The Difference in Climate Signal Between Douglas-fir and Incense Cedar Dendrochronologies in the Oregon Cascades

by
The Lava Team

Members include:

G. Ahlstrand, H. Fritts, H. Grissino-Mayer, P. Haggerty, H. Jiménez-Núñez,
R. Mastrogiuseppe, J. Panek[1], C. Paolazzi, and S. Phillips

Abstract

A high elevation site in the Oregon Cascades was used to test the growth response of two tree species as reflected in tree-ring chronologies, to variability in climate over a period of 100 years. The site -- a scoriacious basaltic lava flow -- was selected because it was expected to provide an environment in which either temperature or precipitation was limiting to tree growth. Therefore, both Douglas-fir and incense cedar were expected to exhibit a pronounced growth response, i.e. sensitivity, to climate. We hypothesized that incense cedar would be more sensitive to climatic factors than Douglas-fir based on higher variability in ring width increments of early cores. Tree-ring chronologies were constructed and analyzed using the latest dendrological techniques, including the statistical and modelling stength of COFECHA, ARSTAN, and PRECON. Results show that annual ring-width growth in Douglas-fir varies more with climatic factors than does incense cedar. Results also indicate that both species are less sensitive to climate on the lava flow than trees on an adjacent, more weathered lava flow. Neither a 2.5°C increase in temperature nor a 20% increase in precipitation -- a scenario predicted for the area by several global climate models -- changes growth in either species significantly at this site, as predicted by PRECON. However, the results of this study must be interpreted with caution. Sample size was small and time limitations precluded a more rigorous exploration of factors controlling variability in tree growth at this site.

---

[1] Errors in grammer and spelling are the fault of this author.

Introduction

Climate is an important factor limiting the growth of trees. The growth response of trees to climate as recorded in tree-ring chronologies may vary in different species and between different environments. The climate signal as reflected in annual tree-ring widths is clearest in trees which grow under conditions where temperature and available soil moisture are limiting. Ring widths of these individuals vary most in response to climatic fluctuations in precipitation and temperature (Fritts, 1976), a characteristic called "sensitivity". Growth increment has the lowest resource priority over other necessary metabolic and growth functions, such that its size is an indication of remaining resources available after the needs of the tree have been met (Waring and Schlesinger, 1985). Small growth increments indicate years in which some resource required by the tree -- e.g., water, nutrients, or a temperature conducive to metabolic activity -- was limiting. Because different species use water and nutrients at different rates and may even have intrinsically different patterns of resource acquisition or assimilation, species will vary in their growth response to the same climatic conditions. Years in which climatic factors cause extreme growth limitations may be present regionally.

To assess how two associated species growing in the same environment respond to climate, 100-year tree-ring chronologies of Douglas-fir (*Pseudotsuga menziesii*) and incense cedar (*Calocedrus decurrens*) were compared to a 100-year climate record. These species occur together on a recent lava flow in the Oregon High Cascades Province (province description in Franklin and Dyrness, 1973).

Numerous Douglas-fir tree-ring chronologies have been constructed, but few chronologies exist for incense cedar. This void is surprising given the observation that incense cedar shows higher ring-width variability, characteristic of a climate-sensitive species. The existence of two adjacent lava flows of different ages on the site make possible the comparison between climate responses of trees growing on an older flow with a slightly developed soil and trees growing on a more recent flow without any soil development. A distinct boundary between the two flows made them easily identifiable. Both lava flows are probably younger than 10,000 years, although absolute dating of the flows was not attempted.

