RECONSTRUCTION OF PAST CLIMATIC VARIABILITY

(A Progress Report)

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SUMMARY (non-technical)

The purpose of this project is to reconstruct past climatic variations by applying multivariate techniques to well-dated proxy series of climate such as tree rings. Progress is reported on three areas of research: 1) the development and expansion of our tree-ring and climatic data base, 2) experimentation on multivariate methods for modeling climatic parameters as a function of tree growth, and 3) reconstruction of past variations in climate, using tree rings.

Ninety percent of our effort has been directed towards the first area of research. Dating has been completed on <u>all</u> tree-ring collections made during the two years since the project was initiated (i.e. the ring-width values are identified as to the year in which they were formed and all problems due to missing and double rings have been eliminated). The specimens showing small effects due to nonclimatic factors and large effects due to climatic variations have been selected. A majority of those chronologies have been processed entirely through computer analysis.

The historical and climatic files have been expanded by the additions of historical material obtained from the University of Wisconsin, and observations on nineteenth century weather from the National Archives. The screening and selection process for a grid of long climate records covering the United States is nearly finished.

Efforts to organize the international program on dendrochronology have been fruitful, and a group of 105 scientists representing countries in

Europe, Asia, and North America has shown interest in collaboration. The visitations by H. C. Fritts in June and October 1973, and the International Workshop on Dendroclimatology held in April, 1974 have laid the necessary foundation for working relationships among a core group and for standardization of procedure. An International Tree-Ring Data Bank is being set up which should allow more use of data samples for an increasing number of sites over the world. One recent development is an agreement signed by the USSR and USA to exchange tree-ring data. Ring width data from 12 USSR tree sites are to be made available for our analysis.

In the second and third areas of research sea level pressure over the North Pacific and North America has been calibrated with tree growth in western North America using several statistical models. Temperature and precipitation have also been modeled and reconstructed. Presently, these reconstructions are being checked against independent data. The results continue to verify the procedure, i.e. it is highly probable that the agreement between the reconstructions and the independent measurements on past climate did not result by chance. The reconstructions back to 1700 are also being analyzed to obtain the generalizations of the past modes of climatic behavior. A new tree-ring data set is being prepared 1) to extend reconstructions back to A.D. 1500, 2) to begin expanding the area of reconstruction to other regions of the world, and 3) to apply them to specific environmental problems as they arise. The focus in the coming year is on improving these techniques and applying them to climate problems using the newly obtained tree-ring chronologies collected as part of the ARPA effort.

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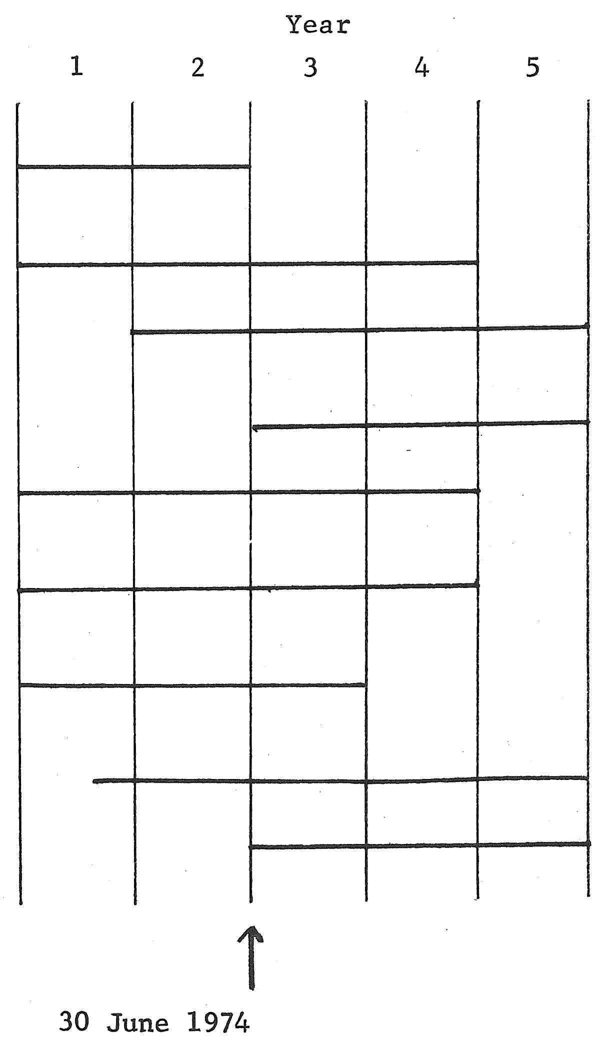
GENERAL SYNOPSIS

This ends the second year of a five-year project to extend our knowledge of year-to-year variations in climate back in time by use of well-dated proxy series of climate such as tree rings. Such climatic reconstruction is possible because ring-width growth on stress sites is limited in years of minimal moisture or anomalous temperatures. Therefore, biological records of climate can be obtained from replicate sampling of rings from trees on a variety of sites over a wide geographic area. Spatial variations in tree growth for each year are calibrated with recorded climate and the calibration equation is applied to growth in past years to estimate the associated variations in past climate. Work up to now has focused mainly on arid site trees from western North America and pressure over North America and the North Pacific Ocean. The first objective of this study is to expand the tree-ring data base. This widened data base is to be applied to an expanded set of climatic data to include the North Atlantic, Europe, and Asia. During the period since 1 January 1974 progress on the ARPA-supported work has not only kept pace with the originally proposed schedule but in certain cases it has exceeded our anticipations.

The status of collection and processing of United States and nearby tree-ring sites (items 1 and 2, Table 1) is shown in Figure 1. It can be summarized as 1) finalized for the Colorado River Drainage sites and Yellowstone (Task 4), 2) in the last stages of processing for the

TABLE 1. TIMING OF DATA COLLECTION AND ANALYSIS (Arizona)
(Revised from Proposal of June, 1972)

1. Collect and process ring data from western North America
2. Collect and process data from other areas in North America
3. Collect and sample ring data from other countries
4. Process collections for density data
5. Collect historical information
6. Development of multivariate and other models
7. Calibrate and relate actual climatic anomalies to synoptic situation
8. Reconstruct past climate
9. Interpret tree-ring and all other information, including pollen data



