Palaeobotanist 50 (2001) 13-19
0031-0174/2001/13-19 $2.00

An improved reconstruction of summer temperature at Srinagar, Kashmir since 1660 AD, based on tree-ring width and maximum latewood density of *Abies pindrow* [Royle] Spach.

MALCOLM K. HUGHES

Laboratory of Tree Ring Research, University of Arizona, Tucson, AZ 85721, USA.
Email : mhughes@ltrr.arizona.edu

(Received 27 September 2000; revised version accepted 10 December 2001)

ABSTRACT

Hughes MK 2001. An improved reconstruction of summer temperature at Srinagar, Kashmir since 1660 AD, based on tree-ring width and maximum latewood density of *Abies pindrow* [Royle] Spach. Palaeobotanist 50(1) : 13-19.

Regional chronologies based on conifer ring width and density variables were developed for the region surrounding the Vale of Kashmir. The effects of age/size trend on the raw data were removed by a more conservative technique than in previous work in this region, in the hope of retaining multidecadal climate variability. A reconstruction of split summer temperature (April through September, excluding July) at Srinagar captured 58% of the variance of the instrumental record (56% in validation). Decadal to multidecadal variability was distributed throughout the reconstructed period, but interannual variability was greater in the first century of the reconstruction than later. In particular, there was a higher concentration of the coolest summers before 1770 than after.

Key-words—Latewood, Tree ring, Reconstruction, Summer, *Abies pindrow*.

एबीज़ पिण्ड्रो स्पैक की वृक्ष वलयी चौड़ाई तथा अधिकतम पश्चदारु घनत्व के आधार पर विगत सन् 1660 ई. से आज तक के श्रीनगर (कश्मीर) के ग्रीष्मकालीन तापमान का परिवर्धित पुनर्सृजन

मैल्कॉम के. ह्यूगेस

सारांश

कश्मीर घाटी के आस-पास के क्षेत्र हेतु शंक्वाकार वलयी चौड़ाई तथा घनत्व प्रसरणों के आधार पर क्षेत्रीय कालानुक्रम विकसित किया गया। बहुदशकीय जलवायुविक प्रसरणों को संरक्षित करने के उद्देश्य से विगत अनुसन्धान कार्य के विपरीत इस बार एक अधिक पारम्परिक प्रविधि के माध्यम से अपरिपक्व आंकड़ों से आयु/आमाप रुझानों के प्रभावों को हटा दिया गया। श्रीनगर में विभक्त ग्रीष्म तापमान का पुनर्सृजन (जुलाई के अलावा अप्रैल से सितम्बर तक) कुल प्रभावी अभिलेखों (56% वैध) में से प्रसरण का 58% ग्रहण कर लेता है। सम्पूर्ण पुनर्सृजित अवधि के दौरान दशकीय से बहुदशकीय परिवर्तिता का वितरण किया गया, परन्तु अन्तिम शती की तुलना में प्रारंभिक शताब्दी में अन्तरवार्षिक परिवर्तिता अपेक्षाकृत अधिक थी। संक्षेप में, सन् 1770 ई. से पूर्व ठण्डी ग्रीष्म की तीव्रता बाद की तुलना में उच्चतर था।

संकेत शब्द—पश्चदारु, वृक्ष वलय, पुनर्सृजन, ग्रीष्म, *एबीज़ पिण्ड्रो*.

INTRODUCTION

THE western Himalayan region contains many potentially valuable natural archives of interannual to century-scale climate variability, notably the size, density and isotopic composition of the annual rings of trees growing in subalpine environments (Bhattacharyya *et al.*, 1988; Bhattacharyya & Yadav, 1989, 1996; Borgaonkar *et al.*, 1994, 1996; Hughes, 1992; Hughes & Davis, 1987; Pant, 1983; Ramesh, 1995; Ramesh *et al.*, 1985, 1986a, b; Yadav & Bhattacharyya, 1992; Yadav *et al.*, 1997, 1999). The ring width and maximum latewood density of subalpine conifers are particularly good archives of information on spring and summer temperatures, but they are limited in temporal and frequency range by the life-span of available trees. Here, the applicability of a summer temperature reconstruction for Srinagar, Kashmir, is extended to 1660 AD by the use of the longest available samples of Himalayan silver fir to create regional chronologies of maximum latewood density and total ring width for the mountains surrounding the Vale of Kashmir.

