FOIA Number: 2012-0769-F

FOIA MARKER

This is not a textual record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

Collection/Record Group: Clinton Presidential Records

Subgroup/Office of Origin: Council on Environmental Quality

Series/Staff Member: Kathleen (Katie) McGinty

Subseries:

OA/ID Number: 2897

FolderID:

Folder Title:
Tree Rings

Stack:	Row:	Section:	Shelf:	Position:
S	61	6	3	1

ALBERT GORE, JR.
TENNESSEE

393 RUSSELL SENATE OFFICE BUILDING
PHONE: 202-224-4944

United States Senate

WASHINGTON, DC 20510-4202

Date: October 2, 1991

To: Albert Gore Jr. S, Anthony Socci

From: Katie McGinty

tree ring analysis --

greenwire abstracted a study of ancient tasmanan trees done by scientists at lamont doherty. the study is significant: first, it is one of the longest high-resolution paleoclimatic records from the SOUTHERN hemisphere; second, altho the record reveals several other earlier warm periods, the study showed that "tasmania has not been as consistently warm in any other period as it has been since 1965."

this same group has also done significant tree ring analyses in Canada and Alaska. their results: "OUr northern hemisphere reconstruction through 1973 thus supports the hypothesis that the current warming trend has exceeded the level of natural climate variability, at least over the past several hundred years." (300 year record).

i asked the authors if they have compared their results with the permafrost warming that lachenbruch has detected in this region.

they said that there is a link, but a detailed comparison has not been done -- this should be done and could be quite interesting -- lachenbruck looks at the norht slope region; tree ring analysis done just below that region at the tree line -- together, the two data sets could provide insight into the entire no. am. continent.

the no. hem. data set should also be compared with the glacier melting data that the tompsons are coming up with.

one other point of interest re: the no hem tree ring study-- the authors found no evidence of a co2 fertilization effect -- as others have noted, co2 probably is not the limiting factor for growth; soil nutrients will not support more rapid growth -- regardless of enriched co2 concentrations.

TREE RINGS re climate change. AG

minuscule.

Steve Aftergood of the watchdog group Federation of American Scientists, admits that in a global sense, the shuttle is only a tiny part of the problem. "But as a single-source polluter of the ozone, the shuttle is a very large part of the problem," he said.

The satellite, called the Upper Atmospheric Research Satellite, will offer scientist more information than they have ever had on the chemical and physical workings of ozone. The satellite should "at least double our knowledge about ozone," said NASA atmospheric physicist Charles Jackman (9/12).

*9 GLOBAL WARMING: SCIENTISTS SAY TREES PROVE EARTH IS WARMING

American and Australian scientists studying growth rings of ancient Tasmanian trees have shown the climate there has been unusually warm since 1965. The study collected corings from the trunks thousand-year-old huon pines and found that growth rings between 1965 and 1988 were larger than other time in the last 1,089 years. In a report published yesterday in the journal SCIENCE, "This growth increase ... supports claims that a climatic change, perhaps influenced by greenhouse gases, is in progress."

The huon pine can live for 2,000 years or more. Each season, the tree adds another layer to its trunk. In warmer years, the layer is wider than years when cold weather hampers growth (N.Y. POST, 9/13).

KW: Is this significant? -M

============== WORLDVIEW ==============

*10 CANADA: PRINCE PHILIP APPEAL TO B.C. TO PROTECT FORESTS

"The royal voice of Prince Philip has joined a chorus of conservationists appealing for British Columbia's government to preserve some of its wildlands from the province's timber industry" (Joel Connelly, SEATTLE POST-INTELLIGENCER). The appeal is part of an effort by the World Wildlife Fund to preserve B.C.'s rapidly diminishing forest land. In a letter to Premier Rita Johnston, Prince Philip asked that the province commit itself to creating a network of protected areas by the year 2000. THe World Wildlife Fund recently released a study showing that only 20 percent of the province's primary river valleys remain pristine. Johnston has not responded to Prince Philip or the fund (9/13).

============== STATE REPORTS ==============

*11 FLORIDA: LEGISLATURE CONSIDERS STRICTER WATER CONTROLS

The FL Legislature "will consider imposing stricter controls next winter over the state's water management districts, lawmakers said Wednesday" (Alan Judd, GAINESVILLE SUN). Legislators may give the Department of Environmental Regulation

Katy - see figures 1+2 and the conclusions on page 55 - Stephanie

RECONSTRUCTED NORTHERN HEMISPHERE ANNUAL TEMPERATURE SINCE 1671 BASED ON HIGH-LATITUDE TREE-RING DATA FROM NORTH AMERICA

GORDON C. JACOBY, Jr. and ROSANNE D' ARRIGO

*Tree-Ring Laboratory, Lamont-Doherty Geological Observatory, Palisades, New York, U.S.A.**

Abstract. Annual Northern Hemisphere surface temperature departures for the past 300 yr were reconstructed using eleven tree-ring chronologies from high-latitude, boreal sites in Canada and Alaska, spanning over 90 degrees of longitude. This geographic coverage is believed to be adequate for a useful representation of hemispheric-scale temperature trends, as high northern latitudes are particularly sensitive to climatic change. We also present a reconstruction of Arctic annual temperatures. The reconstructions show a partial amelioration of the Little Ice Age after the early 1700's, an abrupt, severe renewal of cold in the early 1800's and a prolonged warming since approximately 1840. These trends are supported by other proxy data. Similarities and differences between our Northern Hemisphere reconstruction and other large-scale proxy temperature records depend on such factors as the data sources, methods, and degree of spatial representation. Analyses of additional temperature records, as they become available, are needed to determine the degree to which each series represents fluctuations for the entire hemisphere. There appear to be relationships between trends observed in our Northern Hemisphere reconstruction and certain climatic forcing functions, including solar fluctuations, volcanic activity and atmospheric CO_2. In particular, our reconstruction supports the hypothesis that the global warming trend over the past century of increasing atmospheric CO_2 has exceeded the recent level of natural variability of the climate system.

1. Introduction

Long quantitative records of year-by-year temperature for the Northern Hemisphere (NH) are invaluable to researchers studying climate dynamics and forcing functions that influence the climate system. Such records are of increasing importance in understanding if or when anthropogenic disturbance (e.g. CO_2) has influenced climate. In 1986 Ellsaesser *et al.* presented a series of plots of proxy data from various sources relating to changes in NH temperature over the last few centuries. Only two of the plots are attempts to reconstruct global or hemispheric temperatures. The rest are records or proxies for temperature in certain local areas or regions. Even the records presenting hemispheric or global scale temperatures are limited by geographical representation in the underlying data sets. The reconstructions presented herein are also limited by geographical representation but statistical and graphical comparisons with NH temperature data are favourable enough for us to present it as an index to NH

* Of Columbia University Department of Geological Sciences.

Climatic Change 14: 39–59, 1989.

Post-It™ brand fax transmittal memo 7671 | # of pages ▸ 22

To Katy McGinty	From Stephanie Ottman
Co. Senator Gore's Office	Co.
Dept.	Phone # 212-505-0606 x332
Fax # 202-224-0580	Fax #

temperature with the caveats and limitations discussed in the summary. It is an improvement over some previous reconstructions and hopefully will itself be improved as more proxy records are incorporated in future studies.

Although it is preferable to utilize data sets from as much of the area under consideration as is feasible (Fritts and Lough, 1985), several authors have noted that certain key regions in middle to high latitudes can serve as indicators of hemispheric conditions (Bryson, 1976; Lamb, 1982). In particular, several studies have discussed the significant contribution of high-latitude regions to observed hemispheric-scale temperature changes (Kelly *et al.*, 1982; Van Loon and Williams, 1976; Goody, 1980). For example, the usefulness of Arctic ice variations as an indicator of world climate is believed to result from ice-condition responsiveness to shifts in the circumpolar vortex (Lamb and Morth, 1978). A warming of about 1.5 °C was recorded at Arctic stations over the past century, whereas the Northern Hemisphere as a whole only warmed about 0.5–0.7 °C (Kelly *et al.*, 1982; Hansen and Lebedeff, 1987). General circulation models predict that the greatest greenhouse warming will occur at high latitudes, due to ice albedo feedback and other factors (Hansen *et al.*, 1988; Washington and Meehl, 1984; Manabe and Wetherald, 1980; Hansen and Takahashi, 1984).

Attempts to detect temperature fluctuations in the high northern latitudes of North America from available instrumental data are severely hampered by a spatially and temporally limited network (Bradley and England, 1978). Proxy records are therefore necessary in order to obtain adequate information on past climatic conditions in these regions. The development of quantitative climatic records using time series of absolutely-dated tree-ring width indices has been well documented (Fritts, 1976; Hughes *et al.*, 1982; Jacoby *et al.*, 1985), although the potential value of high-latitude chronologies in assessing large-scale climatic change has not been fully utilized.

Temperature is the primary factor which limits tree growth at higher latitudes, and tree-ring chronologies developed from certain northern treeline sites can yield a clear temperature signal. There are sites where moisture stress or ecological stresses obscure a clear temperature signal. High-latitude trees respond to the thermal regime in an integrative manner, including response to soil temperature and direct solar radiation as well as air temperature (e.g. Goldstein, 1981). Although actual cambial cell division may be limited to as little as six weeks in summer at the northern treeline, photosynthesis, root extension and other biochemical processes related to growth take place over a much longer season. Response functions have been run for the northern treeline chronologies from sites with reliable meteorological data within about 100 km or less. In other cases simple correlations have been calculated between the chronologies and more distant meteorological data. The results show the influence of more than the summer of the growing year. For example, these trees can respond to previous fall temperature (Jacoby and Ulan, 1982; Jacoby and Cook, 1981; Garfinkel and Brubaker, 1980; Cropper, 1982) after radial growth has ceased.

This occurs because photosynthesis of evergreens continues into the fall, resulting in the production and storage of carbohydrates and other substances for next year's growth.

Several other causal relationships can be cited to support the hypothesis that northern tree growth integrates temperature effects outside of the season of actual cambial-cell division. An early or cold fall can prevent bud maturation and full cuticular development on needles (Tranquillini, 1979). Frost damage to immature buds will inhibit production of hormonal growth regulators during next year's growth. Mechanical disbudding has been shown to reduce root growth (several studies cited in Kozlowski, 1971). Needles with less complete cuticular development are vulnerable to damage from winter desiccation and ice particle abrasion. Another effect of bud formation in determinate species like white spruce is that the primordia for next year's shoot and needle growth are formed this year. In a good growing year a healthy bud will be formed with the potential for good growth the next year. If that next year is also favourable, the potential will be realized and more new photosynthetic surface (needles) will be produced to benefit growth in succeeding years. Thus persistence or response for more than one year results from each growing season and produces lower-frequency response to climate.

Milder winters reduce the vernal heat needed to thaw the root zone in the active layer in these regions of continuous and discontinuous permafrost. Heat flow measurements by Lachenbruch and Marshall (1986) in the permafrost in northernmost Alaska document a warming of 2 to 4 °C that should be reflected in the thermal regime of the active layer. Warmer soil temperatures appear to benefit the water balance in white spruce in the Brooks Range in Alaska (Goldstein, 1981), and he suggested that the water balance may be even more important to tree growth than air temperature in his analysis. Also, warmer soil temperatures can increase nutrient recycling. Thus it is understandable that these extreme northern trees can integrate the effects of annual temperature variation.

