

Late Holocene Climatic Variation in Northwestern Alaska
as Reconstructed From Tree Rings

A Final Report on Cooperative Research with
The National Park Service

June 1, 1997

Project Duration: May 1, 1993 – June 1, 1997

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1. Summary

Tree-ring series of white spruce (*Picea glauca* (Moench) Voss) obtained from archeological samples collected by Louis Giddings in the Kobuk River valley in the 1940s provide a rich source of data for paleoclimatic inference. We used 102 Giddings archeological tree-ring series to create an expanded and corrected tree-ring chronology for the Kobuk River for the period AD 978 to 1941. We combined these data with 205 ring-width series from living trees in the Kobuk and Noatak River valleys to create a climatically sensitive chronology that extends from AD 1091 to 1992. The chronology reflects variation in early summer (late June through early July) maximum temperature. The long-term record indicates that the 20th century is anomalously warm compared to the long-term average. Persistent low temperatures occurred from 1763 to 1852, from 1633 to 1687, from 1369 to 1408, and from 1150 to 1206. Short-term warm anomalies occurred at 1688 to 1734 and 1207 to 1294.

2. Statement of problem and objectives

The purpose of this research is to characterize the climatic history of northwestern Alaska over the last millennium for the purpose of establishing a baseline of natural climatic variability in the region. In order to derive a quantitative estimate of past climate from Louis Giddings' archeological samples, we did the following:

- Improved and updated Louis Giddings' tree-ring chronology by increasing sample replication and checking sample cross-dating
- Inferred past patterns of temperature variation for northwestern Alaska based on 20th century relationships between tree growth and climate as derived from living tree samples.

This report summarizes progress to date towards these objectives and describes data and results delivered to Bob Gal, National Park Service, Kotzebue, AK.

3. An improved Giddings tree-ring chronology

3.1. Background

Preliminary work on this project was funded by a grant from the National Science Foundation that extended from June 1991 to June 1992. With that funding I explored the possibility of using the extensive collections of archeological wood made along the Kobuk River by Giddings (1948; 1952 and references therein) to reconstruct temperature back in time. Preliminary work indicated that a vast number of archeological specimens were collected by Giddings and are currently archived at The University of Alaska (on loan to University of Arizona) and in the permanent collection of the University of Arizona. Giddings' primary goal in collecting wood was to develop a tree-ring chronology for dating artifacts and house timbers and, as such, he dated and measured only a fraction of the ring-width sequences in his collections. Given that dendroclimatic reconstructions require a much larger sample size than a chronology used only for dating artifacts, a critical task was assessing the archeological wood specimens in order to find samples to incorporate into Giddings' original tree-ring chronology.

A substantial portion of our effort has been directed towards locating appropriate archaeological samples among the material archived at the University of Arizona. We located not only samples that were measured and plotted in Giddings' published work (1948; 1952), but also additional samples that were collected but not analyzed by Giddings. Of the approximately 150 cross-sections of house timbers from the Kobuk region in the University of Arizona and University of Alaska collections 102 were able to be cross-dated. Many of these are well-preserved and added sample depth to the chronology. Key sample locations for archeological sites are mapped in Figure 1. The sites represent distinct periods of occupancy and form separate but overlapping time periods (Figure 2).

3.2. *Nomenclature*

We will use the following terms for different versions of the tree-ring chronology:

- The “1948 Giddings chronology” refers to the chronology published by Giddings in a 1948 issue of the *Tree-Ring Bulletin* (Giddings 1948)
- The “corrected Giddings chronology” refers to the chronology developed by John C. King in 1995 based on the original Giddings samples along with other archeological specimens. The corrected Giddings chronology has revised dates and a greatly expanded sample size. The chronology starts in AD 978.
- The “composite chronology” is based on the “corrected Giddings chronology combined with modern (living) tree-ring samples to allow us to extend the chronology forward in time to 1991. We use AD 1091 as the starting date for this chronology because at that point in time the sample size of four is adequate for climate inference.

