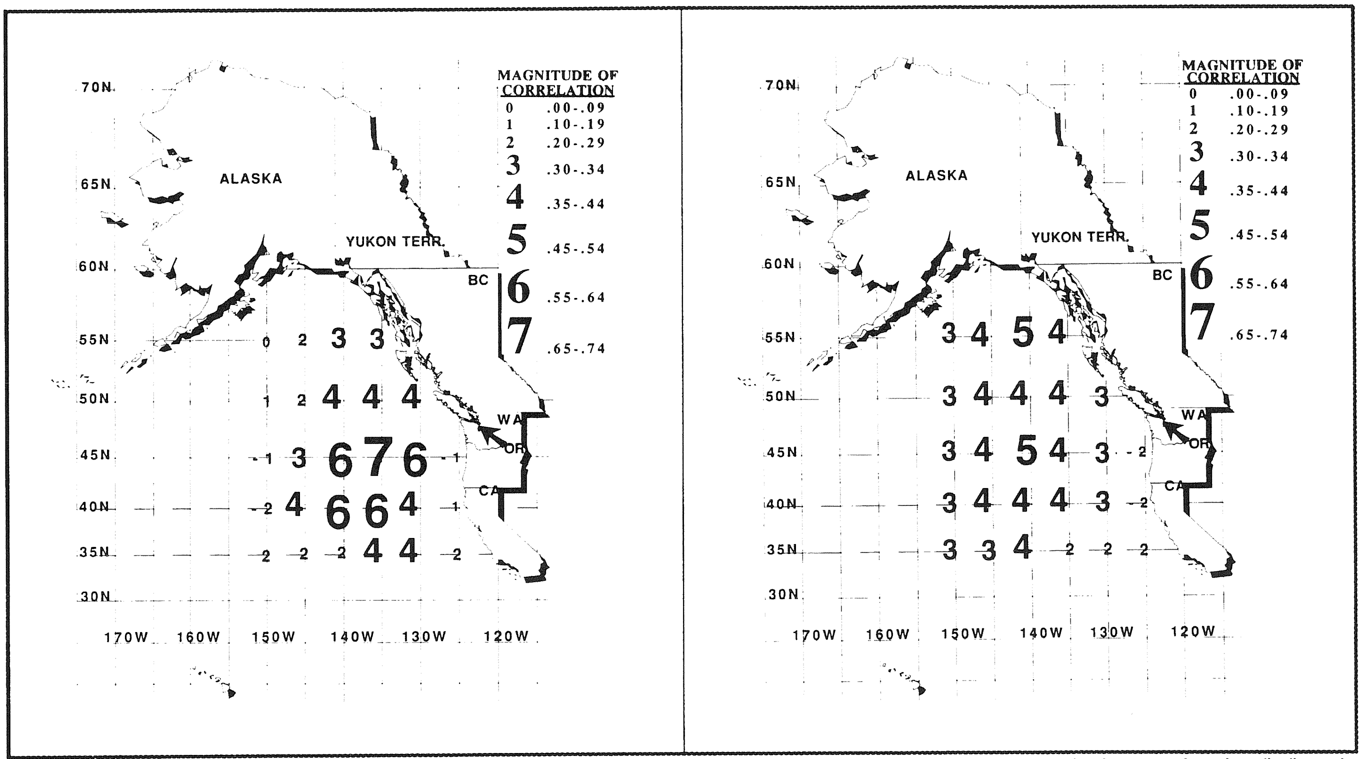


Figure 5. Map showing areal correlation between maximum latewood density indices (left) and ring width indices (right) for the four tree-ring sites (indicated by the arrow) and summer (JAS) sea surface temperature. The strongest correlation (positive) is with the grid point 45N, 135W and maximum latewood density, with a very compact zone of significant correlation around that point. Correlations for ring width basically agree with those for density, although with less significant correlations and over a broader region.

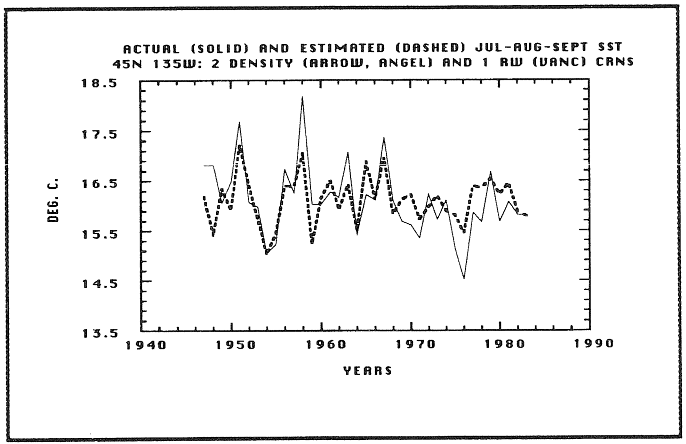


Figure 6. Plot of actual and estimated values of sea surface temperatures for the grid point 45N, 135W, using two density chronologies and one ring width chronology. The amount of variance explained (adjusted for degrees of freedom) is 42 percent.