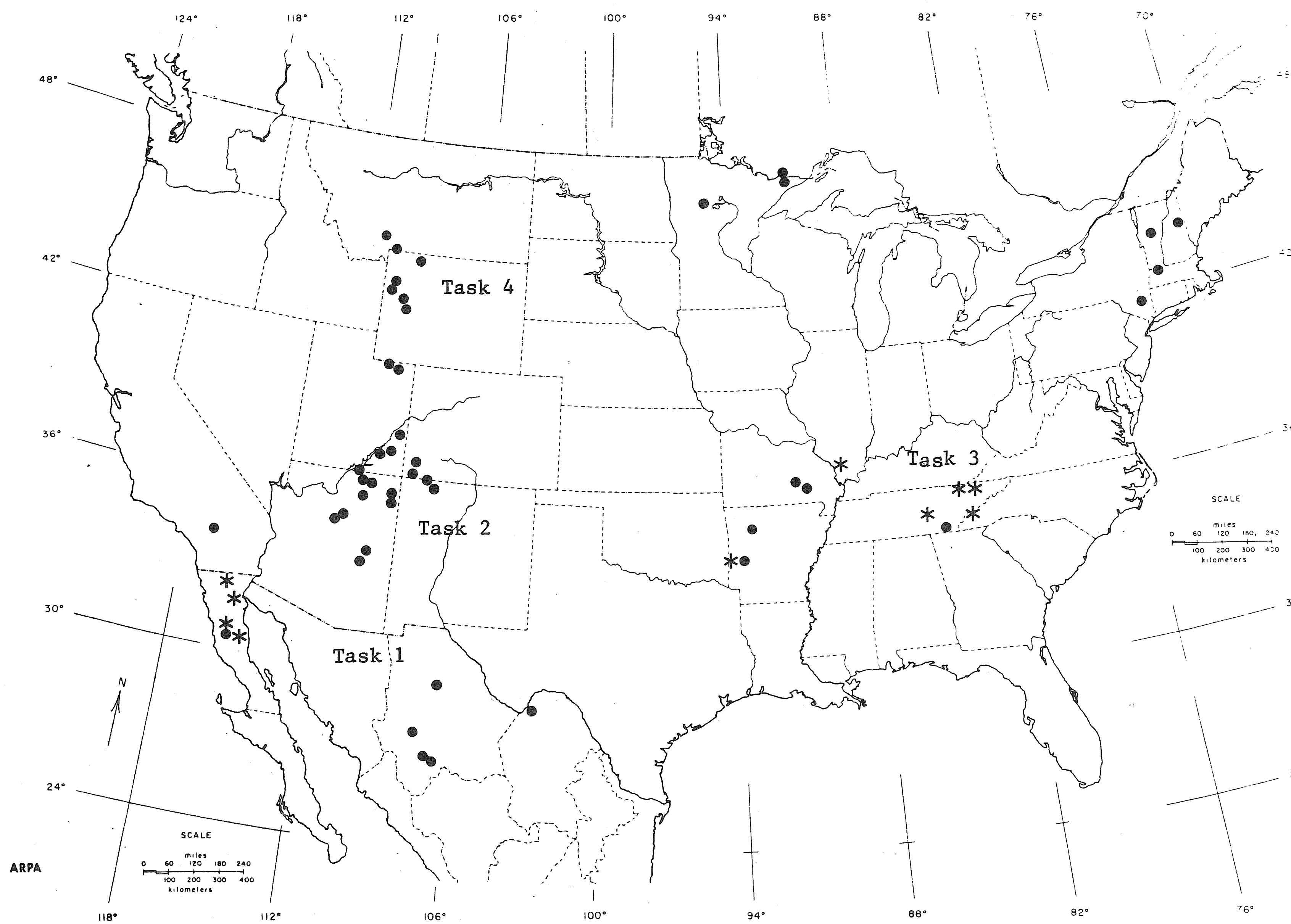


FIGURE 1. Sites of tree-ring collections completed (●) and collections still in progress (✱).

Four Corners Area Grid (Task 2), and 3) in various phases of measurement and computer analysis for other areas of North America (Tasks 1 and 3). Details on the status of Item 2, Table 1 are as follows: a) Collections for Task 3 from New England and northern Minnesota made in 1972 are now fully processed; b) those obtained from the Mississippi Drainage states in 1973 have been entirely examined, the dated specimens have been selected, and many collections are in some stage of computer processing; and c) tree-ring sites sampled in Mexico in 1973 are almost all processed. In summary, the data collection and chronology development for the U. S. portion of the North American sites are nearly completed. Figure 1 is a map of 1) those sites that are completed and which contain a suitable record and 2) those not yet fully processed. The exact stage in the analysis sequence for each sample is indicated on tables accompanying the task reports.

The Swedish chronology included in Task 1 and a long chronology derived from hemlock in Alaska (not indicated in the Tables) are complete. New tree-ring data from Europe and Asia are expected through an international cooperative effort and the International Tree-Ring Data Bank. No materials on x-ray densitometry have been processed by ARPA as the equipment is not yet fully operational.

The historical information file (Table 1, item 5), which is to be used for climate verification, has grown rapidly during the recent six month period, largely through the efforts of the research team at the University of Wisconsin. Also, through the initial prompting by Task 4 personnel, the University of Arizona library has acquired a complete microfilmed set of climatic data from War Department and Smithsonian Institution observations during the nineteenth century at frontier forts and research stations.

Task status has been given to several aspects of the project in recognition of their increasingly significant roles. Task 6 is the planning and coordination of international cooperation initiated last year by H. C. Fritts and continued this year by means of the International Workshop on Dendroclimatology. The Workshop included discussion on problems of crossdating, sampling, tree ecology, and tree physiology, with respect to their role in climate reconstruction. Discussions also focused on several approaches and techniques of collection, measurement, computer processing, and statistical analysis, with emphasis on multi-variate transfer functions. The Workshop was considered by all participants to be an unqualified success which was a significant turning point in the field of dendroclimatology. Prior to the Workshop most tree-ring workers were working essentially in isolation. Now there are good working relationships, communication channels have opened, and a spirit of sharing has evolved. There were concrete decisions to rejuvenate the professional organization, the Tree-Ring Society, to set up a data bank, and to start a newsletter. The first volume of the newsletter has just been mailed. Organization is structured and methods are being standardized in preparation for the proposed International Climate Research Program (ICRP), the International Climatic Decade (ICD), and the International Paleoclimatic

Data Network (IPDN) described by the United States GARP report of the Panel on Climatic Variation entitled "Understanding Climatic Change, A Program for Action" (in press).

The climatic modeling, calibration, and reconstructions (Table 1, items 6, 7, and 8) will now be assigned to a new Task 5. A variety of techniques for reconstructing pressure anomalies over the North Pacific and western North America have been examined. Up to now a large part of this work has been done as part of NSF Grant GA-26581. However, the expansion of these studies to analysis on a larger scale will increasingly become more a part of the ARPA work.

Four papers dealing with various phases of this work are to be presented before the Annual Meeting of the American Quaternary Association in Wisconsin early in August. A paper entitled "Relationships of Ring Widths in Arid-Site Conifers to Variations in Monthly Temperature and Precipitation" is to appear in the summer issue of Ecological Monographs, 1974. Abstracts of these papers are included in the Appendix.

DETAILED TASK REPORTS

Tasks 1 and 3 reported by M. A. Wiseman. Progress on collections from Eastern United States, Alaska, Mexico, and Sweden.

Rapid progress in these tasks during the last six months has been made possible because of the addition of two more dendrochronologists. A total of 23 new collections were examined. Nine of these were deleted, as they were found to be unacceptable for climatic analysis due to poor dating quality, limited tree age, or inadequate sample size (Table 2).

The dating of 5 previously examined sites and 11 of the 23 new sites has been independently checked by a second worker. Ring-width measurements are complete for 30 of these collections. This latter figure includes samples which had been dated and measured prior to January, 1974, but were remeasured because they did not pass the quality control test for accuracy of measurement.