3.3. *Technical aspects of sample dating and chronology development*

We developed a tree-ring chronology for the Noatak and Kobuk river basins in northwestern Alaska in two stages. First, we developed the corrected Giddings chronology (i.e., composed only of archeological samples) for the period AD 978-1941. Second, we combined the archeological reference chronology with modern tree samples to create a composite white spruce chronology for the period AD 1091-1992. The archeological samples, originally collected and analyzed by Giddings during the 1940s, were re-cut into transverse sections and finely surfaced with a belt sander. Live tree increment cores, collected in 1940 and 1941 by Giddings and in 1991 and 1993 by Graumlich, were mounted and surfaced using standard procedures (Stokes and Smiley, 1968). We determined exact calendar year dating by measuring the tree-ring sequences of each sample to the nearest 0.002 mm and subjecting the resulting time series to a set of dendrochronological techniques. Visual comparison of wood samples (Stokes and Smiley, 1968), graphical comparison of time series, and correlation analysis (program COFECHA; Holmes 1983) were applied interactively to assess the position and quality of cross-dating. A random sampling of ring width series (Figure 3) demonstrates that the samples vary in their length of record and that almost all samples show an expected trend of decreasing overall ring width and decreased variation over time. These trends reflect biological growth trends associated with increasing age and girth of the tree (Fritts 1976). We standardized the series to remove the biological growth trend using well-accepted techniques (Fritts 1976), specifically, fitting negative exponential or horizontal growth curves to each ring-width series. We then averaged the standardized series to form the 1995 corrected archeological chronology (Figure 4).

The corrected Giddings chronology differs in several respects from the 1948 Giddings chronology. At the most basic level, small errors in dating in several samples were corrected and all samples have now passed rigorous cross-dating criteria. In addition, the 1948 Giddings chronology had a low sample depth for a given year (average sample depth is 5 samples per year; range is 1 to 10). The corrected Giddings chronology has at least 4 sample from AD 1091 onwards and averages 22 samples per year (Figure 5). The greater sample depth results in a series with less year-to-year variance (Figure 4) and fewer multi-decade excursions from the mean. We interpret this comparison to indicate that the 1948 Giddings chronology was strongly influenced by the small number of individual trees making up the series. In the corrected chronology, the sample size is equivalent to that used in dendroclimatic studies (see Fritts 1976). The strong correlation among the individual tree samples (Figure 5 bottom panel) is further evidence that the series contains a signal of regional significance (vs. growth anomalies of individual trees).

4. Inferring past patterns in temperature variation on the basis of modern tree-ring/climate relationships

4.1. Assumptions underlying our work

The construction and testing of the corrected Giddings chronology was simply the first step in developing a scheme by which we could infer climate patterns back in time. A second critical step was assembling a modern data set that could be used to extend the corrected Giddings chronology to the present day. Mid- to late 20th century data on tree-ring/climate correlations provides the means by which the long-term patterns can be interpreted. Rarely have archeological collections been used to infer climate and we needed to address the following assumptions before using corrected Giddings chronology to infer anything about past variation in climate. The first assumption we made was that the Giddings samples contained a climatic signal in ring-width variation. Our evidence for a common signal stems from the high interseries correlation (Figure 5 bottom panel) as discussed above. There is no factor other than climate that could synchronize ring width growth between trees and between sites in the study area (Fritts 1976).

Our second, and more thorny, assumption is that we can use 20th century tree-growth climate inferences to interpret the growth patterns in the archeological wood. In other words, the trees we sample on the modern landscape must have the same climate/growth relationship as the archeological samples. Our modern tree-ring sampling strategy was informed by the need to assess the validity of this second assumption as described below.

4.2. Modern tree-ring chronologies

Our sampling strategy consisted of collecting cores from old white spruce trees in both the Kobuk and Noatak River valleys (Figure 6 and Table 2). We sampled in the Noatak because wood from the Kotzebue archeological site is most likely derived from Noatak (Giddings 1952). Samples from the Kobuk River would correspond to the wood sources for the Ekseavik and Ambler village sites.

