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Boreal temperature variability inferred from maximum latewood density and tree-ring width data, Wrangell Mountain region, Alaska

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Abstract

Variations in both width and density of annual rings from a network of tree chronologies were used to develop high-resolution proxies to extend the climate record in the Wrangell Mountain region of Alaska. We developed a warm-season (July–September) temperature reconstruction that spans A.D. 1593–1992 based on the first eigenvector from principal component analysis of six maximum latewood density (MXD) chronologies. The climate/tree-growth model accounts for 51% of the temperature variance from 1958 to 1992 and shows cold in the late 1600s–early 1700s followed by a warmer period, cooling in the late 1700s–early 1800s, and warming in the 20th century. The 20th century is the warmest of the past four centuries. Several severely cold warm-seasons coincide with major volcanic eruptions. The first eigenvector from a ring-width (RW) network, based on nine chronologies from the Wrangell Mountain region (A.D. 1550–1970), is correlated positively with both reconstructed and recorded Northern Hemisphere temperatures. RW shows a temporal history similar to that of MXD by increased growth (warmer) and decreased growth (cooler) intervals and trends. After around 1970 the RW series show a decrease in growth, while station data show continued warming, which may be related to increasing moisture stress or other factors. Both the temperature history based on MXD and the growth trends from the RW series are consistent with well-dated glacier fluctuations in the Wrangell Mountains and some of the temperature variations also correspond to variations in solar activity.

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Introduction

Meteorological station records show that temperatures in Alaska have been increasing over the 20th century. Climate models predict that this warming trend will continue and this will be amplified in the northern latitudes especially at interior continental sites (Chapman and Walsh, 1993; Serreze et al., 2000; IPCC, 2001). Herein we describe a network of tree-ring sites developed to extend and better evaluate regional-scale climate variability in the Wrangell Mountain region of Alaska. Considerable spatial variability, due to complex topographies, maritime influences, and circulation variations, define a set of climate subregimes that may not necessarily warm uniformly. These regional land-

scape heterogeneities combined with a dearth of reliable long-term climate observational data in Alaska make it difficult to produce reliable individual tree–climate models. Development of a network of well-replicated long-term paleoclimatic records will help define regional climate and put recent regional environmental change into long-term context. This data set will allow for a deeper understanding of the effects of climate change on regional scales and be useful for ecosystem modeling and climate model predictions.

The Wrangell Mountain region is a very large, relatively undisturbed, land area that represents a major part of Alaska. Elevation ranges from about 240 m near the Chitna River to over 5000 m at the peak of Mount Bona (Fig. 1). A combination of the south-to-north transition from maritime to continental climate and local valleys, glaciers, and orographic effects influence the weather. The Chugach Moun-

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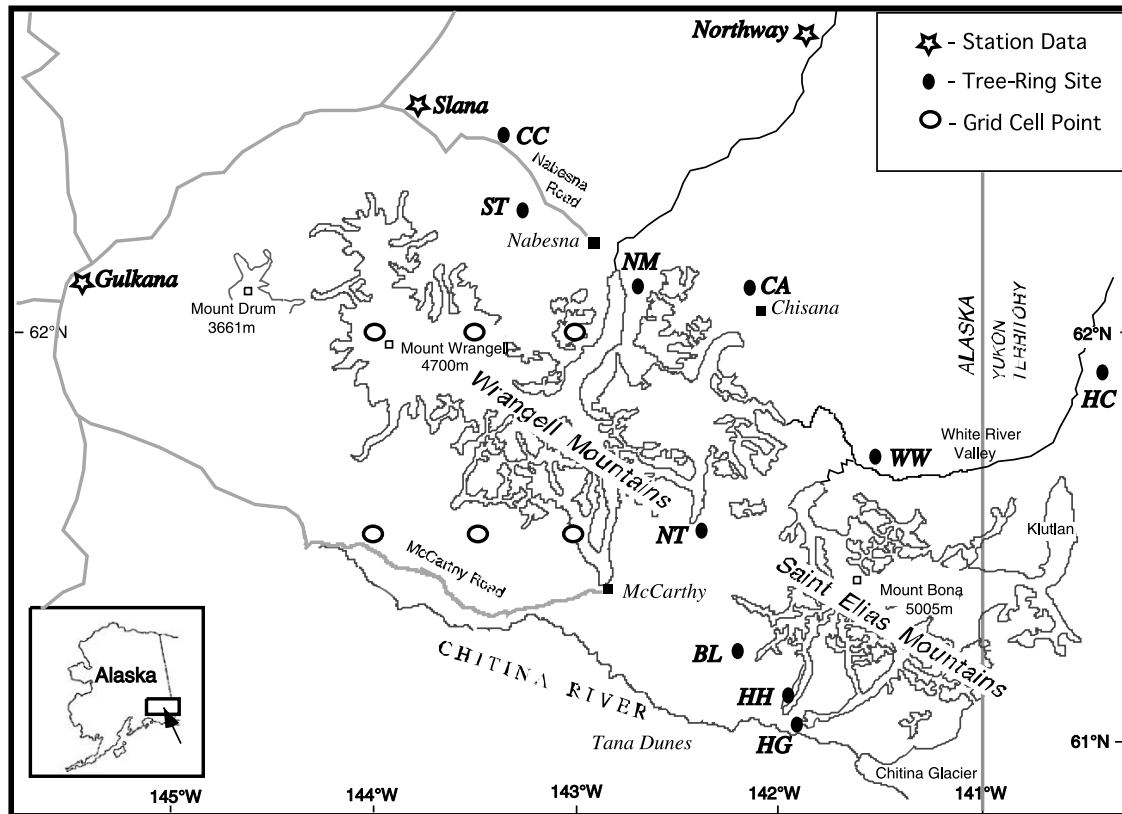


Fig. 1. Map of Alaska showing sampling site locations (black dots) with corresponding abbreviated tree-ring sampling site names in two capital letters, meteorological stations, and grid cell point locations.

tains, which lie to the south and southwest of the Wrangell Range, reach elevations as high as 4020 m and act as a partial block to the influence of maritime climate from the North Pacific, making the Wrangell Mountains primarily continental.