MATERIALS AND DATA USED

Tree-ring materials

The collection and development of the tree-ring materials used to develop this reconstruction was described by Hughes and Davies (1987) and Hughes (1992). Replicated, cross-dated chronologies of *Abies pindrow* were developed from a network of sites distributed in the mountains around the Vale of Kashmir (Fig. 1). All but two of the eight sites used were at elevations between 3100 and 3400 m a.s.l.. The lowest was at 2620 m a.s.l. with an East-Northeast aspect, and all but one of the sites had an aspect between East and North. All but one were on slopes greater than 40 degrees. The earliest dated ring at each site ranged from 1604 to 1777 AD. After crossdating and analysis using X-ray microdensitometry (Lenz *et al.*, 1976; Hughes & Davis, 1987; Hughes, 1992), site and regional chronologies were developed for maximum latewood density (MXD), minimum earlywood density (MND), earlywood width (EWW), latewood width (LWW) and total ring width (TRW). This was done by removing age/size trend from the series of measurements for each core by fitting a spline with a variance reduction function of 50% at two-thirds the length of the series, and taking the quotient of the actual and fitted value for each year as the index. Each series was then prewhitened using a conservatively fit time-series model. The detrended and prewhitened measurement series for the cores were then combined by averaging to produce the site and regional chronologies for four of the five variables. MND was not used because it showed weak correlation between trees at the same site.

Hughes (1992) chose to present reconstructions only as far back as 1780 AD based on the eight TRW and seven MXD series developed from individual site chronologies. These reconstructions are referred to here as being from the 15-series network. This limitation was necessary because the chronologies most strongly weighted in the climate calibrations were poorly replicated in their early decades. However, he also reported that there was a very strong common regional signal in three of the four variables, the percentage of variance accounted for by the first principal component of the network from 1891-1980 AD being: MXD 61%; EWW 29%; LWW 47%; TRW 45%. Fig. 2 gives a graphical representation of

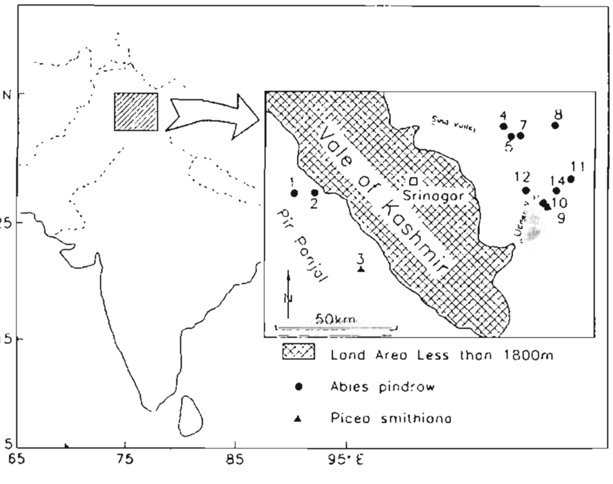

Fig. 1—The location of Srinagar, and of the tree-ring sites used in this paper. The three-letter site codes given in Fig. 2 correspond to numbers on this map thus: GUL-2; KHI-3; SAR-8; SON-7; WSO-4; CHA-11; THI-5; PAH-10. From Hughes (1992).