Many of these samples have been fully computer processed through the ring-width standardization program (Tables 2 and 3), and work on 3 additional sites from Baja California, Mexico, is in various stages of computer analysis (Table 3). Eight of the completed samples actually represent 4 sites, each with 2 collections; one for large samples collected in the 1940's and the second for samples obtained after 1970. These pairs are to be merged to form 4 longterm chronologies, making a total grid of 12 high quality eastern United States sites (Figure 1). A discussion of the problem arising from the merging of the paired chronologies is covered in Task 4.

The unfinished portions of Tasks 1 and 3 will be completed within a few months and the dating will begin on collections to be sampled from northern Canada this summer.

TABLE 2

Progress of Task 3. Collections in eastern United States and Alaska

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREES
ARPA	Nancy Brook, New Hamp.	RS	36/18	*	*	1561-1972	*	*	26/13
ARPA	Livingston, Massachusetts	RS	31/15	*	*	1696-1972	*	*	20/10
Siccama	+Camel's Hump, Vermont A, B, and C	RS	53/27	*	*	1635-1971	*	*	50/25
Siccama	Giant Ledge, New York	RS	22/11	*	*	1678-1972	X	X	20/10
Siccama	Cornell Mt., New York	RS	20/10	*	*	1817-1972	—	—	none
ARPA	Seagull Lake area, Boundary Waters, Minn.	RP	58/30	*	*	1625-1971	*	X	26/13
ARPA	Saganaga Lake area, Boundary Waters, Minn.	RP	117/63	*	*	1671-1968	*	*	34/14
ARPA	Itasca State Park, Minn.	RP	53/27	*	*	1672-1971	*	X	36/18
UNIVERSITY OF CHICAGO COLLECTIONS									
U of C	A-Mo Montgomery Co, Ark.	SLP	45	*	X	1666-1939	X	X	39/39
U of C	A-Po Polk Co, Arkansas	WO	13	*		1676-1940			
U of C	A-Pp Pope Co, Arkansas	WO	61	*	X	1642-1939	X	X	30/15
						1642-1939	(statistical chronology)		20/10

+Siccama-Dr. Thomas G. Siccama (Yale); RS-Red spruce (*Picea rubens*); RP-Red pine (*Pinus resinosa*); WO-White oak (*Quercus alba*); SLP-Shortleaf pine (*Pinus echinata*); ERC-Eastern red cedar (*Juniperus virginiana*); BF-Falsam fir (*Abies fraseri*); TMP-Table Mountain pine (*Pinus pungens*); HM-Hemlock (Tsuga canadensis)

X This step accomplished since last report.

TABLE 2—continued.

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREES
U of C	Mo-Ct Carter Co, Mo.	WO	45	*	X	1642-1936	X	X	57/47
						1642-1936	(statistical chronology)		20/10
U of C	Mo-S Shannon Co, Missouri	WO	106	*	X	1588-1936	X	X	36/36
U of C	O-Cm Comanche Co, Oklahoma	ERC	32	X	X	(deleted from analysis, poor crossdating)			
U of C	T-Wa Warren Co, Tennessee	WO	25	X	X	1669-1941			
U of C	T-An Anderson Co, Tenn.	SLP	5	X		(too few specimens for analysis, used for crossdating check)			
ARPA 1973 COLLECTIONS									
ARPA	Mount Scott, Oklahoma	ERC	28/14	X	X	(deleted from analysis, poor crossdating)			
ARPA	Russellville/A, Arkansas (update for A-Pp)	WO	27/12	*	X	1713-1972	X	X	20/10
						1713-1972	(statistical chronology)		20/10
ARPA	Russellville/A, Arkansas	SLP	24/12	X		1731-1972			
ARPA	Big Brushy Mtn., Arkansas (update for A-Mo)	SLP	40/20	X	X	1760-1972	X	X	41/20
						1760-1972	(statistical chronology)		20/10
ARPA	Crystal Mountain, Arkansas (update for A-Mo)	SLP	32/16	X		1719-1972			
ARPA	Brush Heap Mountain, Ark. (update for A-Po)	WO	30/15	X	X	1720-1972	X		

TABLE 2—continued.

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREES
ARPA	Falls Creek Falls, Tenn. (update for T-Wa)	Oak	34/17	X	X	1767-1972			
ARPA	Savage Gulf High	SLP	28/14	X	X	1646-1972	X		
	Savage Gulf Low, Tenn.	SLP	28/14	X	X	1734-1972	X	X	26/13
						1734-1972	(statistical chronology)		20/10
ARPA	Clingman's Dome, Tenn.	BF	28/14	X		1745-1972	(deleted, used for crossdating check but too short for analysis)		
ARPA	Steiner's Woods, Tennessee	WO	14/7	X	X	1625-1972			
ARPA	Greenbriar Pinnacle, Tenn.	TMP	28/14	X		1830-1972	(deleted, used for crossdating check but too short for analysis)		
ARPA	Norris Watershed Boundary, Tennessee	SLP	24/12	X		1628-1972			
ARPA	Wolf Pen Hollow, Tennessee	TMP	24/12	X		1810-1972	(deleted, used for crossdating check but too short for analysis)		
ARPA	Newfound Gap, N. C.	RS	30/15	X		1685-1972			
ARPA	Ferne Clyffe/A, Illinois (update for Estes FC data)	WO	20/10	X	X	1639-1972	X		
	Ferne Clyffe/B, C, and D	ERC	84/42	X		(deleted from analysis, poor crossdating)			
ARPA	Society American Foresters Plot, Missouri (update for Mo-S)	WO	24/12	*	*	1725-1972	X	X	20/10
ARPA	Mark Twain Nat'l Forest, Mo. (update for Mo-Ct and Estes Winona data)	WO	35/17	X	X	1783-1972	X	X	34/17
						1783-1972	(statistical chronology)		20/10
Estes	Winona, Missouri	Oak	20/10	X		1780-1966	X	X	20/10
ARPA	Herring Alpine, Alaska	HM	24/12	*	*	1422-1972	X	X	26/13

TABLE 3
Progress of Task 1. Collections in Mexico and Sweden.

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREES
ARPA	Baja/N/Topo	JP	50/25	*	*	1616-1972	X		
ARPA	Baja/N/Pond	Pnnq	58/29	*	*	1659-1960	X	X	
ARPA	Baja/C/San Pedro Martir-Low	JP	46/23	*	*	1463-1971	X	X	13/6
						1449-1971	(statistical	chronology)	28/14
ARPA	Baja/C/Vallecito	JP	34/17	*	*	1563-1972	*	X	
ARPA	Baja/C/Tasajera	JP	32/16	*	*	1559-1973	X		
ARPA	Baja/C/Tasajera	WF	30/15	*	*	1663-1972	*		
ARPA	Baja/C/Tasajera	LD	30/15	*	*	1473-1972	*	X	
Naylor	Sierra Madre/Rio Verde Chihuahua	DF	26/13	*	*	1634-1973	X	X	22/11
						1653-1973	(statistical	chronology)	16/8
Jonsson	Muddas National Park, Sweden	SCP	42/21 additional	*	*	1532-1972	*	X	30/15

JP-Jeffrey pine; Pnnq-Parry pinyon (*Pinus quadrifolia*); WF-White fir; LD-Incense cedar (*Libocedrus decurrens*); DF-Douglas fir; SCP-Scotch pine (*Pinus sylvestris*).