In most cases, the sampling sites were located on river terraces of relatively coarse-grained deposits within 500 m of the river channel. There are several notable exceptions that represented our efforts to assess topographic variability in the nature of climatic influence on tree

growth as well as attempts to find very long-lived trees. These exceptions include the following sites in the Kobuk basin that are located near upper (elevational) treeline (Figure 6): Kiana Hills (KI), Kidway's Ridge (KD), Manuilyisat Hills (MU), and Kobuk (KO). In addition, the Tetilesook (TE) site was located in an area of very poorly drained soils.

Samples were processed using the techniques described above, including detrending to remove biological growth trends using horizontal or negative exponential growth curves.

4.3. *Do chronologies contain a regional signal?*

We assessed the degree to which the tree-ring samples, both from living trees and from archeological wood, contained a common, regional signal using two strategies: (1) comparing growth patterns between sites of living trees, and (2) comparing growth patterns between sources of archeological tree-ring samples.

The structure of the common variance in tree-ring chronologies between sites was assessed by performing a principal component analysis (PCA) on the chronologies from all the living tree sites for the period 1900-1991 (Figure 7). The first component (X-axis in Figure 7) represents common variance in all data sets and explains 58% of variation in data. Second component (Y-axis in Figure 7) explains only 13% of residual variation after accounting for common variation in the first component. This residual variation is clearly related to elevation as indicated by the separation of the upper treeline sites (KD, KI, MU) from the rest of the sites. Neither the first nor the second component separate sites by valley system (i.e., Noatak vs. Kobuk) and none of the higher order components show patterns that distinguish the two river valleys. From this analysis we conclude that the growth patterns, especially of trees growing on the river terraces, are highly correlated between sites, including sites from the Kobuk and Noatak River valleys.

We then assessed whether the correlation between trees from the Noatak and Kobuk river valleys was retained over longer periods of time. To accomplish this, we selected the longest individual tree-ring sequences from each drainage (sites were KRS from Noatak and SQ from Kobuk) and assessed whether the pattern seen in a larger PCA described previously would hold when individual samples were compared over 50 year time intervals. We chose three overlapping subperiods to analyze: 1830-1879 (12 trees total), 1850-1899 (18 trees total), and 1870-1919 (26 trees total). The results of the analyses indicate that the correlation pattern is stable over time. In each case, the first principal component dominated the pattern with explained variance ranging from 39% to 48% (Figure 8). The second component was much less important and explained 12 to 24% of the residual variation. More importantly, in two of the three subperiods, the second component variation has NO relationship to drainage basin of origin for the trees (i.e., note scatter of observations along second component or Y-axes). In the subperiod 1870-1919, the trees do segregate by site along the second principal component, but this component is relatively weak, explaining only 12% of the variation in the data.

We extended the above analyses back in time, by comparing individual tree samples from archeological village sites that derived wood from different river valleys. At the Ekseavik village site houses were built from drift wood derived from the Squirrel River, a tributary of Kobuk River. At the Kotzebue village site houses were built from drift wood from the Noatak River (Giddings 1952). We compared growth patterns of individual samples from the two sites for three overlapping 50-year subperiods (1300-1349, 1320-1369, and 1340-1389) using a PCA

scheme like that described above. The results for the extended period reflect the same patterns seen in the modern period. In all cases, the first component explains much more variation in the data set than the second principal component, indicating that regional patterns dominate over site-to-site patterns (Figure 9). In addition, the plots show little separation of the two sites by the second principal component indicating that site differences between the two river valleys are minimal during the extended period.

From these three analyses, comparing variation between sites and between trees and using both living and archeological materials, we conclude that the common pattern in the tree-ring samples is a regional representation of climate effects for northwestern Alaska.