2. Data, Methods and Results

Two temperature reconstructions, based on tree-ring data, were developed by this study: (1) a reconstruction of Northern Hemisphere annual temperature departures (Figure 1) and (2) a reconstruction of Arctic (averaged for 64–90 N.) annual temperature departures (Figure 2). Both reconstructions extend from 1671 to 1973 and are based on eleven tree-ring width chronologies from boreal treeline sites (Figure 3; Table I). Three tree species were used: white spruce (*Picea glauca* [Moench] Voss), eastern larch (*Larix laricina* [DuRoi] K. Koch) and northern white-cedar (*Thuja occidentalis* L.). With the exception of the Fort Chimo larch chronology (Figure 3, Table I) (Cropper and Fritts, 1981) all tree-ring data are from sites sampled by our laboratory. The deciduous larch may not

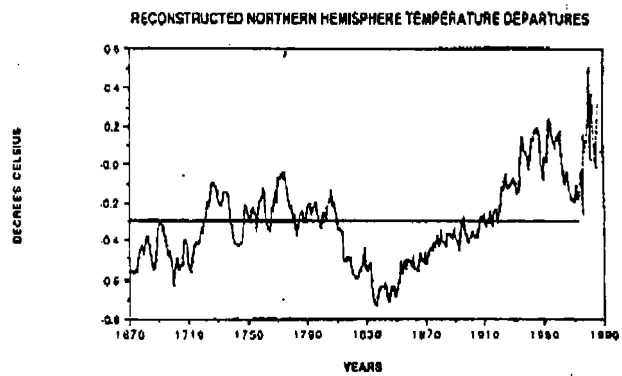

Fig. 1. Northern Hemisphere annual temperature reconstruction (solid line) for 1671–1973 based on tree-ring data. Dashed line = instrumental temperature data for 1974–1987. Departures are from the 1951–1980 mean (recorded temperature data of Hansen and Lebedeff, 1987; 1988).

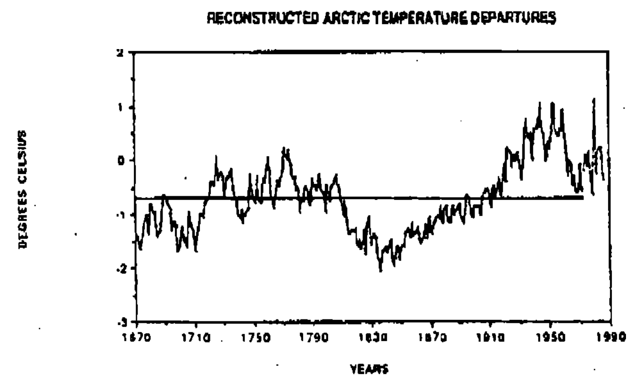

Fig. 2. Arctic (Zone 1) annual temperature reconstruction (solid line) for 1671–1973 based on tree-ring data. Temperature data as in Figure 1.

TABLE I: Tree-ring chronology data for sites shown in Figure 3.

Site	Location	Years	Species
412	Alaska	1515–1977	*Picea glauca*
Arrigetch	Alaska	1586–1975	*Picea glauca*
Sheenjek	Alaska	1580–1979	*Picea glauca*
TTHH	Yukon	1459–1975	*Picea glauca*
Mack. Mt.	N.W. Terr.	1626–1984	*Picea glauca*
Coppermine	N.W. Terr.	1428–1977	*Picea glauca*
Hornby	N.W. Terr.	1491–1984	*Picea glauca*
Churchill	Manitoba	1650–1978	*Picea glauca*
Cape	Quebec	1663–1982	*Picea glauca*
Fort Chimo	Quebec	1641–1974	*Larix laricina*
Gaspe	Quebec	1404–1982	*Thuja occidentalis*

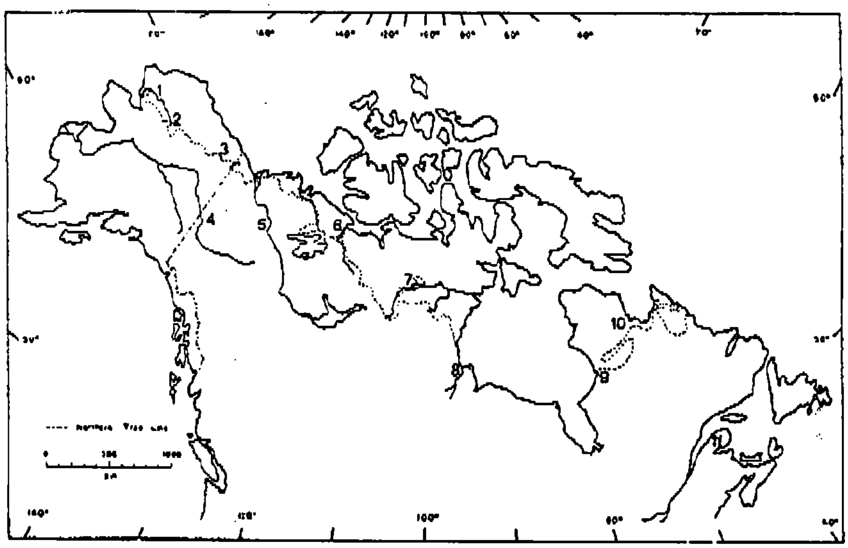

Fig. 3. Map of North American boreal forest treeline. Numbered sites are locations of eleven tree-ring chronologies used in this study and described in Table I.

integrate annual temperature effects as well as the evergreens. The raw ring-width data for the Fort Chimo site were kindly furnished to us by H. C. Fritts and were standardized into a chronology at our laboratory. The time period of comparison ends in 1973 because the Fort Chimo tree-ring data end in 1974 and the modeling used one year past the actual years estimated (explained below). The chronologies used were judged to be the most representative sample available of temperature-sensitive, high latitude chronologies recently collected from sites in North America. Selection criteria include strong common ring-width variation for both low and high frequency for a site and the physiographic site characteristics. There can be some moisture stress on tree growth at high latitudes (Jacoby and Cook, 1981). Sites and trees used in this study were deliberately selected from locations where moisture stress is a minimal factor. There are well over one hundred high latitude tree-ring chronologies from various species and sources (Jacoby, 1982; Cropper and Fritts, 1981). Many of them end in the 1950's and 60's and others have been standardized using methods, such as polynomial or cubic spline, that can remove low-frequency variance. Even in recently-collected tree-ring samples there can be natural site disturbances or stand dynamics that interfere with the formation of common low-frequency variance among the trees sampled. Also, among the sites we have collected in the boreal forests, only trees growing on sites with good exposure to the south and hence low-angle sun have strong, common low-frequency variance. In order to preserve the low-frequency variation we only used very conservative standardization methods. Negative-exponential (to account for juvenile growth trends) (Fritts, *et al.*, 1969), straight line or, in a few cases, a very rigid spline (400 yr) (Cook and Peters, 1981) were the only curve fits used in standardization (Cook, 1985). The standardization process converts ring-width measurements to dimensionless ratios of relative tree growth. Thus, the averaging to produce a mean-value time series or chronology for a site is not biased by faster growing trees (Cook, 1985). The ARSTND standardization process separates the variance of the tree-ring time series into two component data sets; 'white noise' and 'red noise' (Cook, 1985). The white noise has the persistence removed and the red noise contains the autoregressive persistence that contains much of the low-frequency variance of the tree-ring data. Principal components analysis is done on the two component data sets. The eleven chronologies were selected as those with the best common variance in the red-noise analyses. All sites had trees with good common variance in the white noise analyses. Of the 36 northern boreal forest tree-ring sites we have sampled within the last decade, ten are thus judged to provide the best record in time and space of temperature-influenced tree growth for this region of North America. The one chronology from a lower latitude on the Gaspe Peninsula has similarly good common low-frequency variance and is included due to the scarcity of other data in the eastern region.

For this reconstruction, we utilized annual temperature data from Hansen and Lebedeff (1987). This data set was selected in part because it is primarily derived from continental and island stations, which our tree-ring data should reflect better than compilations including both ocean and land data sets (Jones *et al.*, 1986b). According to Hansen and Lebedeff (1987), the station data used in their compilation are combined in such a way as to provide accurate long-term trends, and to fully utilize stations with incomplete data coverage. They conclude that the features of their temperature data sets are real and not artifacts due to poor spatial coverage (Hansen and Lebedeff, 1987).

Principal components analysis (PCA) was performed on the eleven chronologies for the period 1881–1974. The first three eigenvectors (explaining 70.3% of the total variance (44.8, 15.7, and 9.8%, respectively) were tested as predictors of the Northern Hemisphere and Arctic annual-temperature departure time series. The criterion used for selection of the principal components to be retained was for those eigenvalues exceeding unity (Stockton, 1971; Cook and Jacoby, 1977). Table II shows the loadings of the chronologies for the first and second eigenvectors (those eventually included in our analyses – see below). The climatic region from western Alaska to eastern Canada is not homogeneous. Key or pointer years are not the same throughout the region. Thus the PCA process itself dampens out some high-frequency variations. Common variance among all the chronologies reflects cooler or warmer periods which endure long enough to influence growth across the entire region.

The tree-ring and temperature data were not prewhitened in these analyses. This is a departure from some recommended procedures used in other studies, in particular dendroclimatic reconstructions in the semi-arid American south-

TABLE II: First and second eigenvector loadings based on principal components analysis for eleven chronologies.

Site	1st E.V.	2nd E.V.
412	0.2780	0.4123
Arrigetch	0.3798	−0.1581
Sheenjek	0.2999	0.0944
TTHH	0.3848	0.2571
Mack. Mt.	0.3816	−0.0087
Coppermine	0.3551	−0.0303
Hornby	0.0666	0.5891
Churchill	0.1993	−0.2986
Cape	0.2526	−0.4807
Fort Chimo	0.2028	0.1739
Gaspe	0.3459	−0.1773

west (Meko, 1981). There is an obvious trend in the temperature data towards generally higher values over the time period from about 1880 to present (Hansen and Lebedeff, 1987; Jones *et al.*, 1986a). There are equally obvious trends toward increased growth (wider annual rings) in the high-latitude trees. In all locations visited by the authors, (including the sites shown in Figure 3) seedlings have been found as well as other tree growth and distribution evidence that conditions for tree growth and survival are improving in the northern boreal forest and forest-tundra ecotone of North America. These simultaneous trends represent real cause (increased temperature) and effect (wider tree-rings) relationships that should not be expunged from transfer functions attempting to reconstruct temperature. Prewhitening of the data would do so. Similarities between the trends in our reconstruction and those evident in other large-scale proxy temperature records (see next section) further validate this approach.

Because tree growth can be influenced by previous year's temperature it is appropriate to use growth for the next year ($t+1$) to estimate temperature in the current year (t) (Fritts, 1976; Briffa *et al.*, 1986). Additionally, different regions may lead or lag hemispheric mean temperature shifts. The eigenvector amplitudes were therefore lagged to allow years $t-1$, t and $t+1$ to be used as potential predictors. Such leading and lagging of predictors enhances the low-frequency variance modeled but may tend to smooth out year-to-year variance because individual leads or lags with hemispheric changes may not be constant. Thus nine candidate predictors were screened to estimate both Northern Hemisphere and Arctic annual temperature in regression analyses. Only eigenvector amplitudes 1 and 2 proved to be stable predictors of the temperature data (Table II). Statistical results of all our regression modeling are shown in Table III.

The Northern Hemisphere regression model used the period 1880–1973 to model the temperature. Although there are temperature data compiled from

TABLE III: Calibration-verification statistics for temperature reconstruction models based on temperature data from Hansen and Lebedeff (1987). Columns are: a = multiple correlation coefficient, b = variance explained, $c = R^2$ adjusted for loss of degrees of freedom, d = reduction of error statistic, e = Spearman coefficient (** and *** = statistically significant at the 0.05 and 0.01 levels, respectively), and f = variables entered into regression: i.e. vars. 1–3 = 1st eigenvector at $t-1$(1), t(2), and $t+1$(3); vars. 4–5 = 2nd eigenvector at $t-1$(4), and t(5). See text for description of these statistics.

Temp. model	Calibr.	Verif.	r a	R^2 b	aR^2 c	RE d	S e	Var. f
NH	1880–1973	–	0.78	0.61	0.59	-	-	1–4
	1880–1940	1941–1973	0.80	0.63	0.61	0.56	0.34**	
	1941–1973	1880–1940	0.48	0.23	0.12	0.20	0.61***	
Arctic	1880–1973	–	0.78	0.61	0.60	–	–	2, 3, 5
	1880–1940	1941–1973	0.81	0.66	0.64	0.28	0.54***	
	1941–1973	1880–1940	0.68	0.46	0.41	0.39	0.67***	

1851 to 1880 (Bradley *et al.*, 1984) these earlier data are of much more limited coverage than the 1880-present data and thus are not representative of the Northern Hemisphere. Using only four predictors (i.e. the first eigenvector for years $t-1$, t and $t+1$; the second eigenvector at year $t-1$), the variance explained was slightly over 59% after adjustment for loss of degrees of freedom due to the regression (Neter and Wasserman, 1974). Actual and estimated annual Northern Hemisphere temperature departures from the 1951–1980 mean (Hansen and Lebedeff, 1987) are shown in Figure 4 for the 1880–1973 calibration period. The reconstruction shown in Figure 1 is based on this 1880–1973 regression equation.