Tree Growth and Sea Level Pressure

A dominant feature of northeast Pacific circulation is the Aleutian Low (Namias *et al* 1988; Emery and Hamilton 1985). The Aleutian Low Index (ALI) is a representation of the strength of the low, measuring the pressure gradient between two points: 40N/120W and 50N/170W, where the latter is subtracted from the former. A higher value of ALI indicates a stronger gradient and, therefore, a deeper Aleutian Low. Lower values indicate weak development of the low.

Our study region is affected by this system in the following simplified way. In years of a strong Aleutian Low, the near-shore ocean climate is influenced by the northward flow of warm, subtropical water; in years of a weak development in the Aleutian Low, the near-shore ocean climate is influenced by cooler waters, as the northward flow of warm, subtropical water is inhibited. We compared our averaged land temperatures against SLP at 50N/170W and confirmed that the winter strength of the Aleutian Low has a significant, negative correlation with land temperatures all through the year and is consistent with the findings of Namias *et al* (1988). As the winter Low gets stronger (lower), average temperatures at the sites will be higher all year long. It was also shown that the strength of the Low in spring was significantly and negatively correlated with land temperatures for that same period.

We compared our four density chronologies to SLP data representing the three elements of the ALI for 1900-1980. Figure 7 shows the correlations of the density chronologies with 40N/120W (top graph), 50N/170W (middle graph), and the ALI (bottom graph). While there is some indication of a relationship between maximum latewood density and winter

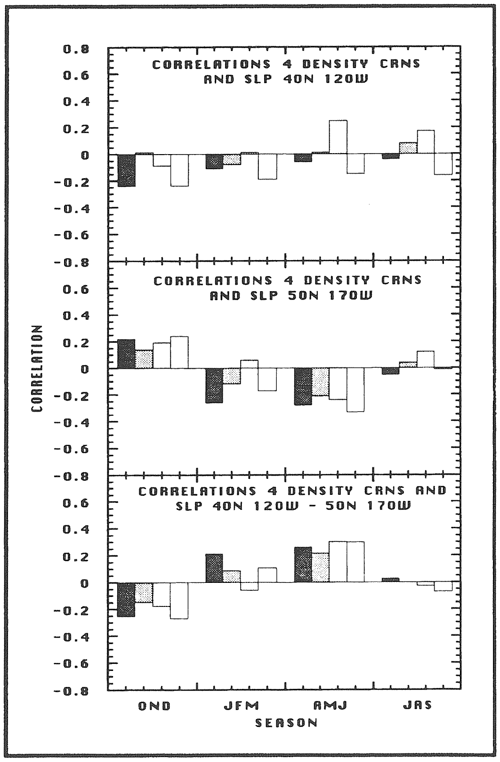


Figure 7. Correlations of the four density chronologies with three parameters of the Aleutian Low Index for four seasons (1900-1980). The top graph compares density with sea level pressure at 40N, 120W; the middle graph at 50N, 170W; and the bottom graph compares density with the Aleutian Low Index itself (the difference between the two points shown above). Note the strong correlation with the spring (AMJ) in the middle and bottom graphs (negative correlation for 50N, 170W, and positive correlation with the Aleutian Low Index). This indicates that maximum latewood density in trees in the study region increases in years of a strengthened springtime Aleutian Low.

intensity of the Aleutian Low, the real influence is from the spring period, which was demonstrated to be an important link between the Aleutian Low and temperature on land. This spring period is strongly affected by the persistence of the winter Aleutian Low (Namias *et al* 1988) and may, therefore, be considered to reflect the strength of the winter development of the Low. This would seem to indicate that maximum latewood density is increased in those years where the spring ALI is greater as the result of the persistence of a strengthened winter Aleutian Low.

Summary

In this paper we have explored some of the linkages between tree-ring data from coastal and near-coastal sites in the Pacific Northwest and several variables related to air/ocean interaction and atmospheric circulation in this region. The land temperature data showed significant positive correlations with SSTs (at 5x5 grid resolution) during the growing season and, in particular, for the spring months (April, May, and June). Monthly SLP data for gridpoints known to be representative of the strength of the Aleutian Low were also demonstrated to influence land temperatures at the stations selected for study: with an increase in the strength of the Aleutian Low during winter, there is an increase in temperature for the rest of the year. Both ring-width and maximum latewood density indices were linked to SST and SLP, with the strongest correlations for the spring months.

Our results indicate that density data is equally or even more sensitive to climate in this region than are ring widths. To date there have been relatively few studies that have modeled or reconstructed Pacific sea surface temperatures using tree-ring data, and these have been almost exclusively through the use of ring-width data (Douglas 1980). From this preliminary study we conclude that reconstructions of northeast Pacific SST and SLP are possible for several centuries or more using maximum latewood density and ring-width chronologies from the Pacific Northwest. There is also the potential for eventual integration of these tree-ring data with other types of proxy records, including varves (Leclerc and Schrader 1987; Baumgartner *et al* 1989). Future research will involve developing a tree-ring database with added geographical coverage to improve prospects for long-term, high-resolution reconstruction of climate in this area.

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