Methods

Site Description

The lava field is located in the Blue River District of the Willamette National Forest at 44°19'N, 122°00'W, along Oregon Highway 126 approximately 13 miles east of the junction with Highway 242. The flows are of scoriacious basalt extruded from volcanic vents probably during the late Pliocene and Pleistocene epochs, but possibly as late as upper Pleistocene and Recent (Franklin and Dyrness, 1973). The site is at 3000 feet elevation and it slopes gently west. Vegetation is sparse on both flows, though stand density is lower on the younger flow than on the older flow. On the younger flow, the widely-spaced trees have stunted and gnarled growth forms, some with broken tops. On the older flow, trees are much larger and crown shape is normal (Figure 1. Site sketch). Vegetation consists of an interesting association of trees: *Pseudotsuga menziesii, Calocedrus decurrens, Pinus monticola, Abies lasiocarpa*; shrubs: *Acer circinatum, Rubus parviflorum, Juniperus communis, Pachystima myrsinites, Arctostaphylos patula, A. nevadensis, Ceanothus velutinus, Castanopsis sempervirens, Rhamnus, Holodiscus, Corylus;* and herbaceous vegetation: *Epilobium, Erigonium, Phacelia, Cheilanthes and Sedum*. *Usnea* is present on many trees. Moss and lichen are frequent as groundcover in the older flow, as well as a covering of coarse woody debris, while the newer flow had virtually no ground cover.

Climate Data

Regional records of mean monthly precipitation and temperature were used in the analysis to determine whether tree growth was more strongly correlated to one or both of these climate variables. The climate records represented a mean of stations in a large-scale division defined by the National Climatic Data Center (~~Figure 2. Climatic map of Oregon~~). A continuous period between 1895 and 1983 represented by the division was compared to the same time period in the tree-ring record of each species.

Sampling Methods

Two cores were taken from each tree of the two species of trees sampled. A total of 40 trees were cored, 18 *P. menziesii* and 22 *C. decurrens*. Thirty-two trees from the younger flow and 8 from the older lava flow were cored. Trees were selected on the older flow well away from the transition zone to reduce edge effects.

All cores were mounted, dried, sanded and dated according to standard dendrochronological techniques (Swetnam et al., 1985). Skeleton plots were constructed to provide a crossdate reference while dating cores (Stokes and Smiley, 1968). Time constraints precluded the analysis of all cores. Therefore, 24 of the best cores were selected. The cores chosen included 8 *P. menziesii* and 11 *C. decurrens* from the younger flow, as well as 2 *P. menziesii* and 3 *C. decurrens* from the older flow. They were chosen based on the reliability of the increment sequence and the presence of variability in the ring-width series. Ring-width increment was measured with a Bannister Incremental Measuring Machine (BIMM). Measurements were converted to TRL format for use in later analysis.

Data Analysis

The accuracy of the ring-width measurements was verified using COFECHA, a computer-assisted quality control cross-dating program (Holmes, 1976). The program creates a master chronology of mean ring-widths from a group of trees (in this application from trees of the same species on the same flow) then flags suspect measurements based on correlation with the master chronology. Once verified as to their accuracy, the chronologies were standardized using ARSTAN (Cook et al, 1986). ARSTAN creates three types of indices. To create a standard index, ARSTAN removes the growth trend from the raw ring-width series with a user-defined function. For the purposes of this study, an 80-year rigid spline was used because the trees sampled were much older than the 100-year period analyzed and were no longer in the exponential phase of growth. ARSTAN also creates a residual index which removes the effects due to prior year's growth, i.e. autocorrelation between years. Finally, ARSTAN creates an index that reincorporates the site-specific average effects of autocorrelation. This study was concerned expressly with the standard and residual index types.

The index chronologies were analyzed with PRECON to determine whether tree-ring growth was related to monthly mean temperature or precipitation. PRECON is a statistical model based on empirically derived relationships between existing standardized tree-ring chronologies and monthly climatic data from nearby weather stations (Fritts et al, 1990). PRECON can be used to assess the ability of climate to predict tree growth and to determine the level of significance of the tree growth response to temperature and precipitation. Furthermore, climate trends can be manipulated by the user. This allows predictions to be made of tree growth response to future climatic change.