X Means this step accomplished since last report.

Task 2 reported by J. S. Dean. Progress on collections from the Southwest Plateau Area.

The principal objective of Task 2 is the construction of a geographical network of tree-ring chronology stations throughout the plateau area of the Southwest in order to assess tree-growth/climate relationships and to isolate spatial and temporal patterns of variation in past climatic conditions in the region. The network of modern tree-ring stations corresponds to an already existing grid of tree-ring chronologies based on samples from archaeological sites. Dendroclimatic analyses of the modern tree-ring series will be used to calibrate the archaeological sequences with local climatic conditions as basis for more accurate reconstructions of past climatic variability in the Southwest. Those modern series that extend far enough back into the past will be merged with their archaeological counterparts to produce long-term chronologies suitable for detailed studies of past climatic conditions in the Southwest from A.D. 700 to the present.

No field collections were undertaken during the past six months and the total amount of material available to the Task 2 research project remains at 1612 cores from 801 trees representing 48 study sites in Arizona, New Mexico, Colorado, and Utah (Table 4).

Laboratory study of the Task 2 collections is slightly behind schedule, because of programming problems in connection with the longer ring chronologies. As of June 30, 1974, specimen analysis has been completed for all 48 sites. Thirty-three individual species chronologies from 27 sites have been constructed, and 9 additional dated species sets are in various stages of computer processing. Twelve of the modern chronologies constructed as part of the Task 2 program are long enough to overlap with their archaeological counterparts to yield continuous chronologies that extend from the prehistoric past up to the 1970's. The areas for which we now have continuous chronological coverage are Tsegi Canyon, Hopi Mesas, and Flagstaff in Arizona, Natural Bridges in Utah, Mesa Verde in Colorado, and Gobernador, Cebolleta, Cibola, Jemez Mountains, Chama, Upper Rio Grande, and Santa Fe in New Mexico. This achievement is of great importance to the Task 2 research program (Figure 1 and Table 4).

Collections and collation of climatic data to be used in dendroclimatic studies of the relationships between modern tree growth and climate continues, and these data will soon be ready for punching onto computer cards.

In summary, the original network of archaeological chronology stations has been duplicated as closely as possible with the modern tree-growth sites, each of which corresponds to one of the prehistoric chronology stations. Laboratory work and computer processing is directed toward the development of the network of standardized tree-ring chronologies that will be used as the basis for specifying the relationships of tree growth to climate, which in turn provide the foundation for detailed reconstructions of climatic variability in the Southwest during the last

1500 years. These reconstructions to be made in Year 3 will provide an expanded basis for modeling possible future trends in Southwestern climate. Furthermore, the Task 2 tree-ring sequences will be incorporated into larger geographic chronology grids to provide paleoclimatic data on a continental and hemispherical scale.

TABLE 4

Progress of Task 2. Collections on the Southwest Plateau Area

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREES
ARPA	Grasshopper, Arizona	PP	36/18	*	*	1641-1972	*	*	
ARPA	Salt River Draw, Ariz.	PP	21/10	*	*	1675-1972	*	*	
ARPA	Oak Creek, Arizona	PNN	30/15	*	*	1694-1972	*	*	
NPS+ ARPA	Spider Rock, Arizona	PNN	46/23	*	*	1601-1972	*	*	
NPS ARPA	Spider Rock, Arizona	DF	32/16	*	*	1598-1972	*	*	
NPS ARPA	Canyon de Chelly, Ariz.	DF	20/7	*	*	1375-1972	*	*	
ARPA	Tseh Ya Kin Canyon, Ariz.	DF	24/12	*	*	1500-1972	*	*	
NPS ARPA	Tsegi Point, Arizona	PNN	40/20	*	*	1411-1972	*		
NPS	Tsegi Point, Arizona	DF	14/7	*	*	1532-1971	*		
ARPA, NPS TRL+	Betatakin Canyon, Ariz.	DF	77/24	*	*	1382-1972	*	X	
NPS ARPA	Kinbiko Rim, Arizona	JUN	22/11	*		1672-1972			
NPS	Kinbiko Rim, Arizona	PNN	18/9						
TRL	Kiet Siel Canyon, Ariz.	DF	48/12	*	*	1688-1963	—	—	none
NPS	Northern Black Mesa, Az.	DF	12/6	*	*	1551-1968	*		

PP-Ponderosa pine; PNN-Colorado pinyon pine; DF-Douglas fir; JUN-Juniper.
+NPS-National Park Service; TRL-Tree-Ring Laboratory; USFS-U. S. Forest Service; MNA-Museum of Northern Arizona
X This step accomplished since last report.

TABLE 4—continued.

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREI
NPS	Northern Black Mesa, Az.	PP	16/8	*	*	1569-1968	*		
NPS	Northern Black Mesa, Az.	PNN	8/4	*	*	1600-1968	*	*	8/4
TRL	Dinnebito, Arizona	PNN	44/20	*	*	1470-1972	*	*	
ARPA	Shonto Plateau, Arizona	PNN	30/15	*	*	1369-1972	*		
ARPA	Show Low, Arizona	PP	30/15	*	*	1595-1972	*	X	
ARPA	Jack's Canyon, Arizona	PNN	30/15	*	*	1533-1972	*		
ARPA	Robinson Mt., Arizona	PP	30/15	*	*	1610-1972	*	X	
ARPA	Medicine Valley, Arizona	PP	30/15	*	*	1679-1972	*	X	
ARPA	White Horse Hills, Ariz.	PP	30/15	*	*	1658-1972	*		
ARPA	SP Mountain, Arizona	PNN	30/15	*	*	1688-1972	*	X	
ARPA	Slate Mt., Arizona	PP	24/12	*	*	1647-1972	*		
ARPA	Cross Canyon, Arizona	PP	31/15	*	*	1611-1972	*	X	
ARPA	Defiance Plateau, Ariz.	PNN	26/13	*	*	1620-1972	*	X	
ARPA	Navajo Mountain, Utah	PP	30/15	*	*	1566-1972	*	*	
ARPA	Navajo Mountain, Utah	PNN	26/13	*	*	1468-1972	*	*	
ARPA	Kane Spring, Utah	PNN	30/15	*	*	1444-1972	*	*	
ARPA	White Canyon, Utah	DF	42/21	*	*	1346-1972	*	*	

TABLE 4—continued.