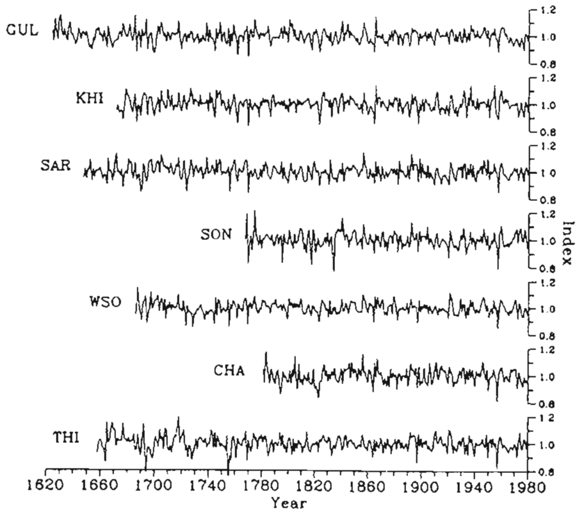

Fig. 2—Maximum latewood density chronologies for seven of the sites shown in Fig. 1. The vertical axes show dimensionless indices produced by standardizing the raw measurements to remove age/growth trend. See text for explanation.

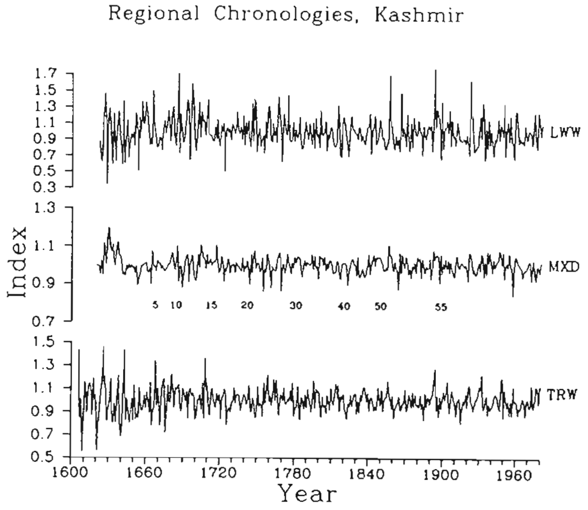

Fig. 3—Regional chronologies developed as described in the text. Each is based on a different tree-ring variable: LWW-latewood width; MXD-maximum latewood density; TRW-total ring width. The numbers over the MXD curve show the number of samples in the chronology at that year. The vertical axes show dimensionless indices produced by standardizing the raw measurements to remove age/growth trend. See text for explanation.

the strength of this regional signal in the case of MXD. This common signal results from a common pattern of climate response as revealed by response function analysis (see below). Therefore Hughes (1992) circumvented the problem of inadequate replication in the early years of site chronologies by calculating mean regional chronologies using the best materials from all the available sites (Fig. 3). The best materials were those with clear cross-dating, maximum length, and strong correlation with measurements from the other trees. All of the original raw data are available on-line at World Data Centre 'A' for Paleoclimatology, International Tree-Ring Data Bank.

Meteorological data

Monthly mean temperature and total precipitation data for Srinagar, Kashmir (34°05' N, 74°50' E, 1587 m a.s.l.) from 1893 AD on were obtained from World Weather Records. Although it is located in a high valley between two major mountain ranges, the summer temperature at Srinagar is well correlated with a region stretching from eastern Iran to the western Tibetan Plateau (Fig. 4).

IDENTIFICATION OF CLIMATE SIGNAL

Response functions

Response functions were calculated according to the procedures developed by Fritts *et al.*, 1971 and Fritts, 1976. The response function is based on an orthogonalized regression of monthly temperature and precipitation on the tree-ring chronology, and permits an examination of the influence of climate variables that may be correlated with one another. The meteorological data from the Srinagar station were used in these analyses. It is clear that MXD and LWW are more strongly correlated with temperature and precipitation than is TRW (Fig. 5). Both MXD and LWW show strong responses to temperature at the beginning (April-May) and end (August-September) of the growing season. This phenomenon has been observed in many other response functions for MXD (e.g., Briffa *et al.*, 1988, 1992; Conkey, 1986). In the case of several of the Kashmir sites, small but significant negative response function elements were found for July temperature in MXD and LWW.