Results

Comparing P. menziesii and C. decurrens

Results from PRECON show that the response functions of climate variables temperature and precipitation are poor predictors of tree growth for both species at the young lava flow site. Actual growth tends to be more variable than predicted by the model (Figures 3,4). This could be due to the small number of samples analyzed of each species, about half the accepted minimum for dendrochronology. The general correlation between climate and tree growth is similar for *P. menziesii* and *C. decurrens.* Growth is positively correlated with cool, wet summers and warm, dry winters (Figures 5,6). Growth in *P. menziesii* is better predicted by climate variables than growth in *C. decurrens* ($R^2_{PSME}=.32$, $R^2_{CADE}=0.18$). Autocorrelation (prior year's growth) in both species accounts for more variation in growth than either temperature or precipitation. When the effect of autocorrelation is removed, significance is evident only in the tree growth response of *P. menziesii* to precipitation. Although tree growth response to temperature appeared consistent, it was not significant. *P. menziesii* growth showed a significant positive response to precipitation when it occured early in the growing season and during the prior year's growing season. *C. decurrens* growth was not as responsive as *P. menziesii* to precipitation but the response was not significant; however, the trend suggests that early fall precipitation is important for growth the following year in *C. decurrens*.

Temperature was not a significant factor in the growth of either *P. menziesii* or *C. decurrens*. However, the trend indicated an inverse relationship between prior summer and fall in both species. The inverse relationship with current summer temperature was stronger in *C. decurrens* than *P. menziesii.*

Comparing Old and Young Lava Flows

The comparison between old and young lava flows was made between uneven sample sizes: the old contained 5 trees and the young contained 19. The old lava flow sample consisted of both tree species. Given these limitations, analysis showed that climate explains 33% of the variation in growth, similar to the growth of *P. menziesii* on the younger flow. The trend in growth response was similar to that of the younger flow: positive growth is correlated with warm, dry winters and cool, wet summers. The older flow is the only site where temperature correlated significantly with growth, in this case positive growth is correlated with warm, winter temperatures. Prior year's growth is significantly correlated with current year's growth, however the correlation is much weaker than either species on the younger flow.

Climate Change

A climate change scenario predicted for the area by several general circulation models shows a step-function increase in precipitation of 20% and a temperature increase of 1.5°C to 3.5°C. We modelled tree growth response to the predicted scenario, using an average step-function temperature increase of 2.5°C concurrent with precipitation change in 1940. This change altered the growth only a small amount for incense cedar on the young flow (Figure 7) and a similarly small amount for both species on the older flow (Figure 8). This small effect could be a result of using an annual effect model for climate change. Temperature effects are correlated with growth positively in the winter and negatively in the summer. Thus the positive response of temperature is cancelled by the negative response in the annual model.

Discussion

That precipitation appears to be an important climatic variable for *P. menziesii* growth at this site, and the only statistically significant climate variable in the study, is consistent with the fact that the soil moisture requirements for *P. menziesii* are higher than for *C. decurrens*. *C. decurrens* is more tolerant of drought and temperature extremes, therefore might be expected to respond less to climate fluctuations. This is, indeed, the case. The positive growth response of both species to cool, wet summers is not surprising given that these conditions allow for photosynthesis in an otherwise hot, essentially lengthening the growing season. Warm, dry winters were positively correlated with increased ring-width in both species, though not significantly. There are several possible explanations for this trend. Dry winters will have reduced snowpacks. Lava may act as a black-body emitter, reradiating absorbed heat, melting snow and effectively increasing the length of the growing season. The same factors may favor winter photosynthesis.

Incense cedar crossdated well among individuals on the younger lava flow, suggesting that growth in this species is responding to the same factors, although apparently not to climate. Other factors controlling growth may include exposure to dessicating conditions, mechanical damage like wind or snow, and fluctuations in nutrient inputs, e.g. due to litterfall or precipitation pulses.

Tree growth on the older lava flow appears to be more sensitive to climate than on the younger flow. Ring-width chronologies on this flow are more complacent, however. It is possible that potential factors causing variability in the tree-ring growth on younger flow are absent at this site, reducing noise in the response to climate. The higher density of trees growing on the older flow afforded greater protection from dessication and from mechanical damage, and the groundcover is more evenly distributed which may reduce the variability in the nutrient flux.

Conclusion

The results of this study must be interpreted in light of the small sample of trees used in the tree-ring chronologies. This may have reduced the accuracy of the master chronology. Given more time, at least twice as many samples should have been analyzed. With this in mind, the data showed a greater sensitivity of *P. menziesii* to temperature and precipitation than *C. decurrens*. In the Pacific Northwest, 32% of the variability being explained by climate is substantial. The response of *C. decurrens* to climate is negligible. Climate explains 33% of the variability in tree ring-width on the older flow, showing it to be a site more responsive to climate than the younger flow.