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREE
USFS+	Milk Ranch Point, Utah	PNN	20/10	*	*	1275-1971	*		
USFS	Milk Ranch Point, Utah	JUN	10/5	*	*	1745-1971	*		
USFS	Devil's Canyon, Utah	PP	12/6	*	*	1572-1971			
MNA+	Cedar Mesa, Utah	PNN JUN	96 Sections	*	*	1491-1972	—	—	none
ARPA	Bobcat Canyon, Colorado	DF	24/12	*	*	1388-1972	*	*	
ARPA	Wetherill Mesa, Colorado	PNN	24/12	*	*	1611-1972	*	*	
ARPA	Wetherill Mesa, Colorado	JUN	16/8	*	*	1817-1972	—	—	none
ARPA	Pueblito Canyon, N.M.	DF	29/14	*	*	1651-1972	*	*	
ARPA	Pueblito Canyon, N.M.	PNN	25/12	*	*	1599-1971	*	*	
ARPA	Ditch Canyon, New Mexico	DF	28/14	*	*	1657-1972	*	*	22/11
ARPA	Ditch Canyon, New Mexico	PP	28/14	*	*	1554-1972	*	*	
ARPA	Ditch Canyon, New Mexico	PNN	24/12	*	*	1574-1972	*	*	
ARPA	Ditch Canyon, New Mexico	JUN	24/12	*	*	1692-1972			
TRL	Aztec, New Mexico	DF	12/6	*	*	1542-1970	*	*	12/6
TRL	Aztec, New Mexico	JUN	12/6	*	*	1417-1970	*	*	12/6
ARPA	El Morro, New Mexico	PP	70/35	*	*	1535-1972	X		
ARPA	El Morro, New Mexico	PNN	40/20	*	*	1638-1972	X		
ARPA	Canyon Lobo, New Mexico	PNN	40/20	*	*	1691-1972	*	X	

TABLE 4—continued.

SPONSOR	SITE NAME	SPECIES	CORES/ TREES	EXAMINED	DATING CHECKED	CHRON. LENGTH	MEASURED	DATA PROCESSED	SELECTED CORES/TREES
NPS ARPA	Satan's Pass, N. M.	DF	54/27	*	*	1381-1972	*	X	
NPS ARPA	Turkey Spring, N. M.	PP	52/26	*	*	1594-1972	*		
NPS ARPA	Turkey Spring, N. M.	PNN	40/20	*	*	1410-1972	*		
NPS ARPA	Fort Wingate, N. M.	PNN	52/26	*	*	1476-1972	X		
ARPA	Mt. Taylor, New Mexico	PNN	40/20	*	*	1690-1972	X	X	
ARPA	Cebolleta, New Mexico	PNN	42/21	*	*	1660-1972	X		
ARPA	Agua Fria, New Mexico	PNN	40/20	*	*	1490-1972			
ARPA	Tajique Canyon, N. M.	PP	32/16	*		1694-1972			
ARPA	Tajique Canyon, N. M.	PNN	24/12	*		1655-1972			
ARPA	Paliza, New Mexico	PNN	28/14	*		1651-1972			
NPS ARPA	Echo Amphitheater, N. M.	DF	34/13	*	X	1362-1972	X	X	
ARPA	Glorieta Mesa, New Mexico	PNN	30/15	*		1554-1972			
ARPA	Ruidosa Ridge, New Mexico	DF	42/21	*		1689-1972			
ARPA	Ruidosa Ridge, New Mexico	PNN	30/15	*		1602-1972			
ARPA	Rito de los Frijoles, N.M.	PP	36/18	*		1716-1972			
ARPA	El Valle, New Mexico	PP	32/16	*		1709-1972			

Task 4 reported by C. W. Stockton. Progress on the screening of climatic data and on chronology merging.

During fiscal year 1973-74 the following accomplishments are reported. First, screening of climatic station records in the United States has been continued to select complete records of temperature and precipitation that are at least 80 years in length. Missing data were estimated and all series were checked for homogeniety. The western portion, which consists of 18 stations, is being utilized in the current modeling and calibration work. The eastern portion of the grid should be completed within 2 months.

In order to extend our record of climatic data as far back in time as possible, the weather records on microfilms from frontier forts supplied to the Surgeon General of the Army and those of the Smithsonian Institution have been acquired. Purchase of microfilms was made in January by the University of Arizona Library. We plan to examine these for possible verification of climatic reconstructions and for use in statistical calibration.

The third effort involves techniques for combining old tree-ring chronologies of uncertain microsite characteristics (i.e. those collected in the 1930's and 40's by University of Chicago Tree-Ring Laboratory) with those collected recently for which microsite information is known. Tests must be made on chronologies to be combined to determine if they are from the same statistical (and hence biological) populations. One empirical modeling test as outlined by Watts (1967) has been made. The basic idea is to fit a time series model--either moving-average, autoregressive, or mixed moving-average-autoregressive scheme--that produces the smallest sums of squares of the residuals to each chronology. The models of the 2 chronologies are compared and tests for significant differences are made. Results so far appear encouraging but more time must be devoted to this problem in the coming year as suitable statistical talent is obtained. Inquiry is being made into the possibility of using a program described by Dr. Rodney Strand at the Oak Ridge National Laboratory which will allow the appropriate tests.

Task 5 reported by T. J. Blasing. Progress on climatic modeling, calibration and reconstruction.*

Reconstructions of past circulation patterns have been made for summers and winters back to 1700 A.D. using information from the western United States grid of 49 ring-width chronologies. The circulation is represented by sea-level pressure at 96 gridpoints in the North Pacific sector and western North America. Both pressure and ring-width data were first reduced to principal component eigenvectors, and then calibrated using canonical correlation and canonical regression as outlined by Glahn (1968). This analysis provides the linear operator to transfer the ring-width data into estimates of the pressure anomalies.

Some of the reconstructions of general circulation in the North Pacific sector and western North America have been independently verified for summers (Blasing and Fritts, in press) and for winters (Blasing, 1974). Calibration and reconstruction of circulation patterns is proceeding for spring and autumn. Much time has been devoted to interpretation of missing pressure data for these seasons to obtain a complete data set for the entire Northern Hemisphere. The statistical model to be used is the same as that used for the summer and winter reconstructions. It includes lagged as well as non-lagged ring-width information as described in detail by Fritts and Blasing (1973).

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* This work so far has been accomplished largely under Grant GA-26581 from the National Science Foundation.

The reconstructions are promising for the temperature and precipitation anomalies for 18 reporting stations throughout western United States selected in the ARPA data search, though the results do not appear as good as those of pressure. The data for the period 1910 to 1962 was used in the calibration. Actual data available from 1909 and before is used to check the accuracy of the reconstructions. Since the quality of temperature and precipitation data prior to 1910 appears better than the quality of pressure data, rigorous statistical test of our reconstructions using independent climatic data is now possible.

Task 6 reported by K. S. Babcock. International Cooperation: International Workshop on Dendroclimatology and the International Tree-Ring Data Bank.

The major effort made during the spring months by the ARPA project personnel was preparation for and participation in the International Workshop on Dendroclimatology, organized by Dr. H. C. Fritts and made possible by a dual grant from both ARPA and the National Science Foundation. It was held at the Laboratory of Tree-Ring Research in Tucson, April 15-26, 1974, with several participants attending a special work session April 1-14. Purpose of the Workshop was to organize collaboration among tree-ring scientists working on global climate reconstruction and to standardize the processing of tree-ring data. The 27 visiting participants represented the countries of West Germany, France, Belgium, Northern Ireland, England, Finland, Sweden, Israel, Canada, Poland, and the United States.