Transfer functions

Hughes (1992) used the earlier version of the MXD regional chronology to reconstruct April-May temperature at Srinagar back to 1690 AD. This reconstruction had a calibration r^2 of 0·37 ($p<0{\cdot}0001$) for 1893-1942, and verification r^2 of 0·29 ($p<0{\cdot}01$) for 1943-1968, compared to 0·53 and 0·40 respectively for the reconstruction based on the 15-series network. As the version of the regional MXD chronology he used contained significant persistence, Hughes (1992) offered both current and next years' MXD chronologies as predictors, but the best model used only the current year values.

In the development of a transfer function using the new version of the regional chronologies, only current year MXD and TRW were offered as predictors, as they had been prewhitened. LWW was not used as it is highly correlated with MXD. As in the earlier work, the period 1893-1970 was used for calibration and verification. A marked decline in correlation between MXD and temperature was noted after 1970 (Hughes, 1992), suggesting a change in the relationship between the two. The mean temperature for a 'split summer' comprising April-September with July omitted was used as predictand. This was done because of the lack of response of the tree-ring variables in July, and because models including July temperature did not perform as well as those without July in terms of calibration and verification statistics. A 'jacknife' calibration-verification scheme was used (Fig. 6), with the periods 1893-1931 and 1931-1970 as complementary calibration and verification periods. Very strong statistics were found for both periods on all tests applied. In addition, the individual terms of the regression equations derived in the calibration stage (not shown) were similar for the two periods, indicating a temporally stable relationship between 1893 and 1970. Therefore, a new calibration was calculated for the whole period 1893-1970 (Fig. 6) with an adjusted r^2 of 0·58 ($F=53{\cdot}52$, $p<0{\cdot}0001$). A leave-one-out approach was used to calculate verification statistics for this calibration, giving an adjusted r^2 of 0·56, and the correct sign of first difference in 63 of the total of 77 years (ST in Fig. 6). The strong relationship between observed split summer temperature and that derived using the transfer function is illustrated in Fig. 7. The tree rings capture the major elements of multi-year to interdecadal variability as well as interannual variability.

THE RECONSTRUCTION

Given these strong diagnostic statistics, the new split summer transfer model was applied to the new versions of the regional MXD and TRW chronologies to produce the reconstruction shown in Fig. 8. This reconstruction may not be directly compared with the spring and late-summer temperature reconstructions reported by Hughes (1992), since they differ from one another as a result of their seasonality. Runs of summers of above-average warmth are reconstructed for the early 18th century, early 19th century, mid-19th century and mid-20th century. Sustained periods of cool summers are reconstructed for the mid-18th century, the early 19th century and from around 1950 to the end of the reconstruction in 1970. Most of the coolest individual summers are reconstructed for the first century of the reconstruction, while the warmest summers are more evenly distributed. It is very unlikely that this is an artefact of the structure of the chronology, as the series is well replicated back as least as far as 1700. A