Calibration and verification tests were next performed for the 1880 to 1973 time period. Results are shown in Table III. Only those predictor variables entered into the regression for the full calibration period (1880–1973; Table III)

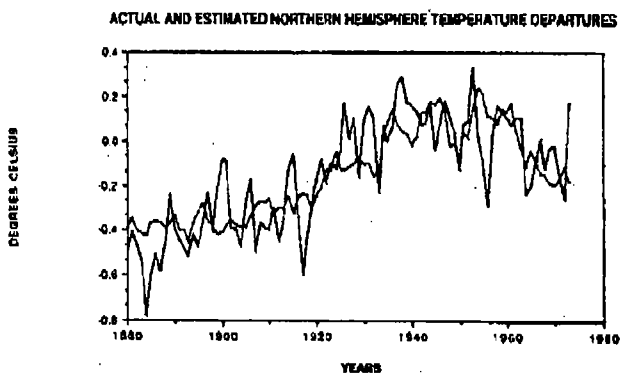

Fig. 4. Actual (solid line) and estimated (dashed line) Northern Hemisphere annual temperature for 1880–1973.

were included as possible predictors in the calibration-verification tests. When the transfer function for 1880–1940 was used for calibration, the adjusted variance explained was 61%. For the 1941–1973 verification period the reduction of error (RE) was 0.56. The reduction of error is a rigorous method of testing significance (Gordon and LeDuc, 1981). Any value above zero indicates significant predictive skill. The Spearman correlation coefficient also verifies for this time period (0.34) at the 0.05 level. When the calibration and verification periods were reversed, the variance explained for the calibration period 1941–1973 was only 12%, however a positive RE (0.20) and significant Spearman coefficient (0.61, significant at the 0.01 level) were again obtained, indicating the time-stable nature of the model used in this reconstruction. When any factor limiting tree growth (e.g. temperature or moisture) increases, the stress is reduced and other factors may become more influential (Fritts, 1976; Cook and Jacoby, 1977). It appears that models based on colder portions of the records are better predictors of temperature in a warmer period and models based on the warmer periods are poorer predictors. Another reason for the poorer model in the 1941–73 calibration appears to be the trees' lack of response to the high-frequency peak and drop in temperature in the 1950's.

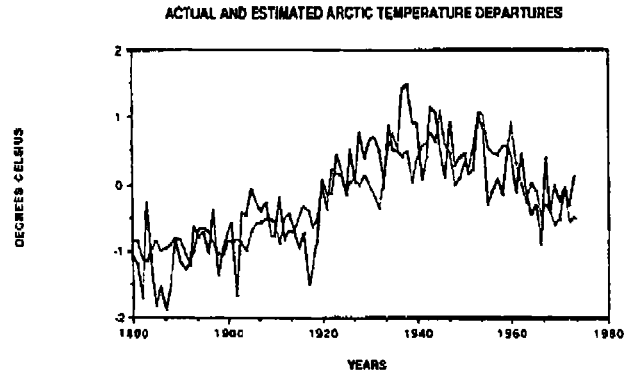

Fig. 5. Actual (solid line) and estimated (dashed line) Arctic (Zone 1) annual temperature for 1880–1973.

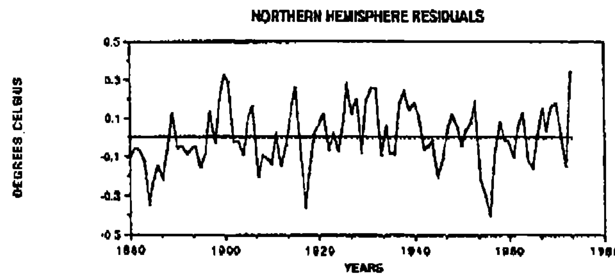

Fig. 6. Residual estimates from Northern Hemisphere 1880–1973 calibration model. Note the random nature of the residual distribution.

Arctic temperature shows a broader (2-year) peak and cooler period in the 1950's (see Figure 5). Analysis of the residual values obtained from the model estimates did not indicate the presence of any unusual trends in the data (Figure 6).

Regression modeling was also performed using annual Arctic (Zone 1 – Hansen and Lebedeff, 1987) temperature departures averaged for 64–90 degrees N. latitude (Figure 2). The statistical results were comparable to (or improved over) those obtained using Northern Hemisphere temperatures (Table III). The differences in the tree-ring variables (leads and lags) selected in the regression models for the Arctic as compared to those for the Northern Hemisphere may reflect the tendency for temperature changes from high northern latitudes to lead those for the hemisphere as a whole (Kelly *et al.*, 1982). Actual and estimated Arctic temperature departures for the period 1880 to 1973 are shown in Figure 5.

Since neither the temperature nor the tree-ring data were prewhitened prior to PCA and regression modeling, the low-frequency variance and autoregressive properties of the two sets of time series, tree-rings and temperatures, do not conform to the theoretical assumptions of standard statistical tests for significance of regression results. Therefore in addition to the standard test results we also tested for the probability of producing the regression results by chance alone. Monte Carlo techniques were used to produce random-number time series with the same autoregressive properties as the 'real' tree-ring reconstructed temperature data. Regressions were then performed with the same number of variables, leads and lags (based on the first and second eigenvectors) as the actual regressions to estimate temperatures. 500 simulation runs were made of each regression. The results indicate less than a 5% chance of producing the actual regression R^2 results in 5 of the 6 regressions shown in Table III. The chance for producing joint occurrences of the 'significant' random R^2's and verifications for the 4 calibration-verification results is much less.

In order to demonstrate the validity of utilizing data from the boreal region of North America as being representative of the Northern Hemisphere, averaged annual temperature data from Boxes 6 and 7 of Hansen and Lebedeff (1987; their Figure 2), which encompass most of the area of our tree-ring sites, were compared to the Northern Hemisphere temperature data set. Using the 1880 to 1935 period for calibration and the period 1936 to 1973 for verification the adjusted R^2, *RE* statistic and Spearman coefficient were 0.55, 0.68, and 0.72 (0.01 level), respectively. When the calibration and verification periods were reversed, the adjusted R^2 was 0.55, the *RE* was 0.52, and the Spearman was 0.73 (0.01 level). These results indicate that the region is large enough to be indicative of hemispheric trends. An additional comparison was made between seasonalized temperatures for averaged Box 6 and 7 (Hansen and Lebedeff, 1987) and our reconstruction for the same time interval. The correlation relationships between the reconstructed temperatures and the seasonalized temperature observations (i.e. DJF, MAM, JJA, SON) were all statistically significant at or near the 0.01 level. This result demonstrates that tree growth from treeline sites in Canada and Alaska can be responsive to temperature variations during the entire year at the regional scale.

3. Northern Hemisphere Temperature Analyses

A variety of temperature series based on different data sources have been developed by past studies. Although derived from limited geographic regions, several of these records have been used to imply larger-scale temperature changes within the Northern Hemisphere. In this section we compare our NH reconstruction (see Figure 7a), based solely on high-latitude tree-ring data, with two other temperature reconstructions developed by: (1) Groveman and Landsberg (1979) (Figure 7b) for the NH and (2) Fritts and Lough (1985) (Figure

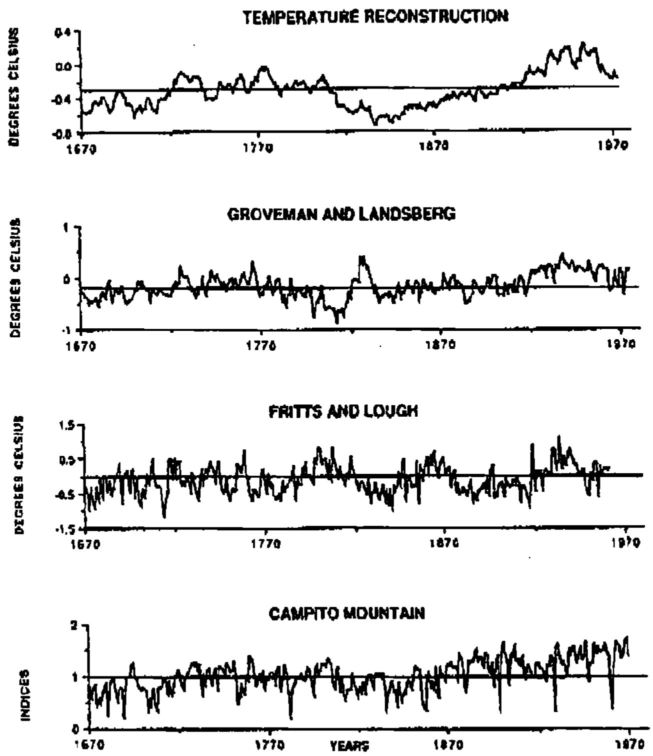

Fig. 7. Comparison of three large-scale temperature reconstructions and a high-elevation tree-ring record in the Northern Hemisphere. (a) Northern Hemisphere annual temperature reconstruction from present study; (b) reconstruction of Northern Hemisphere annual temperatures by Groveman and Landsberg (1979) based on a combination of instrumental and proxy data; (c) reconstruction of U.S. and SW Canada annual temperatures by Fritts and Lough (1985), based on tree-ring data; and (d) tree-ring record of high elevation bristlecone pine from Campito Mountain, California (LaMarche and Stockton, 1974).

7c) for the U.S. and southwestern Canada. We will also briefly compare features in our reconstruction with those found in other proxy time series which may be representative of large-scale temperature trends, including a tree-ring record derived from a high-altitude site (Campito Mountain) in California (Figure 7d; LaMarche and Stockton, 1974).

Using multiple-linear-regression analysis and a combination of instrumental and proxy data, Groveman and Landsberg (1979) compiled records from various middle to high-latitude locations in the Northern Hemisphere (including such diverse sources as tree-ring chronologies from Scandinavia and Alaska, first freeze data for Lake Suwa in Japan (Gray, 1974), and the Manley (1974) temperature series for central England) to extend the temperature series of Borzenkova *et al.* (1976) back to 1579. Although considered to be one of the more geographically extensive and better quality hemispheric-scale reconstructions available, the Groveman and Landsberg (1979) reconstruction has been criticized (Robock, 1979; Fritts and Lough, 1985) for its sparse data representation in the earlier years of the reconstruction. For example, only three variables were used in the regression equation from 1579 to 1658. Groveman and Landsberg (1979) acknowledged that the reliability of their series decreases towards the early part of the record. In addition, the mixing of many different data sources (developed using different methods of analysis and reference periods) without any attempt at standardization should also detract from the quality or homogeneity of the reconstruction. One of the main features of the Groveman and Landsberg (1979) reconstruction (Figure 7b) is that the entire earlier segment of the series (from 1579 to 1880) is for the most part colder (by 0.2 °C) than the more recent interval from 1881 to 1975. This is also the case in our reconstruction, although a pronounced period of relative warmth is evident in the 1700's (Figure 1, 7a). In the Groveman and Landsberg (1979) reconstruction, a major feature is a cold interval beginning in the 1760's, which culminates in a sharp temperature decrease from about 1800–1820. The regression equation used during this time interval incorporates data which are primarily from European sources. In our data set, this cooling does not begin until the early 1800's. Both series demonstrate a cold decade from 1810–1820 which has been well documented in a number of different temperature series (Dansgaard *et al.*, 1975; Lamb, 1977; Manley 1974) and includes the 'year without a summer' in 1816 (Landsberg and Albert, 1974). Following this decade, the temperature continues to decrease in our record but increases abruptly from 1826–1830 in the Groveman and Landsberg (1979) reconstruction. Although supported by some of their data, Landsberg (as noted in Robock, 1979) points out that this warming is probably not representative of the hemispheric average.

Fritts and Lough (1985) developed a time series of reconstructed annual surface temperatures (for the period 1602 to 1961) for the United States and southwestern Canada using a compilation of 65 tree-ring chronologies, mostly from semi-arid sites in the western U.S. (Figure 7c). They compared their data with five other temperature or proxy records in the Northern Hemisphere, including a tree-ring chronology from the Yukon Territory in the Canadian subarctic (Jacoby and Cook, 1981) which is included in our reconstruction.