The climate history of the Wrangell Mountain region is not well known and there have been few regional-scale climate studies in this area. Denton and Karlén (1977) did a classic study on Holocene glacial and tree-line variation that showed that glacial expansion in the White River Valley was concurrent with Little Ice Age cooling and that glaciers were receding during much of the 20th century. Previous tree-ring sampling in or near the Wrangell Mountains was done by H.C. Fritts (one site)¹ and F.H. Schweingruber (two sites Schweingruber et al., 1993). Schweingruber et al. (1993) used two sites from the Wrangell Mountain region as part of 17 chronologies to define an Alaska–Yukon region. Their results showed that maximum latewood density (MXD) variables had strong and consistent correlations with temperature and that ring-width (RW) variables correlated poorly with temperature. The data from Schweingruber et al. (1993)

were also used for hemisphere-scale studies (Briffa et al., 1998). However, these series are relatively short and are therefore not included in this study (ITRDB, 2002). We previously developed one ring-width chronology from elevational tree line, Silver Tip (ST), in the north flank of the Wrangell Mountains (Fig. 1). The ST chronology shares much common variance with other northern boreal data sets, despite the complexity of the region, and was used as part of a reconstruction of annual Northern Hemisphere temperatures (Jacoby et al., 1999; D'Arrigo et al., 1999). Companion studies of neoglaciation and geomorphic response to climate change of the Wrangell Mountain region were undertaken by Wiles et al. (2002, 2003). The mountain glacier history offers a record of past temperature change that is independent of the climate history developed for the current tree-ring study.

This paper describes high-resolution, precisely dated records of warm-season annual temperature variation and tree growth for the past 4 centuries in the Wrangell Mountain region, Alaska. These records are based on a network of tree-ring chronologies developed for both ring width and maximum latewood density. The regional climate record developed for this study allows us to study climate change and investigate the effects of volcanic, solar, and other forcing factors on this regional climate.

¹ This information is from the International Tree-Ring Data Bank, <http://www.ngdc.noaa.gov/paleo/treering.html>.

Table 1a
Maximum latewood density loadings on the first eigenvector from principal-component analysis

Site	Eigenloading
NM	0.444
CC	0.437
HH	0.427
BL	0.422
WW	0.380
ST	0.326

Methods

Chronology development

White spruce (*Picea glauca* (Moench.) Voss) is a dominant tree-line species in Alaska and Canada (Viereck and Little, 1972; Hosie, 1990). In the Wrangell Mountain region, we observed white spruce stands at or near their elevational growth limit where they are extremely sensitive to changes in climate and can provide valuable paleoclimatic information as recorded in the variations of their annual tree rings (Fritts, 1976; Jacoby and D'Arrigo, 1995). During the 1996–1999 summer field seasons, we sampled trees at 14 sites in the region. All trees were sampled nondestructively at breast height using 5-mm-diameter increment corers. Two cores were taken from each tree.

Conventional techniques of dendrochronology were employed in chronology development (Fritts, 1976; Holmes, 1983; Cook and Kairiukstis, 1990). All samples were processed for RW and samples from six sites were also processed for MXD. MXD is an annual ring parameter based on the highest density of the cells formed at the end of the growing season (Parker and Jozsa, 1973; Lenz et al., 1976; Schweingruber, 1988).

Ring widths were measured to the nearest 0.001 mm using a Velmex measuring system. Core samples were processed for MXD using microtome sample preparation (Thetford et al., 1991) and a DENDRO 2003 workstation for scanning. Each series was standardized (detrended) using Turbo ARSTAN, version 33e (E.R. Cook, personal communication, 2002), in order to remove biological factors such as age trends. Conservative detrending methods (negative exponential or straight-line curve fits) were used to generate both MXD and RW chronologies in order to retain low-frequency information (Cook, 1985; Jacoby and D'Arrigo, 1989). We used the Standard version of the MXD and RW chronologies, which contains the common variations among the individual tree core series and retains low-through high-frequency common variance, presumably in response to climate (Cook, 1985).

To develop regional series for dendroclimatic analyses we used principal component analysis (PCA) to merge appropriate series into two sets of eigenvalue series that represented the common variation of MXD and RW. All six

MXD chronologies loaded similarly in the PCA (Table 1a), therefore all six were retained for analysis. The agreement among the 14 RW chronologies varied greatly. The chronologies were grouped to maximize regional climatic information by considering site ecologies, particularly substrate and moisture conditions, and also associated species, slope, and aspect. Correlation coefficients for all paired combinations of chronologies and principal component analyses were also used to aid in grouping similar chronologies. The series were separated into those that describe tree growth driven predominantly by temperature, which were labeled “Mesic,” and those that describe tree growth driven most likely by moisture. Moisture stress was inferred from both edaphic permeability (high in many outwash deposits) at the sample site and suppressed growth indicated by extremely narrow ring widths at certain points that coincided with warm periods in the chronologies of the temperature-limited trees. However, chronologies from moisture-limited sites show weak and inconclusive correlations with regional precipitation records. Nine of the 14 RW chronologies were grouped as Mesic in a PCA (Table 1b) and were therefore retained for analysis. Five chronologies were rejected from this study based on a combination of principal component loadings, anomalous ring-width patterns, and ecological considerations. Site information for each chronology used is listed in Table 2.