The two weeks of sessions covered such topics as the need for paleoclimatic reconstruction; collection tools, techniques, and site conditions; crossdating; data preparation and measurement; computer processing; statistical approaches; techniques of climatic analysis; biology of growth response to climate; and new techniques such as X-ray microprobe analysis, microdensitometry, and gamma ray densitometry. Sessions were intermixed with field trips for demonstration of dendroclimatological techniques in northern Arizona, the Santa Catalina Mountains north of Tucson, and the Arizona-Sonora Living Desert Museum west of Tucson.

The final two days of the Workshop were devoted to discussions of international cooperation. Outcomes of these discussions include the following:

DATA BANK. An International Tree-Ring Data Bank will be established and will be housed at the Laboratory of Tree-Ring Research in Tucson. When in workable form, listings of data which can be obtained from it will be published. All data will be categorized by the contributor as either available to all, or available only by permission of the contributor. User fees will be announced. All data will be stored on computer tapes and will consist of site information, tree-ring widths by core, and indices if they have been provided by the contributor. Minimum requirements for data to be entered into the Data Bank are that

a) They must be replicated and absolutely dated.

b) They must have a minimum length of 100 years.

c) There must be a minimum number of 10 trees per species and site, hopefully with two measured radii per tree.

Contributors appointed to the autonomous Data Bank Committee, of which Dr. Harold C. Fritts is chairman, are Dr. Jon Pilcher, Paleoecology Laboratory, The Queen's University, Belfast; Dr. Bernd Becker, Botanisches Institut, Universität Hohenheim, Stuttgart; Dr. Zdzisław Bednarz, Akademia Rolnicza, Kraków; and Dr. Charles Stockton, Laboratory of Tree-Ring Research, University of Arizona, Tucson. Technical assistants appointed are Mrs. Linda Drew, Data Processor, and Miss Karen Babcock, Assistant to Dr. Fritts; both are at the Laboratory of Tree-Ring Research, University of Arizona, Tucson.

An ad hoc committee at the Workshop composed of members of the Tree-Ring Society voted to offer sponsorship to the newly formed International Tree-Ring Data Bank.

Members of the appointed Data Bank Committee have nearly completed organization of the data entry system, and entry of data should begin within 3 months. Once this facility is available data should not only be more available, but the records will be on permanent file for future scientific use. However, screening and checking of data reliability for our particular use will still be necessary.

An agreement has been signed by Professor Ye. P. Borisenkov, director of the Main Geophysical Observatory, Leningrad, USSR and Dr. W. N. Hess of NOAA's Environmental Research Laboratories, USA, entitled "The First Session of the Working Group VIII on the Influence of Environmental Changes on Climate, 10-21 June 1974 Leningrad." Section 2.3.3. is an agreement among Dr. Bitvinskas and Dr. N. V. Lovelius of the USSR and Dr. Fritts of the USA to share tree-ring data. The scientists from the USSR have agreed to supply ring widths for 11 or 12 circumpolar sites within their country. Fritts will share the 49 tree chronologies from western North America, his methods on multivariate reconstruction of climate from tree rings, and, in the future, some of the chronologies developed for the ARPA work.

OTHER DEVELOPMENTS

reported by K. S. Babcock

In order to increase efficiency in writing and editing multipage manuscripts, the ARPA research team has adapted text editing and formating programs which are available on the University of Arizona's DECsystem-10 computer. These programs allow for justifying of right and/or left margins, automatic hyphenation, text insertions and deletions of any size, changes of spelling, and the automatic building of tables of contents and indices. These attributes of the editing systems make possible a great reduction of the amount of time consumed during revisions, since only insertions and deletions need be made, as opposed to complete retypings of the manuscript. The Texas Instruments computer terminal, recently acquired through ARPA, will not only allow staff use of the editing software, but will facilitate work with the Tree-Ring Data Bank, various types of data retrieval, and program development.

APPENDIX

Abstracts of papers concerning ARPA project results, to be reported at the Third Biennial Meetings of the American Quaternary Association (AMQUA), Madison, Wisconsin, 30 July - 1 August 1974, and to be published in the Proceedings,

Abstract of H. C. Fritts paper to appear in Ecological Monographs,

And list of personnel funded in part by ARPA.

SOME QUANTITATIVE METHODS FOR CALIBRATING RING WIDTHS WITH VARIABLES OF CLIMATE

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The ring widths of trees can be calibrated with climatic or environmental data and the past ring widths used to reconstruct past variations in climate. This is possible because 1) the rings can be dated as to the exact year in which they were formed, 2) the data can be replicated easily by sampling a large number of trees, 3) climatic factors that vary from one year to the next limit processes affecting ring-width growth, and 4) the effects on ring widths of many biological factors that are unrelated to climate can be minimized by using an appropriate transformation. This transformation is accomplished by 1) fitting to the time series of ring widths either an exponential function of the form

$$Y = ad^{-bt} + k \qquad (1)$$

where a, b, and k are constants or a multidegree polynomial function and 2) dividing each ring width by the value of the function for that year. The resulting quantities are indices of growth which, unlike ring widths, form stationary time series that are essentially normally distributed with an average of 1 and a variance that is homogeneous through time. The indices for a given year from a number of trees of a given species on a site are averaged to obtain an estimate of the year's growth resulting from variations in climate. The time series of these averages is referred to as the ring-width chronology for the site. Analysis of variance, cross-correlation and other statistical techniques can be applied to the chronology to identify important characteristics. Digital filtering, power and cross-power spectral analysis and other time-series techniques may be used to describe the behavior of the data as a function of frequency in time.

The task of reconstructing one set of variables such as climate from another set such as tree rings involves 4 basic steps: 1) statistical modeling of the expected biologic-climatic relationship,2) calibration of the model to obtain the appropriate constants, 3) application of the calibrated model to reconstruct climate for past years using one data set such as tree rings as predictors, and the other set, such as climate, as predictands, and 4) independent verification of the reconstructions by comparing statistical estimates to actual data outside the calibration interval.

This paper deals mainly with the problem of calibration. Calibration may involve 1) simple counts of agreement and disagreement in the signs of the first differences for two time series, 2) contingency analysis and conditional probability, 3) simple correlation and regression, 4) multiple correlation and regression, 5) multiple regression with principal component eigenvectors, and 6) canonical correlation and regression.

Multivariate techniques are especially suitable for handling the large numbers of variables frequently encountered in analysis of tree rings and climate. Variables might represent large spatial arrays of tree-ring sites or meteorological stations. Or a large number of variables may be required to adequately characterize the different effects of climatic factors on growth.

Cluster analysis is a multivariate technique which may be used to identify similarities and differences among a large number of variables and to classify them into meaningful groups. Another technique, referred to as the spatial correlation analysis, uses the correlation of patterns through space to identify similarities among data observed in different years or some other interval of time.

Principal component analysis, an exceptionally powerful multivariate technique, may be used to convert a large number of input variables to new variables referred to as eigenvectors, which describe orthogonal (uncorrelated) modes of behavior in the original data. The property of orthogonality may be both a limitation and an asset. The limitation arises because natural systems, unlike eigenvectors, usually behave as a set of highly interrelated phenomena and can be described only by highly correlated variables. Therefore, only the largest and most important eigenvectors may resemble observable features of the natural system. Factor analysis uses various schemes, some of which are not orthogonal, to manipulate the eigenvectors so that they better represent the original observations. None of these manipulative schemes are used in applications described here. On the other hand, the orthogonal property of the eigenvectors can aid the analysis because it satisfies the assumption of independence among predictor variables of a multiple linear regression.