Fritts and Lough (1985) observed that their reconstructed North American temperature averages (and their instrumental data) were correlated with average hemispheric temperatures during the warming period of the early 20th century, although this relationship breaks down after the mid-1940's. It has been noted that the early 20th century warming was more coherent spatially than the subsequent cooling (Jones and Kelly, 1983). Fritts and Lough (1985) state that this weakening in the relationship between tree growth and temperature may have been caused by a shift in the circulation pattern of the atmosphere in the early to mid 1950's. A similar weakening in temperature-tree growth relationships in the past few, relatively warmer, decades has been observed in some of our analyses, as noted before. A simple correlation ('r') of 0.62 was found between Jones *et al.* (1982) annual temperatures and their seasonally-averaged North American reconstruction for the period 1881–1960 (significant at the 0.01 level, allowing for first-order autocorrelation effects). For the 1901 to 1960 interval, significant correlations were found between their temperature series and several of the other independent data sets with regard to long-term trends. However, over the entire earlier period of available record (1602–1900) the data sets are in general not correlated, although correlations (positive or negative) were found for certain 30-year intervals. For example, their reconstruction appears to be out of phase with European temperatures during the late 18th and early 19th centuries. In comparison with the chronology from the Yukon Territory which was included in our reconstruction, agreement was found for 30-year periods at the midpoints 1803–30, 1849–63 and 1916–30. When their temperature series for North America is compared to our entire reconstruction, it is apparent that the long-term trends (including the recent warming of the past century) are more pronounced in our data. This is most likely a result of the amplification of climatic change at high latitudes. As in our reconstruction and the Groveman and Landsberg (1979) series, a marked cooling is seen in the Fritts and Lough (1985) reconstruction in the early to mid-1800's.

Fritts and Lough (1985) obtained their final reconstruction of annual temperatures for North America by first averaging their model results for each season, whereas in our study the annual temperature estimates were derived directly from the principal components. The opposing response of tree growth to temperature in summer and winter at semi-arid sites caused difficulty in calibrating the tree-ring data directly with annual temperatures and resulted in weakened correlations on an annual basis (Fritts and Lough, 1985). As these authors pointed out, the chronologies used in their data set were developed from trees which respond to both temperature and precipitation (i.e. lower altitude and middle latitude semi-arid sites), unlike those from either high-altitude (LaMarche, 1974) or high-latitude (our study) sites, which respond primarily to temperature. Tree growth at these latter sites should therefore be a better recorder of large-scale temperature fluctuations than that from sites which are also moisture-stressed. Not surprisingly, of the independent temperature series compared by Fritts and Lough (1985), our reconstruction appears to have the most in common with the high elevation tree-ring record from Campito Mountain in California (Figure 7d; LaMarche and Stockton, 1974).

Proxy records obtained from ice cores are another fundamental source of climatic data. The percentage-of-melting data set derived from the Devon Island Icecap (Paterson *et al.*, 1977) (to the north of the region of our tree-ring chronology sites in northern Canada and Alaska) is a more direct indicator of summer warmth than O_{18} values (Koerner, 1977; Williams and Wigley, 1983), which can be influenced by precipitation changes. Correspondence between the ice-melting data and northern degree-day reconstructions has been previously noted (Jacoby *et al.*, 1985). As in our present reconstruction, this percentage-of-melting record indicates a generally cold period from the late 1600's to early 1700's, a partial amelioration of this cold in the 1700's, a cooling in the early to middle 1800's and a general trend towards warmer conditions in the past century (Koerner, 1977). Good agreement was also noted between the Ft. Chimo tree-ring chronology in northeastern Canada (Figure 3, Table I) and the Devon Island percentage-of-melting curve for the late 17th to early 18th century time period (Williams and Wigley, 1983).

Analyses of proxy records of Northern Hemisphere temperature trends, as they become available, should also be compared with those available for the Southern Hemisphere to determine whether or not the trends are globally synchronous. For example, an O_{18} proxy temperature record from a southern tropical icecap in Quelccaya, Peru has recently been developed which extends back 1500 yr or more (Thompson *et al.*, 1986). A linear correlation was found between this record and the decadal Northern Hemisphere temperature departures reconstructed by Groveman and Landsberg (1979), with the best agreement since about 1770. A relatively cold interval from about 1500–1900 in the Quelccaya series is apparent evidence of the global nature of the Little Ice Age event (Thompson *et al.*, 1986).

Although certain temperature trends evident in proxy data are hemispheric to global in scale, they tend to vary considerably from region to region (Williams and Wigley, 1983). Comparison of available instrumental data for both hemispheres indicates that the warming trend of the past century is global in scale (Jones *et al.*, 1986b and c; Hansen and Lebedeff, 1987). However, the shorter period of cooling from 1938–1965 in the Northern Hemisphere is not evident in the Southern Hemisphere data (Jones *et al.*, 1986b) and may be confined to high northern latitudes (Hansen and Lebedeff, 1987; Ellsaesser *et al.*, 1986). One possible explanation for this cooling is a change in the rate of oceanic deep water formation (Jones *et al.*, 1987).

4. Discussion and Conclusions

The continued development of additional proxy records and improved temperature reconstructions from different regions is essential to an understanding of how the spatial and temporal climatic variations recorded in each series relate to conditions for the entire hemisphere and for the globe. Fritts and Lough (1985) expressed the opinion that the spatial coverage of available proxy temperature records was too limited to infer information about the hemisphere as a whole, particularly in eastern North America and central Canada. The limited spatial representation and temporal resolution of proxy temperature records for the Northern Hemisphere can therefore present difficulties when temperature information derived from a limited region is extrapolated to much larger areas (Jones and Kelly, 1983). During much of the period known as the Little Ice Age, for example, descriptions of temperature trends for the Northern Hemisphere are heavily biased towards European data sources, (Landsberg, 1975) and may not represent hemispheric-scale fluctuations. A comparison of proxy summer temperature data for the Little Ice Age and other climatic episodes over the past few thousand years indicates that the timing and magnitude of climatic changes, although showing agreement among proxy data within regions, can differ considerably from region to region (Williams and Wigley, 1983).

Barnett (1978) used EOF (empirical orthogonal function) analysis and annual mean temperatures for 1950–77 to examine patterns of variation in Northern Hemisphere temperature related to shifts in the long wave pattern of the atmosphere. The spatial and temporal variability of the temperature field due to such fluctuations is 'local' in scale (i.e. 1000–2000 km), emphasizing the need for a dense sampling network. Despite this relatively local source of variation, he concluded that past land-based temperature reconstructions can be accurate estimations, since temperature fluctuations over land are 2–6 times greater than over the oceans. Barnett (1978) cautioned, however, that fluctuations in ocean temperatures tend to be out of phase with those from land, which may present some difficulty for annual temperature determinations.

Since there is a high land:sea ratio at high northern latitudes, temperature estimates derived from such regions (Barnett, 1978), including our reconstruction, may be particularly useful as indicators of hemispheric-scale conditions. The tree-ring data represent fairly even coverage over 90 degrees of longitude across the North American continent. This range of geographical coverage is large enough to include more than one full wavelength of general circulation patterns for the Northern Hemisphere (Chang, 1972), and thus it is likely that this coverage is sufficient to provide information about hemispheric-scale climatic change. This was also demonstrated by successful modeling of hemispheric temperatures using only temperature data for the boreal region of North America (Hansen and Lebedeff, 1987) (see Data Methods and Results section). We realize, however, that proxy temperature data from high latitudes, such as our tree-ring data, may represent temperature fluctuations which are magnified as compared to the hemisphere as a whole. In addition, the tree-ring data coverage does not include such key climatically-sensitive regions as northwest Greenland and the Kara Sea, (Kelly, *et al.*, 1982) which may at times be out of phase with our reconstruction. Although we are aware of the spatial limitations of our reconstruction and the need to avoid overextrapolation based on limited data, we believe that the addition of this temperature series, when compared with other reconstructions, is a worthwhile contribution which will improve the perspective on hemispheric-scale temperature variations. Since much of the variance modeled appears to be low-frequency, we caution against overinterpretation of individual year variations.

In addition to the internal variability of the atmospheric, hydrospheric and cryospheric system, there are three main forcing functions which are believed to have had a determining influence on hemispheric to global scale temperature fluctuations over the past few centuries: volcanic activity, changes in incoming solar insolation, and atmospheric CO_2 levels. The demonstrated correspondence between volcanic activity and colder temperatures suggests the importance of volcanic activity as a forcing function for large-scale climatic change (Hansen *et al.*, 1978; Hammer *et al.*, 1981; Mitchell, 1975; Self *et al.*, 1981), although no direct cause and effect relationship has yet been demonstrated (Ellsaesser, 1986). The link between variations in solar activity and temperature changes is less certain. Such a relationship was inferred by Eddy (1976) to explain the correspondence between the Maunder Minimum in sunspot activity from 1645–1715 and the cold climatic conditions during this period of the Little Ice Age. A recently developed time series of total solar irradiance observations indicates a systematic decrease of about 0.1% in solar irradiance from 1979 to 1985 (Willson *et al.*, 1986). This decreasing trend, if part of the sunspot cycle, may provide evidence of a direct link between total solar flux and sunspot activity (Willson *et al.*, 1986). The greenhouse warming due to increasing atmospheric CO_2 levels is now rising above the level of natural variability (Hansen, 1988). Shifts in ocean circulation patterns, including ENSO events and changes in deep water production (Jones *et al.*, 1987), as well as the intrinsic variability of the climate system (Lorenz, 1976) must also be considered in attempting to explain climate variations in recent centuries.

Hansen *et al.* (1981) and Gilliland (1982), among others, have modeled Northern Hemispheric or global temperature variations for the past century based on the influence of these three forcing functions, finding a good approximation of hemispheric/global temperatures using different parameterizations and model specifications. However, the statistical significance of these results is unclear due to uncertainties in the forcing function records and model parameterizations, as well as in our understanding of the internal variability of the climate system.

Similar studies (Schneider and Mass, 1975; Robock, 1979, 1981; and Schonwiese, 1984) have modeled the influence of climatic forcing functions over longer time scales (i.e. up to 400 yr). Robock (1979), for example, compared his model results to Groveman and Landsberg's (1979) temperature reconstruction, and concluded that volcanic activity and random variations are the most important factors explaining temperature variations in the past 400 yr.

The effects of these three climatic forcing functions on Northern Hemisphere temperature variability may also be evident in our reconstruction. For example, lower temperature estimates in the earliest part of our reconstruction (from 1671 to the early 1700's) followed by a temperature increase appear to correspond to the latter part and terminations of the Maunder 'sunspot' Minimum (Eddy, 1976). A pronounced cooling in the early 1800's corresponds to the timing of the major volcanic eruption of Tambora in 1815 and Coseguina in 1835 (Hammer *et al.*, 1981). Lowered sunspot activity during this interval 1795–1825, if related to decreased irradiance (Willson, *et al.*, 1986), could have also contributed to the lower temperatures observed in these decades. Preliminary spectral analyses of our reconstruction data do not, however, indicate any significant periodicities which might reflect a correspondence to sunspot or other cycles. The low-frequency positive trend evident since the mid-1850's in our reconstruction corresponds to a similar trend in the recorded Northern Hemisphere temperature data (despite occasional downward inflections in both data sets), which may be a consequence of increasing atmospheric CO_2 levels. Much of the warming is actually a recovery to the long-term mean following the temperature minimum at the close of the Little Ice Age in the mid-1850's (Figure 1). This was also pointed out by Ellsaesser *et al.* (1986). Hansen and Lebedeff (1987), based on their estimate of temperatures back to 1760, contend that the period around 1880 was not unusually cold and that the subsequent temperature increase does not merely represent a return to previously warm temperatures. Our own reconstruction partially supports that contention as substantial recovery occurred between the 1840's to 1880's. Of particular interest regarding the warming trend over the last century is the apparent period of less cold temperatures in the 1700's before any supposed anthropogenic disturbance of climate. Warmer conditions shortly after 1700 are evident in other proxy data from England, China, Greenland, California, and New Zealand, indicating a partial and temporary amelioration of the Little Ice Age at this time (Lamb, 1982). In the eleven individual chronologies, the recent increase in growth over the period of increasing atmospheric CO_2 is more obvious and universal than the earlier (1700's) increase. Our Northern Hemisphere reconstruction through 1973 (Figure 1, with instrumental data added through to the present) thus supports the hypothesis that the current warming trend has exceeded the level of natural climate variability, at least over the past several hundred years. Trees growing at the boreal treeline, as we have discussed, are capable of integrating a number of thermally-related parameters, including changes in active-layer melting (root zone) and permafrost which may result from the effects of anthropogenic climatic change (Lachenbruch and Marshall, 1986). There is as yet (through 1973) no evidence for any direct effects of CO_2 fertilization on tree growth at these northern sites (LaMarche *et al.*, 1984) (Figure 6). This may be due in part to severe nutrient limitations in arctic ecosystems (Oechel and Riechers, 1986).