References

Cook, E.R. 1985. *A time series analysis approach to tree ring standardization.* PhD. dissertation. University of Tucson, AZ.

Franklin, J.F. and C.T. Dyrness. 1973. *Natural vegetation of Oregon and Washington.* Oregon State University Press.

Fritts, H.C. 1976. *Tree rings and climate.* Academic Press, New York.

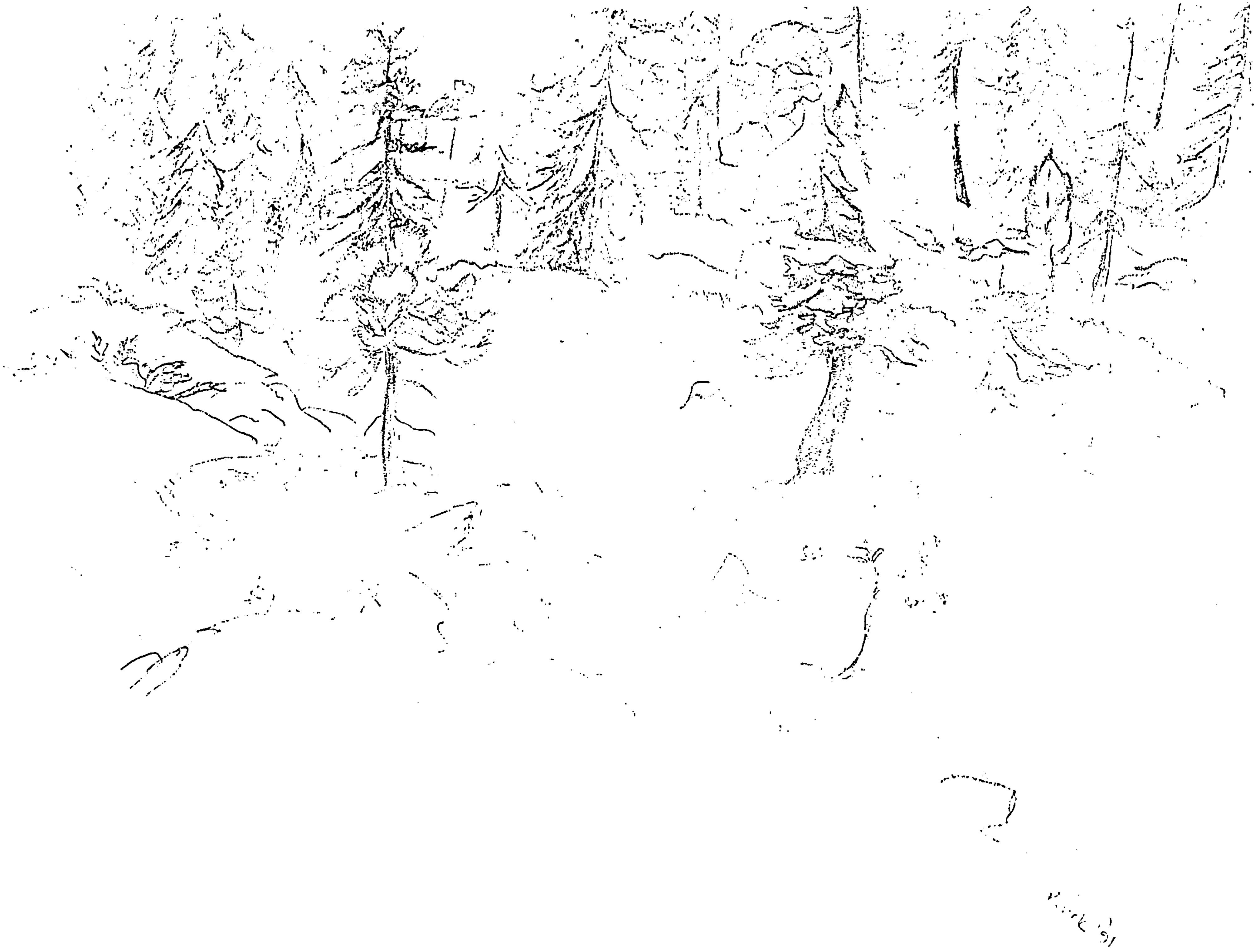
Fritts, H.C., E.A. Vaganov, I.V. Sviderskaya and A.V. Shashkin. 1991. Climate variation and tree-ring structure in conifers. *Climate Research 1(2):* 97-116.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin 43*: 69-75.