4.4. *Merging the modern and archeological chronologies into the composite chronology*

We chose a subset of the modern tree-ring collections to merge with the corrected Giddings chronology to create a composite chronology to be used to infer long-term trends in climate. We did this by performing a cluster analysis on the modern tree-ring chronologies listed in Table 2 for the period 1794 to 1991. Three main groups emerged from the analyses. The largest group had a strong correspondence with the regional patterns we were seeing in early analyses and was made up of sites from both the Noatak and Kobuk valleys (KGU, UKE, SQ, LKE, NON). We merged these data sets with the archeological data set to create a chronology that extends from AD 1091 to 1992. The final composite chronology is plotted in Figure 10 in three forms. The standard chronology is simply a biweight robust mean of all of the detrended ring-width series. The residual chronology is derived by performing autoregressive modeling on the detrended ring measurement series. The autoregressive modeling fits an autoregressive process to each series of the order determined by the first minimum of the Akaike Information Criterion. The smoothed chronology is formed by applying a low-pass digital filter (Fritts, 1976) to the standard chronology. This filter transmits variance with wavelengths greater than eight years. The standard and residual chronologies are listed in Appendix A.

4.5. *Modern climate/growth relationships*

A network of eight monthly climate data sets and two daily data sets were assembled to analyze the relationship between climatic variation and tree growth indices (Table 3). Correlations between various monthly climate variables from the stations listed in Table 3 and the standard or residual chronology were equivocal. On the other hand, analyses incorporating the daily temperature data for Kotzebue showed a high degree of statistical reliability. The strongest and most robust correlations between climate and tree growth were found with the maximum temperature daily data for Kotzebue and the residual form of the chronology. This result is not surprising in that the daily data set allowed us to customize the interval over which the daily data were summed as opposed to using an arbitrary calendar month which may not correspond to the biological activity of the trees. The form of the chronology that showed the maximum correlation was the residual chronology due to its stronger expression of year-to-year variation. Using the daily maximum temperature data, we defined a suite of variables differing in (1) the number of days over which temperature was averaged, and (2) for a given interval length, the starting date. The maximum correlation between tree-ring indices and temperature occurred for a 25-day interval centered on July 1 (Figure 11a). The 25-day interval results in the highest correlation when compared to intervals of varying length, all centered on July 1 (Figure 11b).

From this we infer that the long-term variation in the residual chronology reflects interannual variation in late June/early July maximum temperature.

4.6. Long-term temperature trends

Several features of the long-term summer temperature history of northwestern Alaska are revealed by the smoothed chronology (Figure 10). The 20th century is remarkable for its anomalous summer warmth when compared to the long-term data. Summer temperatures began to rise in 1900, reached a maximum from 1925 to 1965 and showed a short-term decline from 1966 to 1976. (These broad trends are reflected in the observed Kotzebue maximum temperature data from 1950.) Persistent low temperatures are inferred from 1763 to 1852, from 1633 to 1687, from 1369 to 1408, and from 1150 to 1206. Short-term warm anomalies occurred at 1688 to 1734 and 1207 to 1294.

5. References

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6. Samples

All tree-ring samples are archived at the Laboratory of Tree-Ring Research at the University of Arizona. Tree-ring measurements will be archived in the International Tree-Ring Data Bank operated by NOAA's National Geophysical Data Center.

7. Acknowledgements

We gratefully acknowledge the unfailing enthusiasm of Bob Gal of the National Park Service in Kotzebue for this project, including field assistance and logistical support. The National Park Service and National Science Foundation funded this research. We thank Alison, Arians, Andrea Lloyd, Erika Rowland, Craig Gerlach, Owen Mason and Paul Sheppard for assistance in the field. John King directed the laboratory analyses with help from Ginger Burley and Jacqueline Shinker. Steve Nash helped make sense of the chaotic state of the Giddings wood

collection. And finally, I am grateful to Patricia Anderson and Craig Gerlach who inspired me to tackle this project.