In order to estimate the reliability of the tree-ring chronologies, the Expressed Population Signal (EPS) statistic and R_{bar} were calculated using Turbo ARSTAN version 33e (E.R. Cook, personal communication, 2002). EPS evaluates the relationship between the sample size of a chronology and the common variance or “signal” within a chronology. Generally, a value of 0.85 or greater is considered a rough cut-off point for an acceptable level (Wigley et al., 1984). However, EPS estimates chronology confidence and should not be interpreted rigidly (K.R. Briffa, April 15, 1997, ITRDB Dendrochronology Forum posting; <http://listserv.arizona.edu/archives/itrdbrfor/>). The running mean EPS (50-year moving window with 25-year overlaps) is 0.84 over the entire MXD common period (ranging from 0.78 to 0.92) and 0.76 over the entire RW common period (ranging from

Table 1b
Ring-width loadings on the first eigenvector from principal component analysis

Site	Eigenloading
CC	0.389
NM	0.384
HC	0.378
HG	0.362
CA	0.343
ST	0.312
BL	0.286
NT	0.273
HH	0.236

Table 2

Tree-ring site information and locations listing all sample sites with corresponding two-letter abbreviation, coordinates, elevation (m), chronology type (ring width (RW) or maximum latewood density (MXD)), number of trees used for the RW chronology and MXD chronology (when applicable), and time span

Tree-ring site	Lat. (N)	Long. (W)	Alt. (m)	Chron. type	No. of trees	Years
Nabesna Mine (NM)	62°22'	143°03'	1167	RW/MXD	20/17	1471–1997
Big Bend Lake (BL)	61°20'	142°43'	1040	RW/MXD	15/12	1593–1997
Windy Wolf (WW)	61°46'	141°38'	1036	MXD	20	1420–1998
Hawkins Hill (HH)	61°09'	142°05'	1030	RW/MXD	24/19	1580–1998
Silver Tip (ST)	62°34'	142°20'	1020	RW/MXD	12/10	1513–1992
Chisana Air Strip (CA)	62°05'	142°01'	1006	RW	12	1415–1994
Nazina Treeline (NT)	61°22'	142°41'	995	RW	10	1546–1997
Caribou Creek (CC)	62°33'	143°17'	994	RW/MXD	15/14	1559–1996
Hawkins Glacier (HG)	61°08'	141°58'	876	RW	15	1625–1998
Hazel Creek (HC)-YT	61°54'	140°43'	731	RW	12	1679–1999

0.72 to 0.89). The mean R_{bar} for MXD and RW are 0.48 and 0.32, respectively.

The average intercorrelation among the six MXD series is 0.43, correlations for each individual chronology pair are shown in Table 3. The six MXD chronologies span 1513–1998, with a common period from 1593 to 1992. The first eigenvector (EV1) from the six MXD chronologies contains 54% of the total variance. The nine RW chronologies have an average series intercorrelation of 0.50. Correlations for each individual chronology pair are shown in Table 4. The nine RW chronologies span 1415 to 1999 with a common period from 1679 to 1992 (1679–1970 shown). The EV1 from the nine RW chronologies contains 55% of the variance. These first eigenvectors were then used in further analyses.

Meteorological data

Monthly mean temperature data for Northway (1942–1992), Gulkana (1942–1992), and Slana (1958–1992) stations within the Wrangell Mountain region and for Anchorage (1916–1992), McKinley (1923–1992), and Talkeetna (1919–1992) were obtained from the Global Historical Climate Network (Table 5). Missing monthly data for eleven months from Northway and Gulkana were estimated using the Dendrochronology Program Library (www.ltrr.arizona.edu/pub/dpl/) where the departure of the missing value from

the mean for the month is set equal to the average departure from the mean of nearby and similar stations.

Monthly mean temperature grid point data (Table 5), 0.5 by 0.5° square, from 1901 to 1995 were obtained from the Climatic Research Unit (CRU) of the University of East Anglia. Each grid cell was interpolated from station observations based on the eight nearest stations (Jones, 1994; New et al., 2000).

Northern Hemisphere (NH) data

An updated NH temperature reconstruction (minus Wrangell data) is used for comparison with the Wrangell RW EV1. Additional tree-ring series from more diverse regions were added to an older NH temperature reconstruction, as an update of Jacoby and D'Arrigo (1989) and Jacoby et al. (1999), which produced a more geographical representative NH temperature series (see Discussion). The updated NH temperature reconstruction is based on 25 circumpolar, tree-line, RW index chronologies. We then removed tree-ring data from the Wrangell Mountain region from this updated NH temperature reconstruction in order to create an independent data set.

Table 3

Correlation matrix for maximum latewood density

	NM	BL	WW	HH	ST	CC
NM	1	0.52	0.5	0.5	0.44	0.51
BL		1	0.53	0.6	0.27	0.45
WW			1	0.48	0.14	0.39
HH				1	0.19	0.45
ST					1	0.45
CC						1

Site is indicated by two-letter abbreviation. Common period is 1593–1992.

Table 4

Correlation matrix for ring width

	NM	BL	HH	ST	CA	NT	CC	HG	HC
NM	1	0.43	0.48	0.6	0.47	0.39	0.79	0.57	0.71
BL		1	0.61	0.58	0.29	0.41	0.41	0.17	0.42
HH			1	0.49	0.41	0.58	0.48	0.38	0.43
ST				1	0.55	0.35	0.65	0.29	0.67
CA					1	0.38	0.52	0.41	0.75
NT						1	0.52	0.52	0.44
CC							1	0.54	0.72
HG								1	0.53
HC									1

Site is indicated by two-letter abbreviation. Common period is 1729–1970.