Stokes, M.A. and T.L. Smiley. 1968. *An introduction to tree-ring dating.* The University of Chicago Press. Chicago.

Swetnam, T.W., M.A. Thompson, E.K. Sutherland. 1985. Using dendrochronology to measure radial growth of defoliated trees. *USDA Forest Service Agricultural Handbook No 639.*

Waring, R.H. and W. Schlesinger. 1985. *Forest ecosystems: concepts and management.* Academic Press.


'91

Douglas-fir

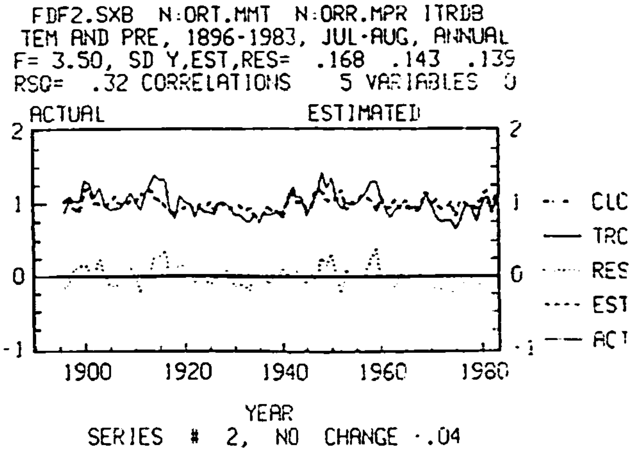


Figure 3

Incense cedar

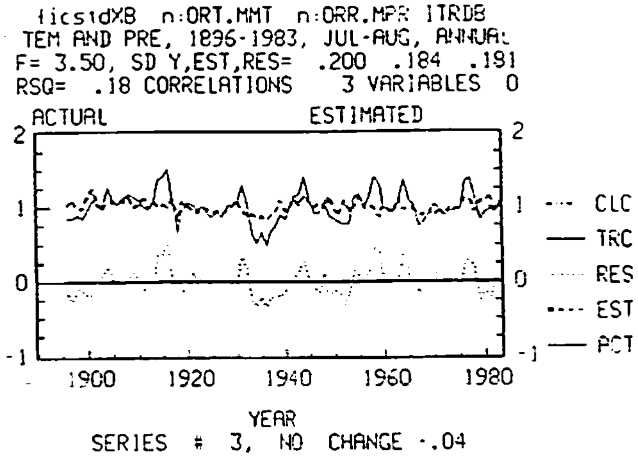
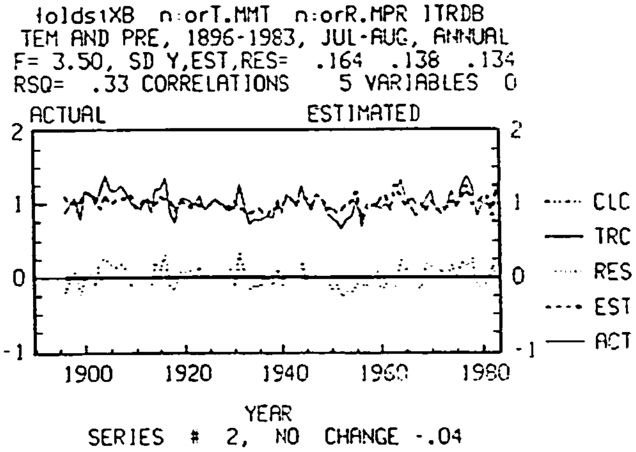