The comparison of our Northern Hemisphere temperature reconstruction with other large-scale temperature estimates, as they become available, will enable us to place the impacts of recent anthropogenic influences on climate in perspective with the effects of natural climatic variability and forcing functions.

Acknowledgements

We thank W. F. Ruddiman, M. A. Cane, W. S. Broecker, J. T. Overpeck and Paul R. Sheppard for helpful reviews and E. R. Cook for technical assistance. We also thank J. Hansen and S. Lebedeff for use of their temperature data. This research was supported by Grants ATM87-16630, ATM83-13789 and ATM85-15290 from the Climate Dynamics Program of the National Science Foundation. This paper is Lamont-Doherty Geological Observatory Contribution no. 4381.

References

Barnett, T. P.: 1978, 'Estimating Variability of Surface Air Temperature in the Northern Hemisphere', *Mon Wea. Rev.* **106**, 1353–67.

Borzenkova, I. I., Vinnikov, K. Ya., Spirina, L. P., and Stekhnovskii, D. I.: 1976, 'Change in the Air Temperature of the Northern Hemisphere for the Period 1881–1975', *Met. I. Gidr.* 7, 27–35.

Bradley, R. S., Kelly, P. M., Jones, P. D., Goodess, C., Diaz, H., Barry, R. G., and Moses, T.: 1984, 'Climate of the Northern Hemisphere 1851–1900 Compared to Contemporary Climate', Second Annual Report to the U.S. Dept. of Energy (DEACO_2-81-10739). University of Massachusetts, Amherst, Massachusetts.

Bradley, R. S. and England, J.: 1978, 'Recent Climatic Fluctuations of the Canadian High Arctic and their Significance for Glaciology', *Arctic and Alpine Res.* **10**, 715–31.

Briffa, K. R., Wigley, T. M. L., Jones, P. D., Pilcher, J. R., and Hughes, M. K.: 1986, 'The Reconstruction of Past Circulation Patterns over Europe using Tree-Ring Data', Final Report Commission of the European Communities, Contract No. CL 111.UK(H).

Bryson, R. A.: 1976, 'Perspective on Climatic Change', *Science* **184**, 753–60.

Chang, J. H.: 1972, *Atmospheric Circulation Systems and Climates*. Oriental Publ. Co., Honolulu, 326 pp.

Cook, E. R.: 1985, *A Time-Series Analysis Approach to Tree-Ring Standardization*, Ph.D. Thesis, University of Arizona, Tucson.

Cook, E. R. and Jacoby, G. C.: 1977, 'Tree-Ring Drought Relationships in the Hudson Valley, New York', *Science* **198**, 399–401.

Cook, E. R. and Peters, K.: 1981, 'The Smoothing Spline: a New Approach to Standardizing Forest Interior Ring-Width Series for Dendroclimatic Studies', *Tree Ring Bul.* **41**, 45–53.

Cropper, J. P.: 1982, 'Climate Reconstructions (1801 to 1938) inferred from Tree-Ring Width Chronologies of the North American Arctic', *Arctic and Alpine Res.* **14**, 223–41.

Cropper, J. P. and Fritts, H. C.: 1981, 'Tree-Ring Width Chronologies from the North American Arctic', *Arctic and Alpine Res.* **13**, 245–66.

Dansgaard, W., Johnsen, S. J., Rech, N., Gundestrup, N., Clausen, H. B., and Hammer, C. U.: 1975, 'Climatic Changes, Norsemen and Modern Man', *Nature* **255**, 24–8.

Eddy, J. A.: 1976, 'The Maunder Minimum', *Science* **192**, 1189–1202.

Ellsaesser, H. W.: 1986, 'Comments on: Surface Temperature Changes Following the Six Major Volcanic Episodes between 1780 and 1980', *J. Clim. and Appl. Met.* **25**, 1184–5.

Ellsaesser, H. W., MacCracken, M. C., Walton, J. J., and Grotch, S. L.: 1986, 'Global Climatic Trends as Revealed by the Recorded Data', *Rev. Geophys.* **24**, 745–92.

Fritts, H. C.: 1976, *Tree Rings and Climate*, Academic Press, New York.

Fritts, H. C. and Lough, J. M.: 1985, 'An Estimate of Average Annual Temperature Variations for North America, 1602–1961', *Clim. Change* **7**, 203–24.

Fritts, H. C., Mosimann, J. E., and Bottorff, C. P.: 1969, 'A Revised Computer Program for Standardizing Tree-Ring Series', *Tree Ring Bul.* **29**, 15–20.

Garfinkel, H. L. and Brubaker, L. B.: 1980, 'Modern Climate-Tree Growth Relationships and Climatic Reconstruction in Sub-Arctic Alaska' *Nature* **286**, 872–74.

Gilliland, R. L.: 1982, 'Solar, Volcanic and CO_2 Forcing of Recent Climatic Changes', *Climatic Change* **4**, 112–31.

Goody, R.: 1980, 'Polar Processes and World Climate', *Mon. Wea. Rev.* **108**, 1935–42.

Goldstein, G. H.: 1981, 'Ecophysiological and Demographic Studies of White Spruce (*Picea glauca* [Moench] Voss) at Treeline in the Central Brooks Range of Alaska', Ph.D. Thesis, University of Washington, Seattle.

Gordon, G. A. and LeDuc, S. K.: 1981, 'Verification Statistics for Regression Models' in *Proceedings of Conference on Probability and Statistics in Atmospheric Science*, November, 1981, Monterey, CA, 129–33.

Gray, B. M.: 1974, 'Early Japanese Winter Temperatures', *Weather* **29**, 103–7.

Groveman, B. S. and Landsberg, H. E.: 1979, 'Simulated Northern Hemisphere Temperature Departures 1579–1880', *Geophys. Res. Letters* **6**, 767–9.

Hammer, C. U., Clausen, H. B., and Dansgaard, W.: 1981, 'Past Volcanic and Climate Revealed by Greenland Ice Cores', *J. Volcanol. Geothermal Res.* **11**, 3–10.

Hansen, J. E.: 1988, 'The Greenhouse Effect: Impacts on Current Global Temperature and Regional Heat Waves', Statement presented to: U.S. Senate, Committee on Energy and Natural Resources, June 23, 1988.

Hansen, J., Fung, I., Lacis, A., Lebedeff, S., Rind, D., Ruedy, R., Russell, G., and Stone, P.: 1988, 'Global Climate Changes as Forecast by the GISS 3-D Model', *J. Geophys. Res.* **93**, 9341–9364.

Hansen, J. and Lebedeff, S.: 1987, 'Global Trends of Measured Surface Air Temperature', *J. Geophys. Res.* **92**, 13345–372.

Hansen, J. and Lebedeff, S.: 1988, 'Global Surface Air Temperatures: Update through 1987', *Geophys. Res. Letters* **15**, 323–6.

Hansen, J., Wang, W. C., and Lacis, A. A.: 1978, 'Mount Agung Eruption Provides Test of a Global Climatic Perturbation', *Science* **199**, 1065–68.

Hansen, J., Johnson, D., Lacis, A., Lebedeff, S., Lee, P., Rind, D., and Russell, G.: 1981, 'Climatic Impact of Increasing Atmospheric Carbon Dioxide', *Science* **213**, 957–67.

Hansen, J. and Takahashi, T.: 1984, *Climate Processes and Climate Sensitivity, Geophysical Monograph* **29**, Maurice Ewing Vol. 5, American Geophysical Union.

Hughes, M. K., Kelly, P. M., Pilcher, J. R., and LaMarche, V. C. Jr. (eds.): 1982, *Climate from Tree-Rings*, Cambridge University Press, Cambridge.

Jacoby, G. C. Jr.: 1982, 'The Arctic', in Hughes, M. K., Kelly, P. M., Pilcher, J. R., and LaMarche, V. C. Jr., (eds.), *Climate from Tree-Rings*, Cambridge University Press, Cambridge.

Jacoby, G. C. Jr. and Cook, E. R.: 1981, 'Past Temperature Variations Inferred from a 400-yr Tree-Ring Chronology from Yukon Territory, Canada', *Arctic and Alpine Res.* **13**, 409–18.

Jacoby, G. C. Jr. and Ulan, L. D.: 1982, 'Reconstruction of Past Ice Conditions in a Hudson Bay Estuary using Tree-Rings', *Nature* **298**, 637–9.

Jacoby, G. C. Jr., Cook, E. R., and Ulan, L. D.: 1985, 'Reconstructed Summer Degree Days in Central Alaska and Northwestern Canada since 1524', *Quat. Res.* **23**, 18–26.

Jones, P. D., Wigley, T. M. L., and Raper, S. C. B.: 1987, 'The Rapidity of CO_2-induced Climatic Change: Observations, Model Results and Paleoclimatic Implications', in Berger, W. H. and

Labeyrie, L. D., (eds.), *Abrupt Climatic Change: Evidence and Implications*, D. Reidel Publ. Co., Dordrecht, Holland.

Jones, P. D., Raper, S. C. B., Bradley, R. S., Diaz, H. F., Kelly, P. M., and Wigley, T. M. L.: 1986a, 'Northern Hemisphere Surface Air Temperature Variations, 1851–1984', *J. Clim. and Appl. Met.* **25**, 161–79.

Jones, P. D., Wigley, T. M. L., and Wright, P. B.: 1986b, 'Global Temperature Variations Between 1861 and 1984', *Nature* **322**, 430–434.

Jones, P. D., Raper, S. C. B., and Wigley, T. M. L.: 1986c, 'Southern Hemisphere Air Temperature Variations', 1851–1984', *J. Clim. and Appl. Met.* **25**, 1213–30.

Jones, P. D. and Kelly, P. M.: 1983, 'The Spatial and Temporal Characteristics of Northern Hemisphere Surface Air Temperature Variations', *J. of Climatology* **3**, 243–52.

Jones, P. D., Wigley, T. M. L., and Kelly, P. M.: 1982, 'Variations in Surface Air Temperature, I. Northern Hemisphere, 1881–1980', *Mon. Wea. Rev.* **110**, 59–70.

Kelly, P. M., Jones, P. D., Sear, C. B., Cherry, B. S. G., and Tavakol, R. K.: 1982, 'Variations in Surface Air Temperatures: Part 2, Arctic regions, 1881–1980', *Mon. Wea. Rev.* **110**, 71–83.

Koerner, R. M.: 1977, 'Devon Island Icecap: Core Stratigraphy and Paleoclimate', *Science* **196**, 15–18.

Kozlowski, T. T.: 1971, *Growth and Development of Trees, II. Cambial Growth, Root Growth, and Reproductive Growth*, Academic Press, New York.

Lachenbruch, A. H. and Marshall, B. V.: 1986, 'Changing Climate: Geothermal Evidence from Permafrost in the Alaskan Arctic', *Science* **234**, 689–96.

LaMarche, V. C. Jr.: 1974, 'Paleoclimatic Inferences from Long Tree-Ring Records', *Science* **183**, 1043–8.

LaMarche, V. C. Jr. and Stockton, C. W.: 1974, 'Chronologies from Temperature-Sensitive Bristlecone Pines at Upper Treeline in Western United States', *Tree Ring Bul.* **34**, 21–45.

LaMarche, V. C. Jr., Graybill, D. A., Fritts, H. C., and Rose, M. R.: 1984, 'Increasing Atmospheric Carbon Dioxide: Tree-Ring Evidence for Growth Enhancement in Natural Vegetation', *Science* **225**, 1019–21.