Table 5
Meteorological stations

Station	Lat. (N)	Long. (W)	Alt. (m)	Years
Northway	62°57'	141°56'	521	1942–2000
Gulkana	62°09'	145°27'	479	1942–2000
Slana	62°42'	143°55'	733	1958–2000
Grid point	62°00'	144°00'		1901–1995
Grid point	62°00'	143°50'		1901–1995
Grid point	62°00'	143°00'		1901–1995
Grid point	62°50'	144°50'		1901–1995
Grid point	62°50'	144°00'		1901–1995
Grid point	62°50'	143°50'		1901–1995

Analysis

Principal-component regression analyses (Cook and Kairiukstis, 1990) were used to evaluate the relations between (1) each individual chronology and (2) the first eigenvectors from MXD and RW and the annual, seasonal, and individual monthly mean temperature data from both station records and CRU grid point data (Jones, 1994; New et al., 2000). We limited the analysis to six grid points located within the sampling region (Fig. 1) in order to make within-region comparisons. Individual months from the six grid-point records were combined in a PCA to create a single eigenvector for each month of the year.

Results

Individual mean monthly July, August, and September temperatures for the current growing season derived from the three closest instrumental temperature records, Northway (1942–1992), Slana (1958–1992), and Gulkana (1942–1992), showed significant (0.05) positive correlations with the MXD chronologies. Based on these relations, station temperature means for these months were merged using PCA to form one new predictor (the first eigenvector). This new predictor contains 66% of the total temperature variance of the original data set and represents a regional warm-season temperature record for the Wrangell Mountains with a common period of 1958–1992. Correlations between the MXD EV1 and the regionalized monthly temperature record (Fig. 2) are higher than for individual stations, which agrees with previous findings by Blasing et al. (1981) and Jacoby et al. (2000) that a combination of stations may be better for defining the climate/tree relationship than individual stations.

This regionalized warm-season temperature record produced the strongest model with the MXD EV1 ($R = 0.73$, Fig. 3). Meteorological stations with longer records (Anchorage, McKinley, and Talkeetna), located farther from the sampling sites, were also tested; however, the correlations were much weaker ($R = 0.41$ over the 1923–1992 common period and 0.42 over 1958–1992) than the local, shorter

station records. When the MXD EV1 was tested with CRU grid-point data the correlations were also much weaker ($R = 0.34$) relative to the model developed with the local regionalized three-station record.

Linear regression was used to develop a July–September temperature reconstruction (1593–1992) for the Wrangell region (Fig. 4a). The climate/tree-growth model (Fig. 4b) accounts for 51% of the temperature variance over the 1958–1992 calibration period used for the reconstruction and demonstrates valid verification statistics based on undifferenced data, over the independent 1958–1975 and 1976–1992 calibration and verification periods (Table 6).

The MXD-based temperature reconstruction shows a cold period in the late 1600s–early 1700s followed by a warmer period, with cooling again in the late 1700s–early 1800s and then warming in the 20th century. The 20th century is the warmest of the past four centuries. The coldest warm-season temperature value reconstructed for the Wrangell Mountain region is 1810 (3.7 standard deviations below the mean (Fig. 4a)).

The RW EV1 showed only positive correlation with current-season June temperatures ($R = 0.47$ (0.002)) from the Slana station data over the 1958–1992 interval and also showed positive correlation with current-season June ($R = 0.41$ (0.002)) from Talkeetna station data over the 1923–1970 interval, dropping to $R = 0.27$ when using the entire length of the record (1923–1992). Similar correlations were seen when using the nine individual tree-ring chronologies.

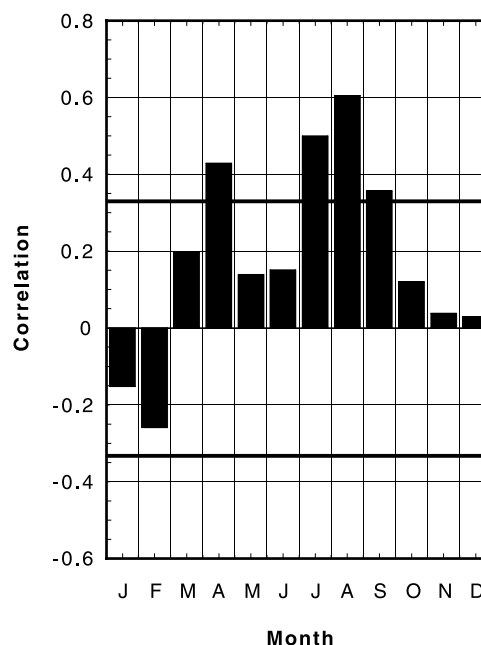


Fig. 2. Correlation plot comparing the first principal component of average monthly temperatures from Northway, Gulkana, and Slana over the current year, January to December, with maximum latewood density series based on the first principal component of six chronologies over the 1958 through 1992 common interval. Horizontal lines indicate 95% significance levels.

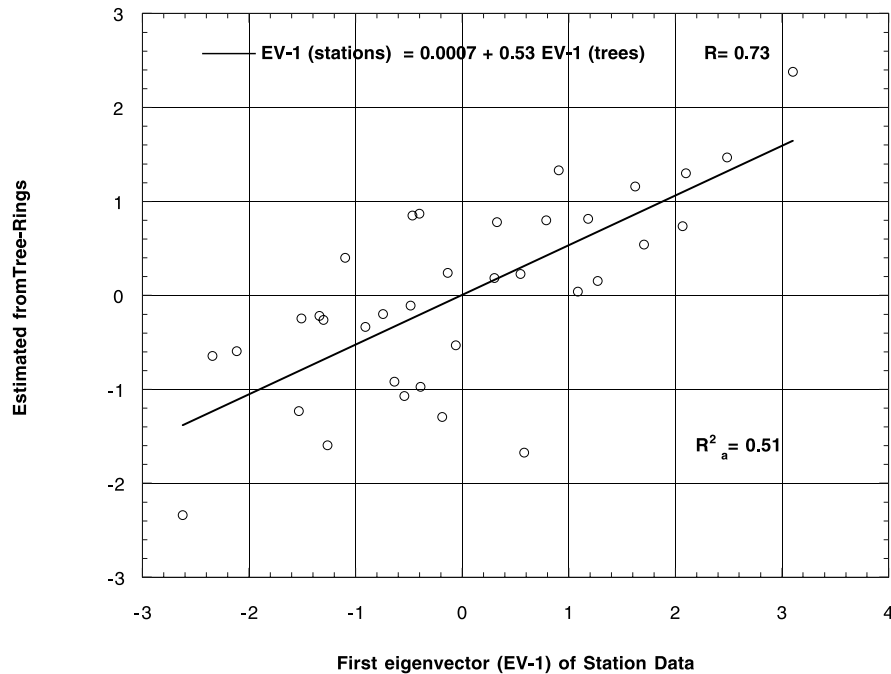


Fig. 3. Scatter plot and equation of the line for the first eigenvector from station data with the first eigenvector from maximum latewood density.