Figure 4

Older Lava flow

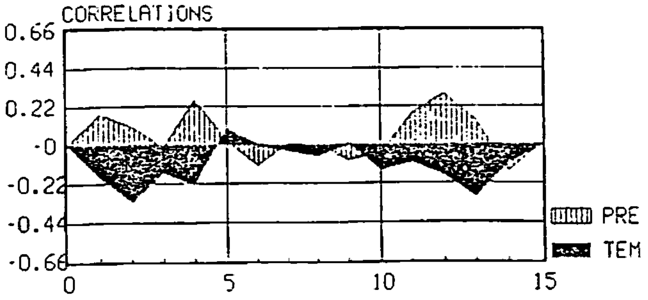


Douglas-fir

Figure 5

See also 5a

FDF2.SXB N:ORT.MMT N:ORR.MPR DIV 4
ITRDB , TEM & PRE, 1896-1983
FOR JUL - AUG, N: 88
SIG SIMPLE R .220



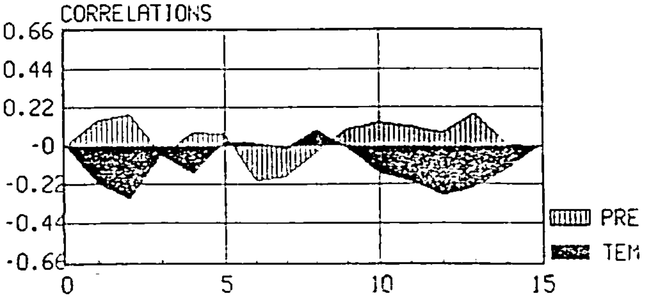
NO 1, 14 MONTHS, JUL - AUG

Incense Cedar

Figure 6

See also 6a

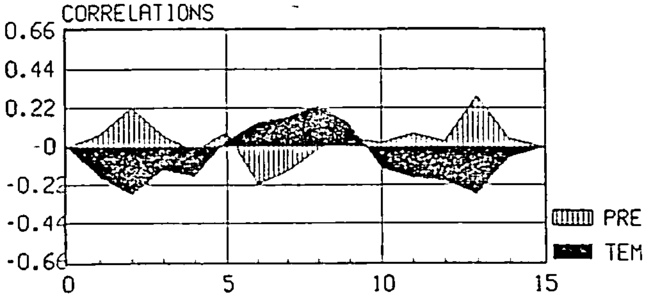
IicsidXB n:ORT.MMT n:ORR.MPR DIV 4
ITRDB , TEM & PRE, 1896-1983
FOR JUL - AUG, N: 88
SIG SIMPLE R .220



NO 2, 14 MONTHS, JUL - AUG

Older Lava Flow

IoldsiXB n:orT.MMT n:orR.MPR DIV: 4
ITRDB , TEM & PRE, 1896-1983
FOR JUL - AUG, N: 88
SIG SIMPLE R: .220

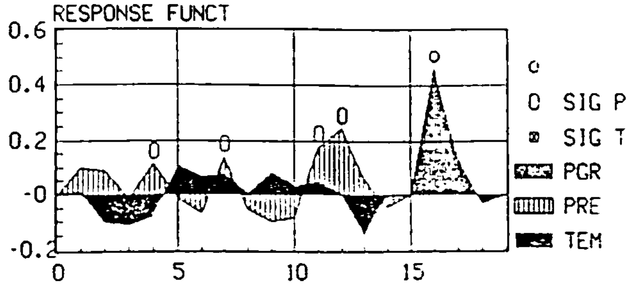


NO 1, 14 MONTHS, JUL - AUG

Douglas-fir

Figure 5a

FDF2.SXB N:ORT.MMT N:ORR.MPR DIV 4
TEM & PRE, 1896 - 1983 ,JUL - AUG, N= 88
20 REP, Rd:.850 +/-.031, Ri:.560 +/-.147
RSQ CL= .277, P GRO= .314, TOT= .591