Lamb, H. H.: 1977, *Climate: Past, Present and Future. II. Climate History and the Future*, Methuen, London.

Lamb, H. H.: 1982, *Climate History and the Modern World*, Methuen, London.

Lamb, H. H. and Morth, H. T.: 1978, 'Arctic Ice, Atmospheric Circulation and World Climate', *Geogr. J.* **144** (Pt. 1), 1–22.

Landsberg, H. E.: 1975, 'Historic Weather Data and Early Meteorological Observations', pp. 27–70, in Hecht, A. D. (ed.) *Paleoclimatic Analysis and Modeling*, J. Wiley and Sons, N.Y.

Landsberg, H. E. and Albert, J. M.: 1974, 'The Summer of 1816 and Volcanism', *Weatherwise* **27**, 63–6.

Lorenz, E. N.: 1976, 'Nondeterministic Theories of Climatic Change', *Quat. Res.* **6**, 495–506.

Manabe, S. and Wetherald, R.: 1980, 'On the Distribution of Climate Change Resulting from an Increase in the CO_2 Content of the Atmosphere', *J. Atmos. Sci.* **37**, 99–118.

Manley, G.: 1974, 'Central England Temperatures: Monthly Means from 1659 to 1973', *Quat. J. Roy. Met. Soc.* **100**, 389–405.

Meko, D. M.: 1981, *Applications of Box-Jenkins Methods of Time Series Analysis to the Reconstruction of Drought from Tree-Rings*, Ph.D. Thesis, Univ. of Arizona, Tucson.

Mitchell, J. M. Jr.: 1975, 'Note on the Solar Variability and Volcanic Activity as Potential Sources of Climatic Variability', in *The Physical Basis of Climate and Climate Modelling*, Report of International Study Conference, 29 July–10 August 1974, Stockholm. GARP Publication Series No. 16, pp. 127–31.

Neter, J. and Wasserman, F.: 1974, *Applied Linear Statistical Models*, Richard D. Irwin, Inc., Homewood, Ill. 842 pp.

Oechel, W. C. and Riechers, G. W.: 1986, 'Impacts of Increasing CO_2 on Natural Vegetation, Particularly the Tundra', in C. Rosenzweig and R. Dickinson, (eds.), *Climate-Vegetation Interactions*, Proceedings of a Workshop held at Goddard Space Flight Center, Greenbelt, MD. NASA Conference Publ. No. 2440, pp. 174–7.

Paterson, W. S. B., Koerner, R. M., Fisher, D., Johnsen, S. J., Clausen, H. B., Dansgaard, W., Bucher, P., and Oeschger, H.: 1977, 'An Oxygen-Isotope Climatic Record from the Devon Island Icecap, Arctic Canada', *Nature* **266**, 508–11.

Robock, A.: 1979, 'The "Little Ice Age": Northern Hemisphere Average Observations and Model Calculations', *Science* **206**, 1402–4.

Schonwiese, C. D.: 1984, 'Northern Hemisphere Temperature Statistics and Forcing: 1579–1980 AD', *Arch. Met. Geoph. Biocl. Ser B35*, 155–178.

Schneider, S. H. and Mass, C.: 1975, 'Volcanic Dust, Sunspots and Temperature Trends', *Science* **190**, 741–6.

Self, S., Rampino, M. R., and Barbera, J. J.: 1981, 'The Possible Effects of Large 19th and 20th Century Volcanic Eruptions on Zonal and Hemispheric Surface Temperatures', *J. Volc. and Geoth. Res.* **11**, 41–60.

Stockton, C. W.: 1971, *The Feasibility of Augmenting Hydrologic Records Using Tree-Ring Data*, Ph.D. Thesis, University of Arizona, Tucson.

Thompson, L. G., Mosley-Thompson, E., Dansgaard, W., and Grootes, P. M.: 1986, 'The Little Ice Age as Recorded in the Stratigraphy of the Tropical Quelccaya Icecap', *Science* **234**, 361–4.

Tranquillini, W.: 1979, *Physiological Ecology of the Alpine Timberline*, Springer-Verlag, New York.

Van Loon, H. and Williams, J.: 1976, 'The Connection Between Trends of Mean Temperature and Circulation at the Surface: Pt. 1 Winter. Pt. 2 Summer', *Mon. Wea. Rev.* **104**, 365–80; 1003–11.

Washington, W. M. and Meehl, G. A.: 1984, 'Seasonal Cycle Experiment on the Climate Sensitivity due to a Doubling of CO_2 with an Atmospheric General Circulation Model Coupled to a Simple Mixed-Layer Ocean Model', *J. Geophys. Res.* **89**, 9475–503.

Williams, L. D. and Wigley, T. M. L.: 1983, 'A Comparison of Evidence for Late Holocene Summer Temperature Variations in the Northern Hemisphere', *Quat. Res.* **20**, 286–307.

Willson, R. C., Hudson, H. S., Frohlich, C., and Brusa, R. W.: 1986, 'Long-Term Downward Trend in Total Solar Irradiance', *Science* **234**, 1114–7.

(Received 19 August, 1987; in revised form 15 July, 1988)

toring of the transient tracer concentrations of GSDW will be valuable in studying the variability of deepwater formation in the Greenland Sea.

In our model calculations we assumed that the deepwater formation in the Greenland Sea operates in two modes (deepwater formation at full intensity before 1980 and slowed down deepwater formation during the 1980s). Such a simplistic view is certainly not correct. Instead, deepwater formation is a highly variable process in time and space. Whether formation of GSDW occurred continuously or sporadically in the period before 1980 cannot be derived from the tracer data because of a lack of time resolution. However, the observed tracer concentrations in GSDW between 1972 and 1979 clearly demonstrate that intensive deepwater renewal must have taken place between the appearance of the tritium bomb peak in the mid-1960s and the early 1970s. The observed tracer concentrations can be reconstructed by the model for the case of a constant deepwater renewal rate before 1980. The results demonstrate that on average formation of GSDW stopped almost completely during the 1980s. The model calculations have to be seen as a first-order approximation. Tracers are the only tool to monitor the average deepwater formation rate in the Greenland Sea on the basis of a station grid that can be realized in practical terms.

The model yields no information on the reason for the reduction of GSDW formation in the 1980s. Reduction could be connected to the appearance of the salinity anomaly observed in the northern Atlantic and the Greenland-Norwegian seas in the 1970s (*21*). This anomaly reached the Norwegian Current and Fram Strait in 1978 and the East Greenland Current between 1981 and 1982. This period coincides with the estimate of the start date of the cessation (1978 to 1982). A decrease in the salinity of the upper water column in the Greenland Sea can lead to the situation that the waters sinking from near-surface layers to deeper layers are, even after winter cooling, not sufficiently dense to reach the deep and bottom waters of the Greenland Sea. Such a scenario is also consistent with the observation that the temperature of GSDW increased during the 1980s (*3*). The deep and bottom waters would be affected first by a weakened convection. However, a further decrease of the salinity of the surface waters leading to even shallower convection depths would influence the formation of Arctic Intermediate Water. This water contributes significantly to the Denmark Strait overflow. In this way the properties of the newly formed North Atlantic Deep Water (NADW) can be changed. Another possible process for reduction of GSDW formation could be an increase in the influence of the East Greenland Current on the surface waters of the Greenland Sea leading to a freshening of the upper water column (*22*). To obtain a clear link between the processes in the European Polar seas and variability in NADW requires a long-term monitoring program at key positions north and south of the Scotland-Iceland-Greenland ridges.

REFERENCES AND NOTES

1. K. Aagaard, J. H. Swift, E. C. Carmack, *J. Geophys. Res.* 90, 4833 (1985).
2. J. H. Swift, K. Aagaard, S.-A. Malmberg, *Deep-Sea Res.* 27, 29 (1980).
3. R. A. Clarke, J. H. Swift, L. J. Reid, K. P. Koltermann, *ibid.* 37, 1385 (1990).
4. Greenland Sea Project Group, *Eos* 71, 750 (1990).
5. M. Rhein, *Deep-Sea Res.*, in press.
6. The tritium data were obtained on cruises of R.V. *Meteor* (Me42, 1976; Me52, 1979; Me61, 1982; Me71, 1985; Me8, 1988) and of R.V. *Knorr* (GEOSECS, 1972; TTO/NAS, 1982). The *Meteor* tritium samples were measured in the Heidelberg tritium laboratory and the data (except those from Me71 and Me8) are reported by Schlosser (*7*). The *Knorr* tritium data were produced in the Miami tritium laboratory and reported by Östlund and Brescher (*8*) and Östlund and Grall (*9*). The ^3He data were collected on cruises Me52, Me61, Me71, and Me8 and on the *Knorr* GEOSECS cruise. The *Meteor* samples were measured in the Heidelberg helium isotope laboratory and are partially reported by Schlosser (*7*) (Me42 and Me52). The GEOSECS ^3He data were measured at the Scripps Oceanographic Institution (*10*). The concentrations of CFCs were measured on cruises of R.V. *Hudson* (1982) and R.V. *Valdivia* (1989). The data are reported by Bullister and Weiss (*11,12*) and Rhein (*5*).
7. P. Schlosser, thesis (in German), University of Heidelberg, Heidelberg, Germany (1985).
8. H. G. Östlund and R. Brescher, *Tritium Lab. Data Rep. 12* (Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, 1982).
9. H. G. Östlund and C. Grall, *ibid.* 16, (1987).
10. GEOSECS Atlantic, Pacific, and Indian Ocean Expeditions, Shore-based data and graphics, vol. 7 (National Science Foundation, Washington, DC, 1987).
11. J. L. Bullister, thesis, University of California, San Diego (1984).
12. ——— and R. F. Weiss, *Science* 221, 265 (1983).
13. C. Heinze *et al.*, *Deep-Sea Res.* 37, 1425 (1990).
14. B. Rudels, *ibid.*, p. 1491.
15. T. J. McDougall, *ibid.* 30, 1109 (1983).
16. E. C. Carmack and K. Aagaard, *ibid.* 20, 687 (1973).
17. E. Dreisigacker and W. Roether, *Earth Planet Sci. Lett.* 38, 301 (1978).
18. W. M. Smethie, Jr., D. W. Chipman, J. H. Swift, K. P. Koltermann, *Deep-Sea Res.* 35, 347 (1988).
19. G. Bönisch and P. Schlosser, in preparation.
20. H. Craig, W. B. Clarke, M. A. Beg, *Earth Planet Sci. Lett.* 26, 125 (1975).
21. R. P. Dickson *et al.*, *Progr. Oceanogr.* 20, 103 (1988).
22. K. Aagaard and E. C. Carmack, *J. Geophys. Res.* 94, 14485 (1989).
23. K. Aagaard, *Deep-Sea Res.* 28, 251 (1981).

24. The officers and crews of the research vessels *Meteor*, *Knorr*, and *Valdivia* provided logistical support during sample collection. G. Fuchs, K. P. Koltermann, J. Meincke, A. Suckow, and W. Weiss collected part of the tracer samples. G. Bader and G. Zimmek performed most of the tritium and ^3He measurements. We profited from discussions with K. Aagaard, K. P. Koltermann, W. Smethie, J. Swift, and D. Wallace. This work was supported by the Deutsche Forschungsgemeinschaft and the Office of Naval Research through contract N00014-90-J-1362. L-DGO contribution no. 4749.

24 September 1990; accepted 18 December 1990

E
P
D
Th
de
sp
be
sp
Al
30
co
de
aci
D. I
mon
D. S
Univ
*Pre
Univ
tory,

Katy - this is the study that I mentioned to you - I actually don't have it here. It might be faster if you asked CRS to get it for you. Let me know if you can't track it down.