The RW EV1 from nine chronologies is positively correlated with recorded annual NH temperatures from CRU (Jones, 1994; New et al., 2000), $R = 0.51$ (0.05) over the 1880–1989 time period. However, when the nine individual tree-ring chronologies were tested with average monthly grid-point data from CRU, they showed differences in their response. The correlation analyses between the RW EV1 and the CRU monthly data indicate that spruce trees at these northern sites respond to more than current growing season conditions (Fig. 5) and integrate temperatures over prior years. In the Wrangell study, the highest positive seasonal correlation is 0.56 for June–September of the 3 prior years, plus the growth year (Fig. 5). The RW EV1 also shows good agreement ($R = 0.65$ (0.001)) with the updated NH temperature reconstruction (Fig. 6). In a PCA, the RW EV1 loads similarly within the 25 circumpolar tree-ring chronologies used to update the NH temperature reconstruction.

Despite the good agreement with regional signals, these models failed calibration/verification tests and no reconstruction was created. Even though a formal reconstruction was not possible significant observations can be inferred from the nine-chronology ring-width EV1. The RW EV1 series shows suppressed growth (indicating cooling) around 1700, a growth release (indicating warming) after 1710, and suppression again in the early 1800s. In the 1900s there is an increasing growth trend, followed by a decrease in growth after 1970 (Fig. 6), when the meteorological records show continued warming.

Discussion

The tree-ring chronologies in this study reveal strong spatial differences in temperature variation in the same region. All sites are white spruce growing at or near elevational tree line with site-to-site correlations ranging from 0.14 to 0.75 (Tables 3 and 4), underscoring the local differences within the region. This variability is attributed to slope aspect, slope, cold air drainage from upvalley glaciers, and other small-scale geoclimate factors. Using PCA to extract the common variations from a network of tree-ring sites (separating RW and MXD data sets), regional temperature variations and trends can be inferred from the trees. The series preserve much of the low-frequency temperature variation.

Several of the coldest reconstructed warm-season temperatures from the Wrangell Mountain region are years that follow known volcanic eruptions (Fig. 4a). The coldest, 1810, coincides with an unidentified explosive volcanic event in 1809 (Dai et al., 1991). The 1809 eruption was first identified in ice-core records (Dai et al., 1991) and has subsequently been identified in tree-ring density records (Jones et al., 1995; D'Arrigo and Jacoby, 1999). The cooling of 1810 may have been further sustained by the 1815 eruption of Tambora, Indonesia (Simkin and Siebert, 1994). This volcanic event is popularly known in western literature as the “the year without a summer” and is seen in the 1816/1817 years (10th coldest in the Wrangell record (Fig. 4a)).

The Wrangell Mountain tree-ring record shows periods of warm and cold that are in phase with well-dated glacier