It is my proposition that, because of the orthogonality among eigenvectors, principal component analysis should be coupled with stepwise multiple regression to resolve the intercorrelations and simplify the analysis whenever large numbers of interrelated variables are involved. Since this method can be applied to many studies outside the field of tree-ring analysis, the most pertinent equations are included here in hopes of stimulating discussion and promoting use of the technique.

The predictors representing m variables for n observations (in our case years) are first subjected to routine principal component analysis to obtain the matrix ${}_mE_m$, with m new variables called eigenvectors with elements associated with each of the original m variables. The matrix equation is

$$ {}_mC_mE_m = {}_mE_mL_m \qquad (2)$$

where ${}_mC_m$ is the complete symmetric matrix of correlation coefficients or covariances for the m variables and ${}_mL_m$ is a diagonal matrix of m eigenvalues which are proportional to the variance reduced by the m eigenvectors. The eigenvectors can be used to transform the original predictor data into m amplitudes (${}_mX_n$) which are sometimes referred to as factor scores. They represent the values of the new variables corresponding to each of the n observations. The equation for this transformation is

$$ {}_mX_n = {}_mE'_m {}_mF_n \tag{3} $$

where E' designates the transposed eigenvectors and ${}_mF_n$ represents n observations of data for m variables normalized to obtain a mean of zero and unit variance. The complete amplitude matrix contains all the information (variance) in the original data matrix but it differs in that each amplitude associated with each eigenvector is uncorrelated with all other amplitudes of the set. The amplitude matrix may be multiplied by the eigenvectors to recover the original data matrix ${}_mF_n$

$$ {}_mF_n = {}_mE'_m {}_mX_n \tag{4} $$

One can move from ${}_mF_n$ to ${}_mX_n$ and back to ${}_mF_n$ by matrix multiplication with the complete eigenvector matrix without any loss of information (variance).

In practice, only a subset of the p most important eigenvectors are used. Those that reduce little variance are discarded as they represent small-scale variations, orthogonality constraints, and unwanted noise. Multiple regression can then be run using the amplitudes of the selected set as statistical predictors of a dependent variable such as tree growth. The matrix equation is

$$ {}_1\hat{P}_n = {}_1R_p X_n \tag{5} $$

where ${}_1\hat{P}_n$ is the estimated predictand for n observations and ${}_1R_p$ is the row matrix of significant partial multiple regression coefficients which transform variations of the p amplitudes into estimates of the predictand. (All insignificant regression coefficients, at least those with an F ratio < 1, are omitted from regression and are assigned a value of zero.)

Just as the amplitudes may be converted to the original data (equation 4), the matrix of p regression coefficients originally associated with the eigenvector amplitudes can be converted to a new set of m coefficients associated with the original variables, ${}_mF_n$, by multiplication of the regression coefficients by the eigenvectors.

$$ {}_1T_m = {}_1R_p E'_m \tag{6} $$

The new matrix of coefficients, ${}_1T_m$, referred to as the transfer function, may be multiplied with the original data to obtain estimates of the predictand identical to those in equation 5.

$$ {}_{1}\hat{P}_{n} = {}_{1}T_{m}F_{n} \qquad (7)$$

The transfer function differs from the coefficients of multiple regression on the m original variables because the small-scale eigenvectors which are likely to represent noise have been omitted from the analysis and some of the amplitudes were excluded from regression by the stepwise analysis (Fritts, 1962). Since the omitted regression coefficients and their error terms do not enter into the computation, the errors of the elements of ${}_{1}T_{m}$ are smaller than those obtained by regression on the variables ${}_{m}F_{n}$ and the statistical reconstructions based on ${}_{1}T_{m}$ are better estimates of the most important large-scale variations. More details of the method are described by Fritts (1971) and Fritts et al. (1971). Examples are presented which illustrate the above features and which demonstrate how the technique can be used to simplify large variable sets and to sort out large-scale information from smaller-scale noise.

However, it is emphasized that elegant and powerful statistics cannot extract information that is improperly collected, carelessly assembled, or inappropriately transformed. For example, if exact dating of rings cannot be achieved, there is no certainty that observations used to compute the chronologies are correctly associated with the year in which they were formed. If large non-climatic variations are not removed or if climate is rarely limiting to a growth-controlling process, there may be insufficient climatic information in the ring widths. In such cases, no calibration technique could be expected to produce meaningful results.

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A PATTERN CORRELATION APPROACH TO PALEOCLIMATIC STUDIES

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If a series of maps of some climatic parameter (such as July maps of sea-level pressure anomaly over the Northern Hemisphere) are each represented by a spatial array of numerical observations at fixed points, then the correlation coefficient between any two such maps can be computed and used as a measure of similarity between them. If each map in a series is so compared with every other map, then maps which are highly correlated with each other may be identified and grouped as a set of representative maps of a particular type of situation. Another set of maps, highly correlated with each other, but different from the first set, may represent another type of situation, and so on. I have used this approach to find summer and winter anomaly type-patterns of sea-level pressure over the North Pacific sector and western North America. Those summers (or winters) of a particular pressure type may be studied as a group to determine anomaly patterns of temperature, precipitation, or any other parameter, associated with the occurrence of that pressure type.

For example, one type-pattern of sea-level pressure is associated with a pattern of anomalous cool and wet conditions, and wide tree rings, in the area of Colorado, but with warm and dry conditions, and narrow rings, in the Washington-Oregon region. This type of summer might also favor a pattern of glacial response including, for example, mass accumulation on the Colorado Front Range and mass wastage in the Cascades. Thus relationships between climatic types and response patterns of other environmental variables (climatic proxy variables) can be depicted. Past occurrences of a climatic type might then be inferred from past occurrences of its associated proxy response pattern.

Some kinds of proxy data may be classified into types by the correlation method, and then related to climate. For example, tree ring width anomalies from a wide variety of locations can be mapped on an annual basis, and these maps can then be classified into types. The occurrence of a ring width anomaly type-pattern in the past may then be used to infer the past occurrence of the climatic conditions associated with that type. This approach has been applied by Blasing and Fritts (1973, Proceedings of the 24th Alaskan Science Conference).

The correlation approach can be applied to classify anomaly types occurring in a series of measurements of any assemblage of variables. Pollen assemblage types, for example, might be determined from a series of measurements (in space or time) of several pollen variables.

More complex multivariate statistical techniques are available for the purpose of reconstructing past climate from proxy data. The correlation technique, however, is designed to identify, and aid in interpreting, specific occurrences of those climate-proxy relationships which form the basis for such reconstructions. If such relationships are so identified, the choice of an appropriate statistical model for reconstruction becomes easier, and the reconstructions are more amenable to verification using independent lines of evidence.