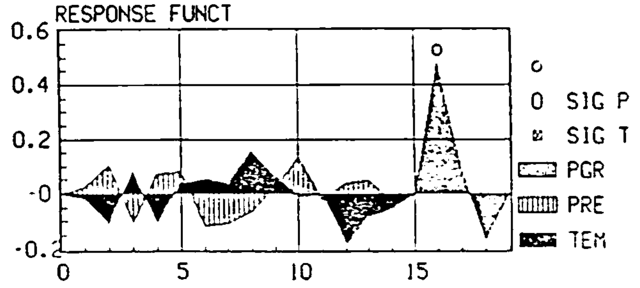


NO 5, 14 MONTHS, JUL - AUG
& 3 YEARS PRIOR GROWTH

Incense cedar

Figure 6a

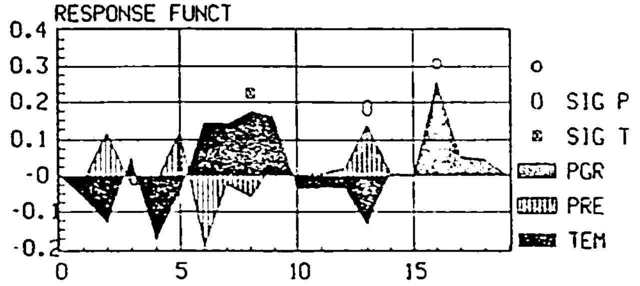
licsldXB n:ORT.MMT n:ORR.MPR DIV 4
TEM & PRE, 1896 - 1983 ,JUL - AUG, N= 88
20 REP, Rd:.836 +/-.028, Ri:.406 +/-.180
RSQ: CL= .237, P GRO= .260, TOT= .497



NO 6, 14 MONTHS, JUL - AUG
& 3 YEARS PRIOR GROWTH

Old Lava Flow

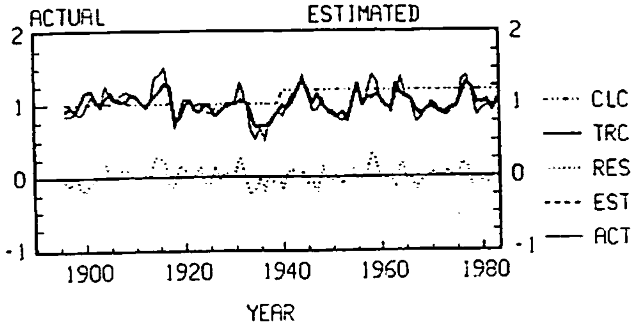
ioldslXB n:orT.MMT n:orR.MPR DIV 4
TEM & PRE, 1896 - 1983 ,JUL - AUG, N= 88
20 REP, Rd:.761 +/-.045, Ri:.370 +/-.119
RSQ: CL= .316, P GRO= .104, TOT= .420



NO 4, 14 MONTHS, JUL - AUG
& 3 YEARS PRIOR GROWTH

Figure 7

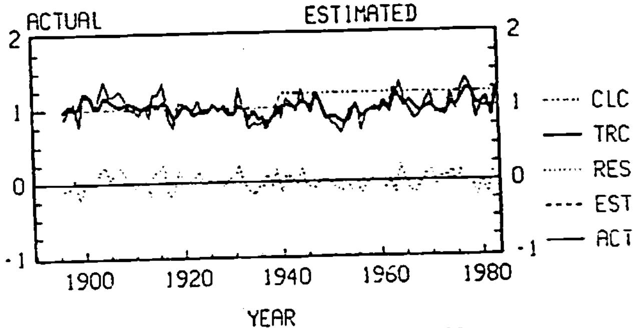
licstdXB n:ORT.MMT n:ORR.MPR ITRDB
TEM AND PRE, 1896-1983, JUL-AUG, ANNUAL
F= 3.50, SD Y,EST,RES= .200 .140 .121
RSQ= .65 RESPONSE FUNCT 31 ENTERED 0



SERIES # 8, PRE CHANGE .20

Figure 8

loldstXB n.orT.MMT n.orR.MPR ITRDB
TEM AND PRE, 1896-1983, JUL-AUG, SPRING
F= 3.50, SD Y,EST,RES= .164 .105 .115
RSQ= .51 RESPONSE FUNCT 31 ENTERED 0



SERIES # 7, PRE CHANGE .20