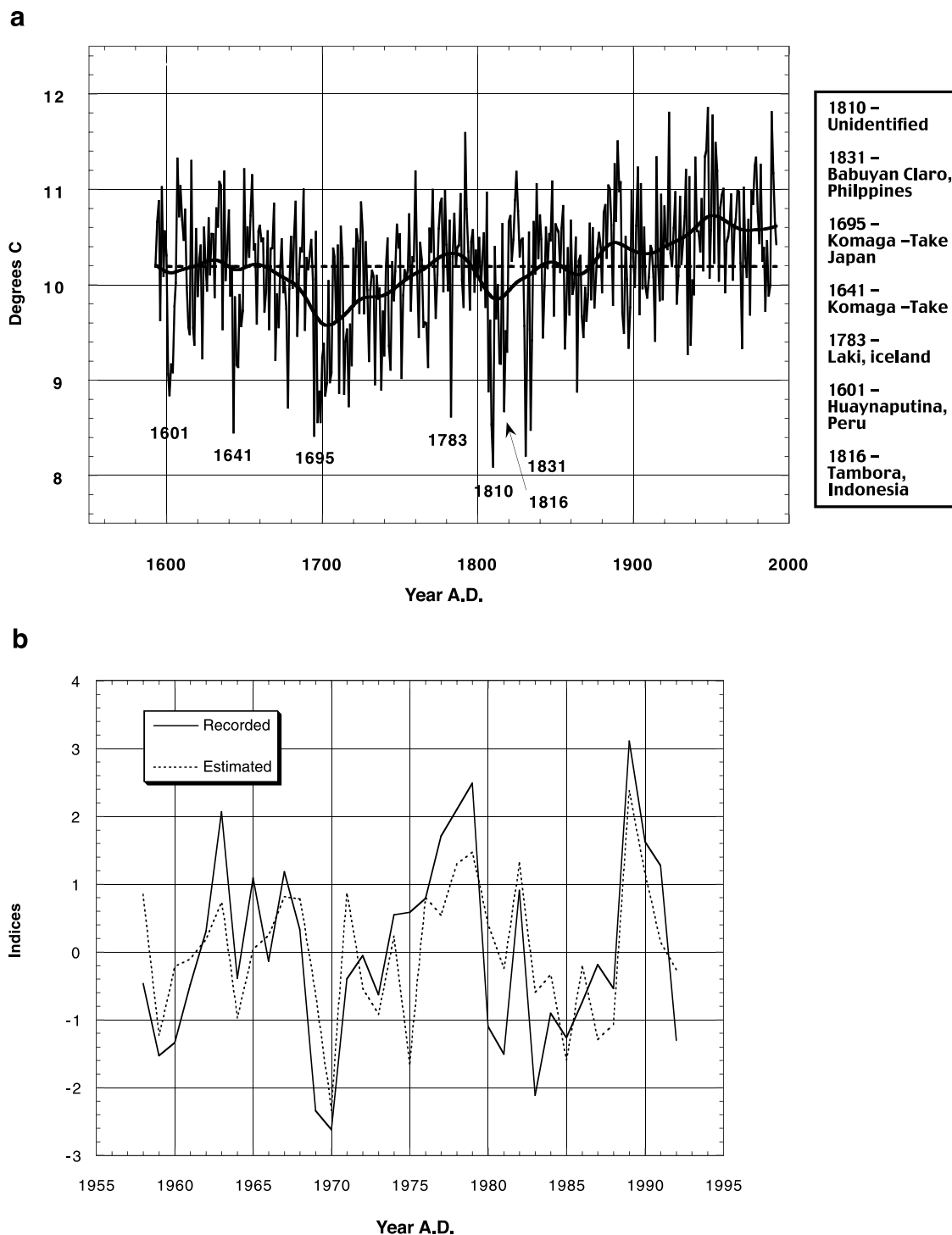


Fig. 4. (a) Reconstructed July–September temperatures from the Wrangell Mountain region based on maximum latewood density data from 1593 to 1992. Years of extreme cold and associated volcanic events are listed to the right. (b) Recorded and estimated July–September regional temperatures for the 1958–1992 calibration period.

fluctuations from nine Wrangell–St. Elias glaciers (Wiles et al., 2002). Glacial reconstructions are based on tree-ring dating of glacially overrun trees and moraine studies. The inferred warm period in the mid-1500s coincides with tree establishment identified along glacial forefields (Fig. 7). The following extreme cold period in the late 1600s to early

1700s is seen in both the MXD and the RW series and coincides with minimum tree-ring ages of glacial advance based on kill dates from overrun logs and a period of moraine building (Wiles et al., 2002) (Fig. 7). The cold pulse of the early 1800s, both seen in the MXD reconstruction and inferred from the RW series, is followed by mo-

Table 6

Calibration and verification statistics for Wrangell Mountain region warm-season temperature model for calibration (1958–1975) and verification (1976–1992) time periods

	ar ²	RE	Sign test	P
1958–1975	34%	0.34	13+ 5– (0.05)	59 (0.005)
1976–1992	61%	0.64	15+ 2– (0.01)	80 (0.001)

ar² is the variance accounted for by the calibration model, adjusted for degrees of freedom; RE is the reduction of error statistic; P is the Pearson correlation coefficient (Fritts, 1976; Cook and Kairiukstis, 1990). Levels of significance are indicated in parentheses.

rairie building caused by glacial advance (Wiles et al., 2002) (Fig. 7). Overall observed glacier retreat has followed in the wake of the unprecedented temperature rise over the past 100 years.

Reconstructed and inferred cold periods correspond with solar minima over the past several hundred years. The cooling of the late 1600s to early 1700s, seen in the MXD-based temperature reconstruction and the RW EV1 and the glacial record, coincides with a period of minimum solar irradiance known as the Maunder Minimum (Maunder, 1922; Eddy, 1976). This period is seen in many other northern reconstructions (Jacoby and D'Arrigo, 1989; Briffa et al., 1992; Mann et al., 1999). The severe cold pulse of the early 1800s seen in both the MXD and the RW series coincides with a period of low solar irradiance known as the Dalton Minimum (Eddy, 1992).

The RW EV1 shows an increasing growth trend in the 1900s that coincides with hemispheric 20th-century warm-

ing, as described by others (e.g., Jacoby and D'Arrigo, 1989; Mann et al., 1999; Esper et al., 2002). The comparison between RW EV1 and the updated NH reconstruction (Fig. 6) shows similarity ($R = 0.65$). They both show a warmer late 1800s than previous versions of the NH reconstruction. Previous published NH temperatures reconstructions (e.g., Jacoby and D'Arrigo, 1989; Jacoby et al., 1999) gave a generally accurate picture of long-term variations, but due to limited replication may not have been fully representative of low-frequency temperature variations. The change in the late 1800s is attributed to improved geographical representation in the updated NH reconstruction.

The RW EV1 from the Wrangell Mountain region shows great similarity to reconstructions for central and northern Alaska (Jacoby and D'Arrigo, 1995). The Wrangell results show more low-frequency trends than reconstructions of temperature for coastal Gulf of Alaska (Wiles et al., 1998). One Gulf of Alaska reconstruction, using eight coastal sites, is for a season of March through September and shows the cooling around 1810 and muted response to other trends. A Gulf of Alaska spring reconstruction (Wiles et al., 1998) using only three elevational tree-line coastal sites shows more correspondence with the Wrangell results but the mid-1800s are relatively warmer. It is reasonable for the coastal area to have some significant differences from the interior but they do show the effects of 20th-century warming.