PAST AIR-SEA INTERACTIONS OFF SOUTHERN CALIFORNIA AS REVEALED BY COASTAL TREE-RING CHRONOLOGIES

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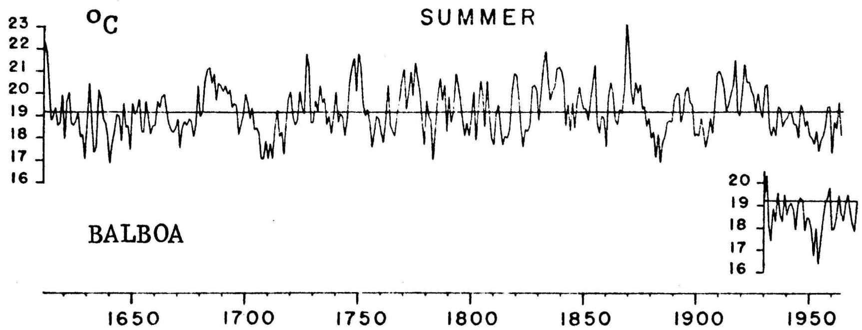
Analyses are made of sea surface temperature (SST) data and tree-ring data from Southern California. Multiple linear regression analyses of the two sets of data indicate that SST data for Port Hueneme, Balboa, and La Jolla can be reconstructed using tree-ring data from five tree-ring sites in Southern California. Prediction equations were obtained from the analyses, and 23% to 63% of the year-to-year variance in seasonal SST were explained, with the highest percentages for the spring and summer seasons.

Actual SST records from a number of sources tend to verify the type and magnitude of SST anomalies predicted for the three stations since the mid 1800's. In addition, biologic evidence strongly confirms the predicted SST values for the mid 1800's. Likewise, deep sea core evidence seem to confirm the predicted SST values for the mid 1880's, as well as for the entire length of SST reconstruction 1611-1964. A simple correlation analysis was run between the Pacific hake scale counts and the predicted SST data for Port Hueneme. The two variables were positively correlated at 0.22, but this correlation is not significant at the 95% level. It was noted, however, that the decades with large year to year variations in SST appeared to be highly correlated with the scale counts. A simple correlation analysis indicated a significant correlation of 0.35 between the decade scale counts and the standard deviations for each decade's SST.

The recontructed SST data are believed to be a conservative estimate of past SST anomalies, but independent data suggest the predictions are qualitatively accurate. An analysis was made of possible air-sea interactions using the reconstructed SST data which begin in 1611. The reconstructed SST data suggest that at times during the decades of 1610, 1680, 1770, 1830, and 1850, sea surface temperatures may have been 2°C or 3°C warmer than the present averages. At times during the decades of 1640, 1710, and 1880, sea surface temperatures may have been 2°C or 3°C cooler than the present averages. An analysis presented indicates that these reconstructed SST data for coastal Southern California may be reflective of broad scale SST anomalies in the eastern North Pacific, and thus, the uses of the reconstructed data need not be limited to local problems along the coast of Southern California.



PROTO-HISTORIC AND HISTORIC PERIOD DENDROCHRONOLOGY IN EASTERN AND MIDWESTERN UNITED STATES

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Several stands of old aged trees have been sampled in the Mississippi Drainage states, northern Minnesota, and New England for the purpose of building well-replicated chronologies for use in paleoclimatic reconstructions beyond A.D. 1700.

The availability of these chronologies has important implications for Contact and Pioneer Period archaeology in the Midwest and East by

1) Providing a precise dating tool ready for use in answering refined temporal questions, and
2) Providing environmental indices of moisture, temperature, and atmospheric circulation against which to test the archaeological record.

With the models presently being constructed for ways in which collected tree species respond to climate, the archaeologist may anticipate in the future being able to use seasonal and yearly paleoclimatic reconstructions based upon tree-ring data together with historical records to answer questions of concern to processual archaeology and cultural ecology.

If exhaustive sampling of archaeological wood at a site is taken with good provenience controls, it is possible not only to give dates of construction to the year from unhewn timbers but also to provide some independent behavioral information about cutting, shaping and scheduling of building practices, species preference for different purposes, stockpiling or re-use of timber, and modifications made through time within a single dwelling or in an entire settlement pattern. I have outlined steps for structuring an archaeological/dendrochronological dating project in the East for those interested.

The data base so far covers the time period from the latter 1600's to the present, represented by species utilized mostly by European settlers: Pine and oak from the Ouachita and Ozark Mountain areas of Arkansas and Missouri, pine from northern Minnesota, oak from southern Illinois, both pine and oak from east Tennessee, and spruce from northern New England.

With increased sampling of historical structures, tree-ring chronologies will be extended back in time providing better chances for dating prehistoric archaeological and climatic events. A feedback is also requested in return for dendrochronological dating in the East: The historian or archaeologist can help the paleoclimatologist substantiate or refute his climatic reconstructions by supplying him independent information about periods characterized in a given region by environmentally imposed hardship.

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RELATIONSHIPS OF RING WIDTHS IN ARID-SITE CONIFERS TO VARIATIONS IN MONTHLY TEMPERATURE AND PRECIPITATION[1]

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Abstract. Two multivariate techniques for evaluation of ring-width and climatic relationships are described. One technique employs multiple regression on principal components of climate. Response functions are obtained which express in mathematical form the relative effect of monthly temperature and monthly precipitation during a 14-month period on ring-width variations. Response functions are calculated for 127 coniferous tree sites in western North America. The other technique is a cluster analysis which is used to identify similarities among the response functions and classify them on the basis of their similarities and differences. Higher-than-average precipitation most commonly results in higher-than-average growth, though on cold sites the effects of precipitation during the cooler parts of the year are sometimes lacking or inverse. Precipitation is directly related to growth throughout the entire year for 32% of the sites representing many that have been used in dendrochronology. In the remaining 68% of the sites the effects of precipitation vary from season to season. Temperature is most commonly inversely related to ring width during autumn, spring, and summer. Inverse relationships occur in mid-winter for trees on the warmest sites and on certain high-altitude sites. However temperature effects are often direct ones, especially during winter and for many sites at high altitudes, high latitudes or on north-facing slopes. Site factors appear most responsible for variations in the growth responses. Aspect of slope appears to be the most critical, followed by altitude and latitude. There are fewer differences between species than between factors of the site, although certain species such as bristlecone pine have a more or less unique growth response. Some speculations are offered on the effects of the sites and their microenvironments on biological processes linking the climatic variables and growth. The variety of ring-width responses to variations in climatic factors suggest that more physiological study of trees on extreme sites may reveal unique growth-environment relationships that have not been observed on more optimum sites. The median percent of tree-growth variance accounted for by climate is approximately 60 to 65%. With such a high percentage of variation related to climate, ring-width variability, if adequately sampled, dated, and calibrated with climate, can be used successfully to estimate past climate, even though all linkages of cause and effect have not been demonstrated by physiological research. It is proposed for reconstruction of past climate that many ring-width chronologies be used with diverse tree-growth responses, because the differences can be handled by multivariate techniques and provide more information on various climatic factors than chronologies with the same growth response. It is also proposed that response functions have applications in the modeling of productivity in forest ecosystems. They can be used to ascertain the effects of climatic variation on tree growth and to help in extrapolating information gathered in one area to other tree sites.

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