Stephanie

9/13/91

by stepping the telescope at the end of each right ascension scan. A 2.1-arc sec square aperture was used for mapping, but the step size was 1 arc sec in both directions to provide Nyquist sampling. Several successive scans of the planet were made and subsequently added together to improve the signal-to-noise ratio. The sky brightness and the different zero points of the 16 detectors were estimated from measurements of the sky in the corners of each image and subtracted from the images. To reduce the effects of scattered sunlight from the bright crescent, we subtracted an appropriately scaled out-of-band image, taken at a wavelength where the Venus night side produces little radiation.
14. The first model was identical to that described by Bell *et al.* (*5*). The δEddington/Adding algorithm was used to solve the equation of transfer in an absorbing, emitting, scattering atmosphere [D. Crisp, *Icarus* 67, 484 (1986)]. Monochromatic gas absorption coefficients were computed on a 0.01 cm^{-1} grid with a modified version of the line-by-line model described by D. Crisp [*J. Geophys. Res.* 95, 14577 (1990)]. The model atmosphere was divided into 50 vertical layers between the surface and 100 km.
15. The second model was developed by B. Dalton at NASA Ames Research Center. It is based on a two-stream source function solution to the equation of transfer [O. B. Toon, J. B. Pollack, C. Sagan, *Icarus* 30, 663 (1977); O. B. Toon, C. P. McKay, T. P. Ackerman, K. Santhanam, *J. Geophys. Res.* 94, 16287 (1989)] and uses monochromatic gas absorption coefficients from FASTCODE [S. A. Clough, F. X. Kneizys, L. S. Rothman, W. O. Gallery, *SPIE* 277, *Atmospheric Transmission*, 152 (1981)]. The spectral resolution was 0.1 cm^{-1}. The model atmosphere was divided into 22 vertical layers.
16. L. Rothman *et al.*, *Appl. Opt.* 26, 4085 (1987); N. Husson *et al.*, *Ann. Geophys.* 4, 185 (1986).
17. For CO_2, we adopted an approach similar to that described by Bezard *et al.* (*4*) and augmented the line parameters on the 1986 version of the HITRAN database with weaker transitions listed by L. S. Rothman [*Appl. Opt.* 25, 1795 (1986)]. The band parameters for H_2O and CO were taken directly from the HITRAN database. The spectral line parameters for the OCS $2\nu_3$ band at 2.45 μm were taken from L. R. Brown *et al.*, *ibid.* 26, 5154 (1987)]. In addition, we included collision-induced absorption by CO_2 by combining the absorption coefficients given by J. F. Moore [*Rep. X-630-72-48* (NASA Goddard Space Flight Center, Greenbelt, MD, 1971)] with a wavelength-independent component of 4×10^{-8} cm^{-1} $amagat^{-2}$. The latter source of continuum opacity was needed to produce an adequate fit to the shape of the spectrum at wavelengths between 2.15 and 2.3 μm, where CO_2 and the H_2CO_4 cloud particles are the only known sources of extinction. It has no known theoretical justification, but it may compensate for errors introduced by uncertainties in the shapes of the far wings of CO_2 lines or other factors.
18. The new database was constructed from solutions to the quantum mechanical equations based on the direct numerical diagonalization (DND) technique [R. B. Wattson and L. S. Rothman, *J. Mol. Spectrosc.* 119, 83 (1986)]. The DND method yields line positions that are accurate to a 0.01 cm^{-1} and line intensities with accuracies exceeding 10%.
19. A. Seiff, in *Venus*, D. M. Hunten, L. Colin, T. M. Donahue, V. I. Moroz, Eds. (Univ. of Arizona Press, Tucson, 1983), pp. 215–279.
20. D. Crisp, *Icarus* 67, 484 (1986). The main cloud deck consists of upper (57 to 70 km), middle (49 to 57 km), and lower (47 to 49 km) layers, each containing mixtures of H_2SO_4 droplets with the four distinct particle size populations described by R. G. Knollenberg and D. M. Hunten [*J. Geophys. Res.* 85, 8039 (1980)]: mode 1 (0.3 μm), mode 2 (1.0 μm), mode 2′ (1.4 μm), and mode 3 (3.6 μm). The numbers in parentheses give the modal particle radius. A Mie-scattering model (J. B. Pollack *et al.*, *ibid.*, p. 8141) was used to derive the wavelength-dependent optical properties of each particle mode from the optical constants of liquid H_2SO_4 [K. F. Palmer and D. Williams, *Appl. Opt.* 14, 208 (1975)]. Log-normal size distributions were used for all modes.
21. P. J. Connes *et al.*, *Astrophys. J.* 233, L29 (1979).
22. J.-P. Parisot and G. Moreels, *Icarus* 42, 46 (1980).
23. Y. L. Yung and W. B. Demore, *ibid.* 51, 199 (1982).
24. This work was funded in part by grants from the NASA Planetary Astronomy and Planetary Atmospheres Programs to the Jet Propulsion Laboratory, California Institute of Technology, and the NASA Ames Research Center. Much of the computer time was provided by the Wide-Field–Planetary Camera II Project at the Jet Propulsion Laboratory. We thank B. Dalton for developing and assisting in the use of the computer program for the second model (*15*) and for running some of the simulations presented here. We thank the AAT Time Allocation Committee for awarding the observing time for this program.

19 March 1991; accepted 21 June 1991

Climatic Change in Tasmania Inferred from a 1089-Year Tree-Ring Chronology of Huon Pine

EDWARD COOK, TREVOR BIRD, MIKE PETERSON, MIKE BARBETTI, BRENDAN BUCKLEY, ROSANNE D'ARRIGO, ROGER FRANCEY, PIETER TANS

A climatically sensitive huon pine tree-ring chronology from western Tasmania allows inferences about Austral summer temperature change since A.D. 900. Since 1965, huon pine growth has been unusually rapid for trees that are in many cases over 700 years old. This growth increase correlates well with recent anomalous warming in Tasmania on the basis of instrumental records and supports claims that a climatic change, perhaps influenced by greenhouse gases, is in progress. Although this temperature increase exceeds any that are inferred to have occurred during the past 1089 years at this location, it has not yet clearly emerged from the natural background variability of climate in this part of the Southern Hemisphere.

COMPARED TO THE INSTRUMENTAL and historical climate records of the Northern Hemisphere (*1*), the Southern Hemisphere has relatively few high-resolution climatic time series that extend back more than 100 years (*2*). Yet, to evaluate properly recent climatic trends and fluctuations, especially for changes that might be induced by radiatively active trace gases, much longer records are needed (*3*). To help fulfill this need, we developed a climatically sensitive tree-ring chronology from Tasmania that extends back to A.D. 900.

The tree-ring site is a disjunct, subalpine stand of huon pine (*Lagarostrobus franklinii* C. J. Quinn) located at 950-m elevation on Mount Read, a 1124-m-high massif located in western Tasmania (Fig. 1) that projects above the local timberline. In all, 56 radii from 23 trees were sampled and processed for tree-ring analysis with the use of established methods (*4, 5*). After cross-dating and measurement, the ring-width series were standardized (*6*) to remove long-term growth trends attributed to increasing tree size and maturation. This approach was taken in order to avoid removing any long-term climatic variance that was potentially distinguishable from purely biological growth trends. We then averaged the standardized tree-ring indices using a robust mean to discount the influence of outliers (*6*). The result was a mean site chronology that covered the interval A.D. 900 to 1988 (Fig. 2).

Both very poor and very rapid growth periods have occurred over the past 100 years in the huon pine chronology. Growth was poor from 1898 to about 1913; four of the nine poorest years of accumulated growing degree-days since 1870 in Canterbury, New Zealand (7), occurred during this period, and it overlaps with part of the coldest period (1900 to 1935) in recorded New Zealand history (*8*). It also coincides with the occurrence of a cold sea-surface temperature (SST) anomaly off the west coast of Tasmania (*9, 10*) that presumably contributed to reduced air temperatures over the island and reduced tree growth at other subalpine sites on the island (*11*). Growth has been unusually rapid since 1965 and parallels recent temperature increases in New Zealand (*8*), warm SSTs around Tasmania (*10*), and increased warming throughout much of the Southern Hemisphere (*12, 13*).

These apparent temperature changes were statistically modeled by comparing the huon

E. Cook, B. Buckley, R. D'Arrigo, Tree-Ring Laboratory, Lamont-Doherty Geological Observatory, Palisades, NY 10964.
T. Bird, Tasmanian Trades and Labour Council, Forestry Unit, New Town, Tasmania 7008, Australia.
M. Peterson, Tasmania Forestry Commission, Hobart, Tasmania 7001, Australia.
M. Barbetti, N. W. G. Macintosh Centre, University of Sydney, New South Wales 2006, Australia.
R. Francey, Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Atmospheric Research, Mordialloc, Victoria 3195, Australia.
P. Tans, Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, Boulder, Colorado 80309.

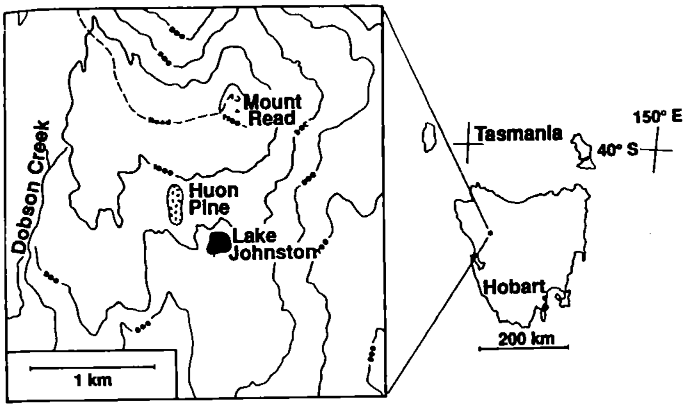

Fig. 1. Map of Tasmania and locations of Lake Johnston and the huon pine tree-ring site on Mount Read.

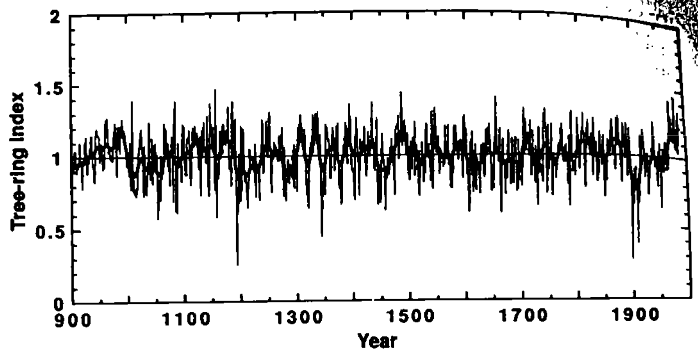

Fig. 2. The Lake Johnston huon pine tree-ring chronology. The time span is A.D. 900 to 1988, inclusive. The smoothed curve superimposed on the annual tree-ring indices emphasizes fluctuations of 20 or more years in duration.

pine chronology with long mean monthly temperature records from three Tasmanian meteorological stations: Hobart (1883 to 1989), Launceston (1885 to 1989), and Low Head Lighthouse (1895 to 1989). Only the 1895 to 1989 period common to all stations was used for analysis. Before 1895, the temperature data appear to be seriously inhomogeneous. We computed correlations between huon pine tree rings and Tasmania temperatures for the months of October to May, which include the current growing season, using the original tree-ring indices (Fig. 2), a prewhitened chronology of residuals obtained by modeling and removing autoregressive persistence (*14*) from the indices, and a chronology of first-differenced indices. The last two chronologies emphasize in different ways the high-frequency growth variations; they thus make the determination of statistical significance more robust. For comparison with the tree-ring residuals and first-differences, the monthly temperatures were similarly prewhitened and differenced. The common time period used to compute the correlations was 1896 to 1988, which provided 91 degrees of freedom for testing.

Positive correlations are seen for November through April that meet or exceed the 95% and, in most instances, the 99% confidence limits (Fig. 3). There is also relatively little difference among the patterns of the original, residual, and first-differenced correlations. This similarity indicates that autocorrelation has not seriously inflated the indicated temperature signal in the original chronology. This stability implies that current growing season temperatures and huon pine growth are causally linked.

Comparison of the best correlated November–April temperatures averaged into one season and the huon pine chronology indicate the degree to which the recent growth fluctuations have probably been caused by climate (Fig. 4). Each series was smoothed in order to emphasize decadal-scale fluctuations and longer term trends. The correlations between the unsmoothed temperatures and the original, prewhitened, and first-differenced tree-ring indices were 0.60, 0.51, and 0.49, respectively, a result highly consistent with the earlier monthly correlation analyses. In contrast, the correlation between the smoothed curves is 0.82, which is high enough to indicate that the low-frequency temperature signal in the tree rings is real. This result was validated with the use of cross-spectral analysis (*15*), which indicated that there is statistically significant ($\alpha < 0.05$) coherence at all periods greater than 12 years. Thus, changing warm season temperatures appear to be largely responsible for the observed huon pine growth fluctuations, especially the growth increase since 1965.