A composite RW series from Southwest Yukon Territory, based on eight elevational tree-line chronologies (Luckman et al., 2002), show similarities to the Wrangell

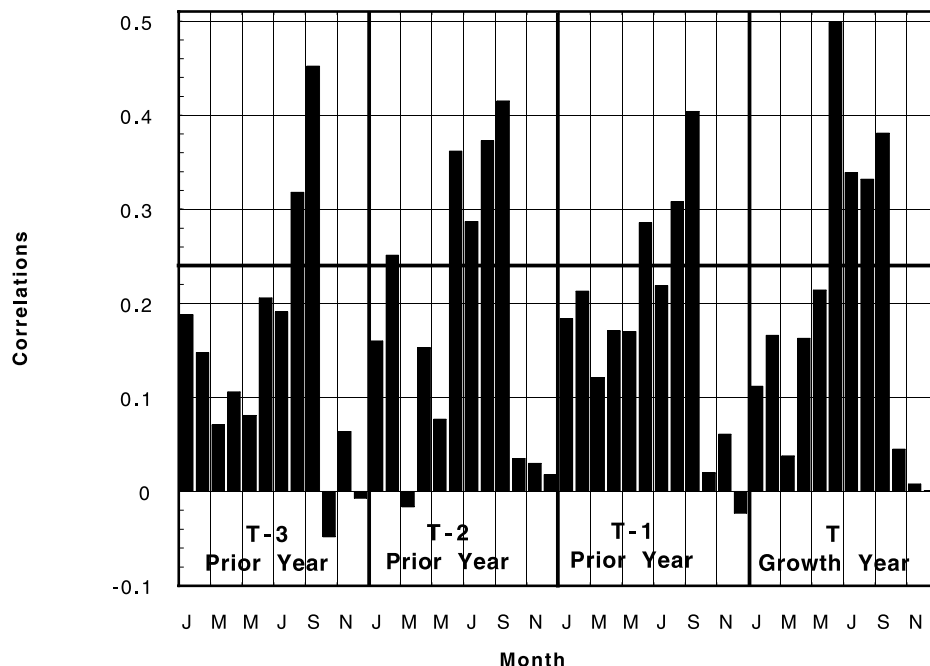


Fig. 5. Correlation plot comparing the first eigenvector from nine ring-width chronologies with monthly grid-point data from the Climatic Research Unit over a 4-year period. Horizontal lines indicate 95% significance levels.

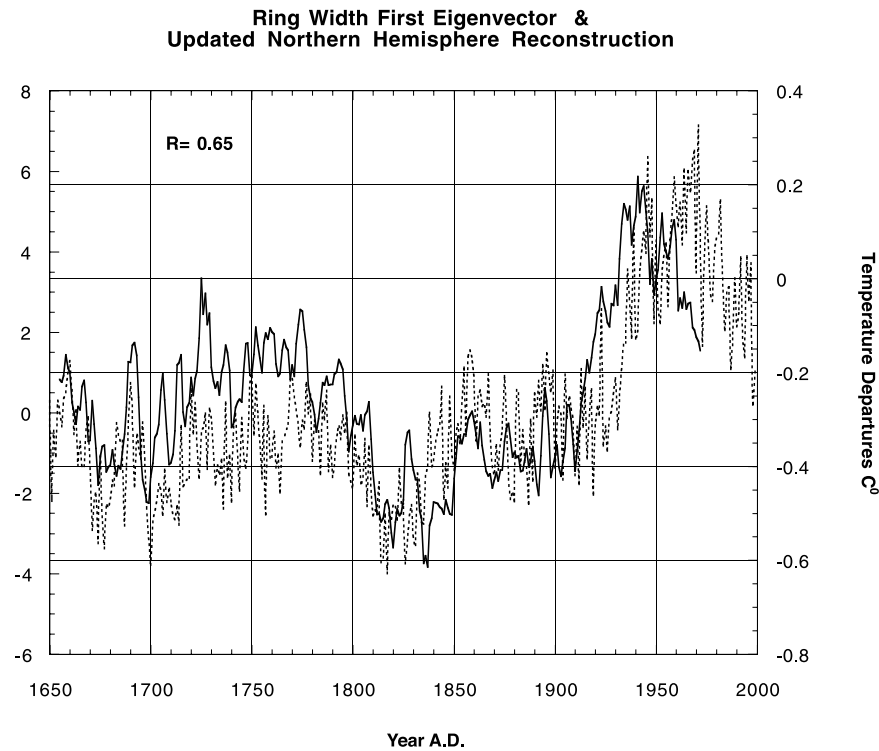


Fig. 6. Ring-width first eigenvector (dashed line) with updated reconstructed Northern Hemisphere temperature departures from 1950 to 1980 (solid line).

Mountain region RW data. Both data sets correlate with station data for current-season June temperatures and exhibit similar low-frequency variation up until the mid-1900s (not shown). After a peak in the 1940s to 1950 both series decrease in growth. The chronologies differ in the magnitude of the growth increase, with the Wrangell RW EV1 showing a relatively larger growth increase in the mid-1900s than the Southwest Yukon Territory series.

In most of the Wrangell RW chronologies there is a decrease in sensitivity to temperature starting at about 1970. An earlier study showed this decrease in sensitivity in northern Alaska and was attributed to increasing moisture stress (Jacoby and D'Arrigo, 1995). Others reached similar conclusions in Alaskan studies (Barber et al., 2000; Lloyd and Fastie, 2002). In the Wrangell region, evidence of moisture stress after 1970 is seen in only one site, Hazel Creek. Since 1970 the correlations with temperature are strongly negative. At the same time the correlations with precipitation shifted from consistent positive but not statistically significant to significant positive for June and July, both current and prior year demonstrating a change in the climatic response of white spruce at this site.

The Wrangell MXD parameter does not show a decrease in sensitivity to temperature change in recent decades and the MXD EV1 appears to continue to represent temperature. Others have detected a decrease in density sensitivity. Briffa et al. (1998) show a decrease in sensitivity of MXD during the second half of the 20th century at many sites over large areas of North America and Eurasia. The underlying

cause(s) of the decrease in sensitivity of most high-latitude trees to temperature is not understood although some hypotheses have been suggested—such as increased snow depth (Vaganov et al., 1999), air pollution, and UV damage (Briffa et al., 1998). Tree response may not be the same in all locations for all species.