With its statistically modeled temperature signal, our huon pine chronology is one of the longest high-resolution paleoclimatic records from the Southern Hemisphere. Among its many uses, it allows the recent climatic warming in Tasmania to be placed in context with 1089 years of temperature change. From Fig. 2, it is apparent that the temperature increase since 1965 is anomalous compared to most earlier periods of comparable duration. Of the earlier periods that include some years of comparable warmth, the most notable were A.D. 940 to 1000, 1100 to 1190, and 1475 to 1495. Interestingly, the period from A.D. 1100 to 1190 was contemporaneous with the Medieval Warm Epoch (*16*), which has been considered to have been the warmest event since A.D. 1000 in the Northern Hemisphere. However, neither in that epoch nor in any other period has Tasmania been as consistently warm as it has been since 1965 on the basis of our tree-ring record. This finding lends credence to some claims that recent hemispheric and global temperature increases are being driven by the greenhouse effect. We do not consider our results as added proof of that assertion yet, because the recent warming still appears to be within the range of natural low-frequency variabil-

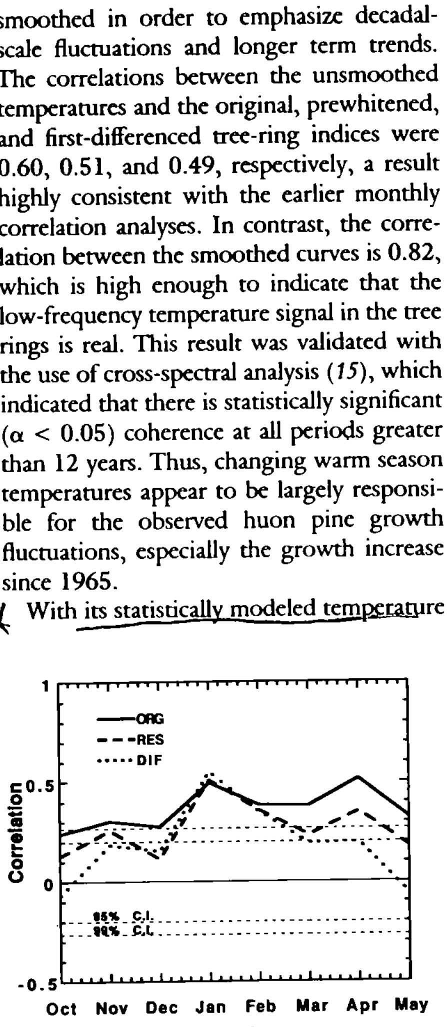

Fig. 3. Correlations of mean monthly temperatures in Tasmania with huon pine tree rings for 8 months that include the current growing season (November–April). The solid line is for the original (ORG) tree-ring indices, the dashed line is for the same index residuals (RES) after prewhitening to remove autoregressive persistence, and the dotted line is for the first-differenced (DIF) tree-ring indices. The two-tailed 95% and 99% confidence limits are only valid for the correlations based on the prewhitened and differenced data. Note the significant positive response to current growing season temperatures.

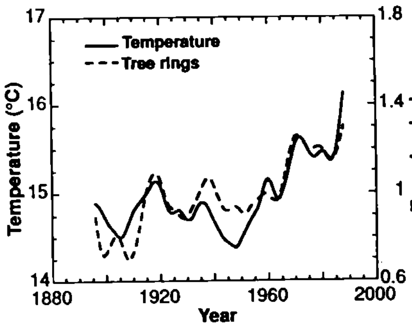

Fig. 4. Comparisons of November–April average temperatures for Tasmania with the original huon pine tree-ring indices. The data have been smoothed to emphasize decadal fluctuations and longer trends.

ity seen in the complete record.

The huon pine chronology also reveals numerous past episodes of persistently above- and below-average summer temperatures lasting ten or more years. Yet the coldest and warmest periods inferred from our tree-ring record apparently occurred within about 50 years of each other in the 20th century. This pattern of unusual cold followed by unusual warmth could strongly skew the evaluation of recent temperature trends in Southern Hemisphere instrumental records, which are relatively infrequent before 1900 (*13*). As this study shows, long, high-resolution paleotemperature records from the Southern Hemisphere can help in properly evaluating the current warming trend.

In many respects the cold event of the early 1900s is as interesting as the post-1965 warming in Tasmania. It is present in both land and marine instrumental temperature records covering much of the Southern Hemisphere (*7–10, 13, 17–19*). The temperature decline was apparently preceded by a circumpolar expansion of Antarctic pack ice and the irruption of numerous icebergs into normally ice-free low latitudes (*20*). Other manifestations of this anomaly were a decrease in scalar wind speed in the Tasmania–New Zealand sector (*17*) and circumpolar changes in middle latitude (40° to 50°S) sea-level pressure associated with oscillations in zonal flow with a wave number of zero (*21*). Thus, there appears to have been a significant reorganization of the Southern Hemisphere ocean-atmosphere system in the early 1900s. A similar event of lesser magnitude may have also occurred around A.D. 1190 on the basis of qualitatively similar changes in the huon pine record. Understanding the mechanisms responsible for these and other past climatic fluctuations could contribute greatly toward explaining the recent warming in the Southern Hemisphere.

REFERENCES AND NOTES

1. H. H. Lamb, *Climate: Past, Present, and Future* (Methuen, London, 1977), vol. 2.
2. R. G. Barry, in *Climatic Change and Variability*, A. B. Pittock, L. A. Frakes, D. Jenssen, J. A. Peterson, J. W. Zillman, Eds. (Cambridge Univ. Press, London, 1978), pp. 150–166.
3. R. A. Bryson, *Science* **184**, 753 (1974).
4. H. C. Fritts, *Tree Rings and Climate* (Academic Press, London, 1976).
5. J. R. Pilcher *et al.*, in *Methods of Dendrochronology*, E. R. Cook and L. A. Kairiukstis, Eds. (Kluwer, Dordrecht, 1989), pp. 40–50.
6. E. R. Cook *et al.*, in *ibid.*, pp. 104–123.
7. M. J. Salinger, *Clim. Change* **2**, 109 (1979).
8. _____ and J. M. Gunn, *Nature* **256**, 396 (1975).
9. C. K. Folland, D. E. Parker, F. E. Kates, *ibid.* **310**, 670 (1984).
10. M. Bottomley *et al.*, *Global Ocean Surface Temperature Atlas* (Meteorological Office, Bracknell, U.K., 1990).
11. J. Ogden, *Tree-Ring Bull.* **38**, 1 (1978).
12. G. Paltridge and S. Woodruff, *Mon. Weather Rev.* **109**, 2427 (1981).
13. P. D. Jones, S. C. B. Raper, T. M. L. Wigley, *J. Clim. Appl. Meteorol.* **25**, 1213 (1986).
14. G. E. P. Box and G. M. Jenkins, *Time Series Analysis: Forecasting and Control* (Holden-Day, San Francisco, 1976).
15. G. M. Jenkins and D. G. Watts, *Spectral Analysis and Its Applications* (Holden-Day, San Francisco, 1968).
16. H. H. Lamb, *Palaeogeogr., Paleoclimatol. Paleoecol.* **1**, 13 (1965).
17. J. O. Fletcher, U. Radok, R. Slutz, *J. Geophys. Res.* **87**, 4269 (1982).
18. A. H. Oort, Y. H. Pan, R. W. Reynolds, C. F. Ropelewski, *Clim. Dynam.* **2**, 29 (1987).
19. J. Hansen and S. Lebedeff, *J. Geophys. Res.* **92**, 13,345 (1987).
20. C. J. Burrows, *N. Z. Geogr.* **32**, 127 (1976).
21. H. Enomoto, *Clim. Change* **18**, 67 (1991).

22. We thank the Climate Center of Lamont-Doherty Geological Observatory, the National Science Foundation Division of Climate Dynamics (grant ATM 89-15353), the NOAA Climate and Global Change Program (grant NA 98AA-D-AC199), the CSIRO Division of Forestry and Forest Products, and the Tasmania Forestry Commission for research support; and W. S. Broecker, M. Cane, G. Jacoby, D. Peteet, and two anonymous reviewers for critical reviews. Lamont-Doherty Geological Observatory Contribution No. 4824.

18 April 1991; accepted 24 June 1991

Rel-Associated pp40: An Inhibitor of the Rel Family of Transcription Factors

NATHAN DAVIS,* SANKAR GHOSH,*† DANIEL L. SIMMONS, PAUL TEMPST, HSIOU-CHI LIOU, DAVID BALTIMORE, HENRY R. BOSE, JR.

The Rel-associated protein pp40 is functionally related to IκB, an inhibitor of the transcription factor NF-κB. Purified pp40 inhibits the DNA binding activity of the NF-κB protein complex (p50:p65 heterodimers), p50:c-Rel heteromers, and c-Rel homodimers. The sequence of the complementary DNA encoding pp40 revealed similarity to the gene encoding MAD-3, a protein with mammalian IκB-like activity. Protein sequencing of IκB purified from rabbit lung confirmed that *MAD-3* encodes a protein similar to IκB. The sequence similarity between MAD-3 and pp40 includes a casein kinase II and consensus tyrosine phosphorylation site, as well as five repeats of a sequence found in the human erythrocyte protein ankyrin. These results suggest that *rel*-related transcription factors, which are capable of cytosolic to nuclear translocation, may be held in the cytosol by interaction with related cytoplasmic anchor molecules.

THE PRODUCTS OF THE PROTO-ONCOGENE c-*rel* and the *rel* viral oncogene are members of a family of transcription factors that include the two subunits of transcription factor NF-κB (p50 and p65) and the *Dro-sophila* maternal morphogen *dorsal* (*1–4*). These proteins share sequence homology over 300 amino acids at their NH_2-terminus, a region that includes the DNA binding and dimerization domains. These proteins specifically bind to DNA sequences that are the same or slight variations of the 10-bp κB sequence in the immunoglobulin κ light chain enhancer. This κB binding sequence is present in a number of cellular and viral enhancers, and c-*rel* associates with these sites in the human immunodeficiency provirus (*5*).

Among the Rel-related proteins, NF-κB has been studied most extensively. NF-κB, a heterodimer of p50 and p65 subunits (*6*), is present ubiquitously in an inactive form in the cytosol, but is a constitutively active, nuclear protein in mature B cells (*7*). The DNA binding activity of NF-κB is activated and rapidly transported to the nucleus in cells exposed to mitogens or growth factors (*6–9*). The inactive cytosolic form is bound to IκB, which was initially characterized as a protein that specifically inhibits DNA binding by NF-κB (*8*). Purification of IκB from cell extracts reveals two forms, the major form of 35 to 37 kD (IκB-α) and a minor form of 40 to 45 kD (IκB-β) (*10, 11*). Treatment with the detergent deoxycholate (DOC) disrupts this NF-κB:IκB complex, releasing NF-κB, which then binds to DNA (*8*). Thus NF-κB may act as a second messenger, as the stimulatory signals initiated at the cell surface are transduced to the nucleus through the phosphorylation of IκB.

The products of c-*rel* and v-*rel* are found in the cytosol of avian lymphocytes associated with a distinct set of cellular proteins (pp40, p70, p115, and p124) (*12–16*). The molecular size of the 40-kD phosphoprotein (pp40) is close to that of IκB. In addition,

N. Davis and H. R. Bose, Jr., Department of Microbiology and Cell Research Institute, University of Texas at Austin, Austin, TX 78712.
S. Ghosh and H.-C. Liou, Whitehead Institute for Biomedical Research, Cambridge, MA 02142.
D. L. Simmons, Department of Chemistry, Brigham Young University, Provo, UT 84602.
P. Tempst, Memorial Sloan Kettering Cancer Center, New York, NY 10021.
D. Baltimore, Whitehead Institute for Biomedical Research, Cambridge, MA 02142, and Rockefeller University, New York, NY 10021.

*The first two authors contributed equally to this work.
†Present address: Section of Immunobiology, Yale University School of Medicine, New Haven, CT 06510.