Conclusions

A 400-year warm-season (July–September) temperature reconstruction based on MXD and a temperature-sensitive RW series are some of the first proxy records from the Wrangell Mountain region of Alaska. These records show that by using regional networks of tree-ring sites, it is possible to create a temperature model (MXD) and tree-growth series (RW) that reflect large-scale temperature variation, despite a complex mountain terrain and spatial differences in local temperature and tree growth. The strength of the warm-season reconstruction and the similarities of low-frequency trends from both MXD and RW to other proxy records suggest that there are common large-scale climatic forcings.

The Wrangell tree-ring records from both MXD and RW show evidence of an increasing warming trend over the past century that is warmer than in previous centuries. The RW record shows similar trends seen in both a NH station record (CRU) and an updated NH tree-ring reconstruction (Jacoby and D'Arrigo, 1989; Jacoby et al., 1999). These results

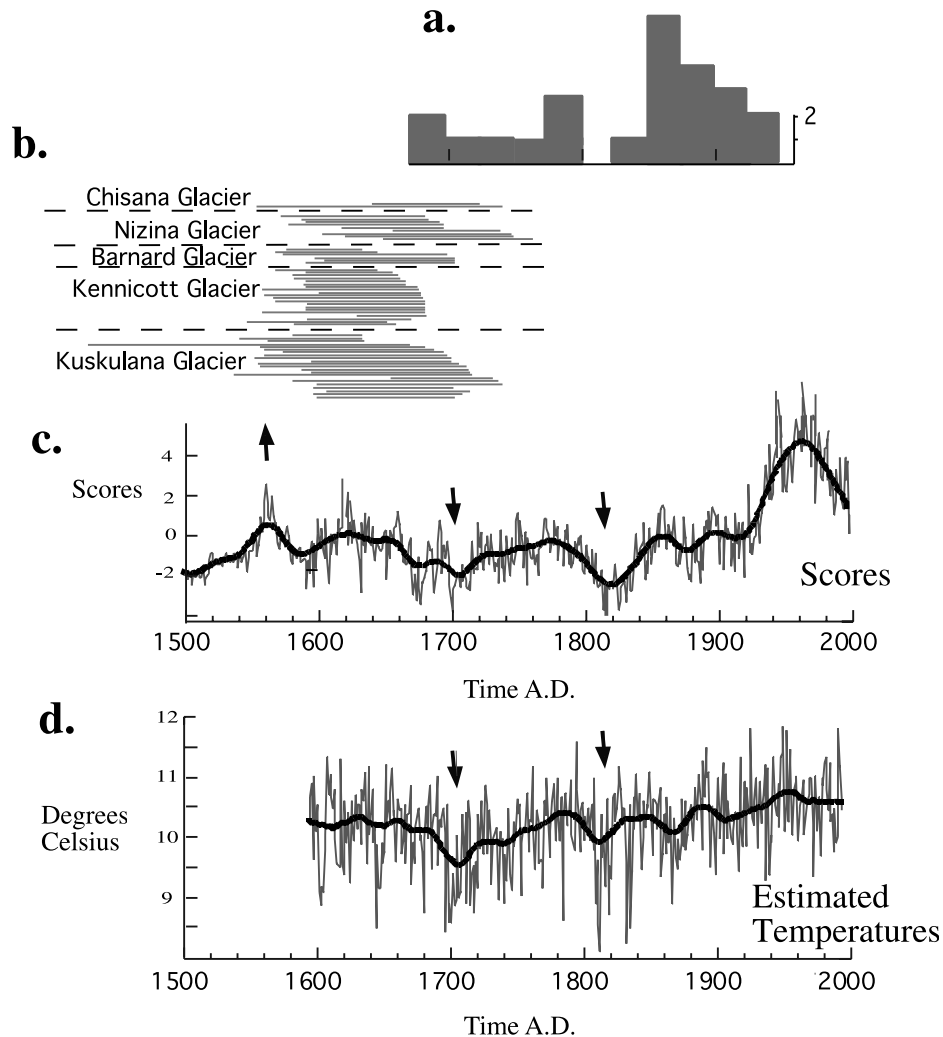


Fig. 7. Diagram showing the relations among (a) estimated moraine ages, based on 20 moraines from nine glacial forefields (Wiles et al., 2002), (b) tree-ring crossdates from glacially overrun trees (Wiles et al., 2002), (c) the first principal component of the nine ring-width chronologies (this study), and (d) the July–August temperature reconstruction (this study) based on maximum latewood density from the Wrangell Mountain region, Alaska. Up arrow shows an inferred period of warmth in the mid-1500s that coincides with tree establishment dates (b) seen along the glacial forefields. Down arrows mark both reconstructed and inferred cold pulses in the late 1600s to early 1700s that coincide with minimum ages of glacial advance (b) based on kill dates from overrun logs (Wiles et al., 2002). General trends are evident even though many of these logs often lose their outermost rings due to abrasion and decay. Minimum ages are assigned to the moraine dates based on lichen ages and tree-ring establishment following glacial recession (Wiles et al., 2002). Gray boxes in the histogram (a) represent the outermost moraines at individual glaciers.

indicate that the Wrangell Mountain region, despite local variations, has a climate history in general agreement with large-scale NH paleorecords.

Some of the multidecadal to century-scale variations are in agreement with hypotheses of solar influence on climate. The MXD-based temperature reconstruction and the RW series indicate that there was pronounced cooling in the Wrangell Mountain region during the time of the Maunder Minimum (late 1600s to early 1700s) and during the Dalton Minimum (early 1800s). Shorter periods (years) of extreme cold in the temperature reconstruction coincide with major volcanic eruptions.

The low-frequency warming and cooling trends provided by the Wrangell Mountain tree-ring network are in agreement with glacial retreat, indicated by forest growth on the

moraines, and glacial advance, indicated by death dates of overrun trees (collected when reexposed by a receding glacier). The Wrangell Mountain tree-ring network combined with the independent glacial history provides a more complete climatic history of the entire Wrangell region. The results are mutually supportive, indicating the value of multiproxy paleoclimate studies.

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