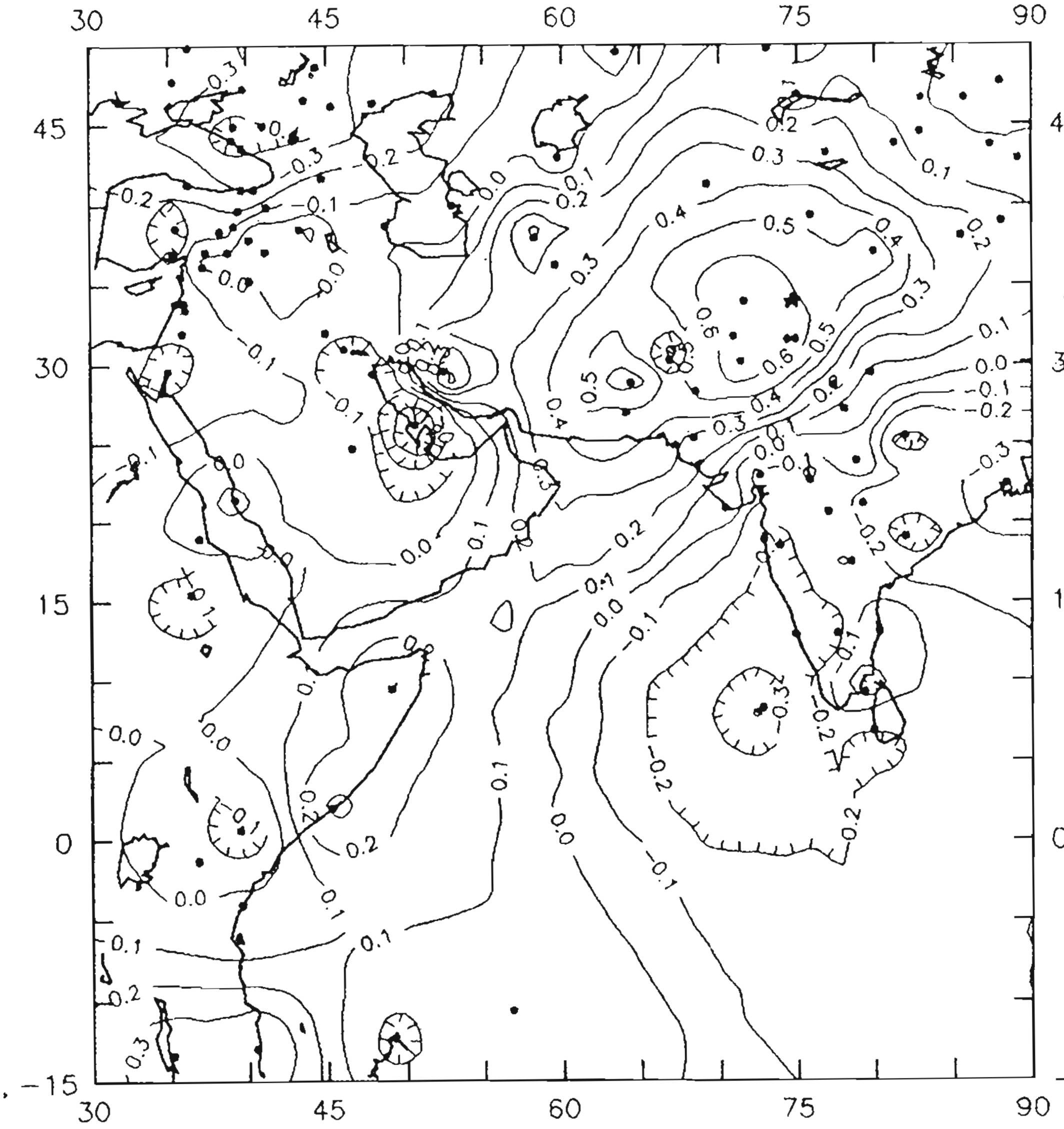

Fig. 4— Correlations between split summer (April-September without July) temperature at Srinagar (shown as a star) and stations throughout west Asia. Symbol sizes are proportional to correlation. Correlations were calculated for the period 1953-1972. All stations were screened for missing data and tested for homogeneity before being included in the data set prepared by G.M. Garfin.

reconstruction produced using only the 10 longest cores, and hence having little change in sample depth along its length, displayed this same feature. This rules out variation in sample depth as the cause of this feature. There is no consistent relationship between the timing of the coldest reconstructed summers and indices of explosive volcanic eruptions in the 24 months prior to the beginning of the growth season in April. This contrasts with work by, for example, Briffa *et al.* (1998a) and Hughes *et al.* (1999).

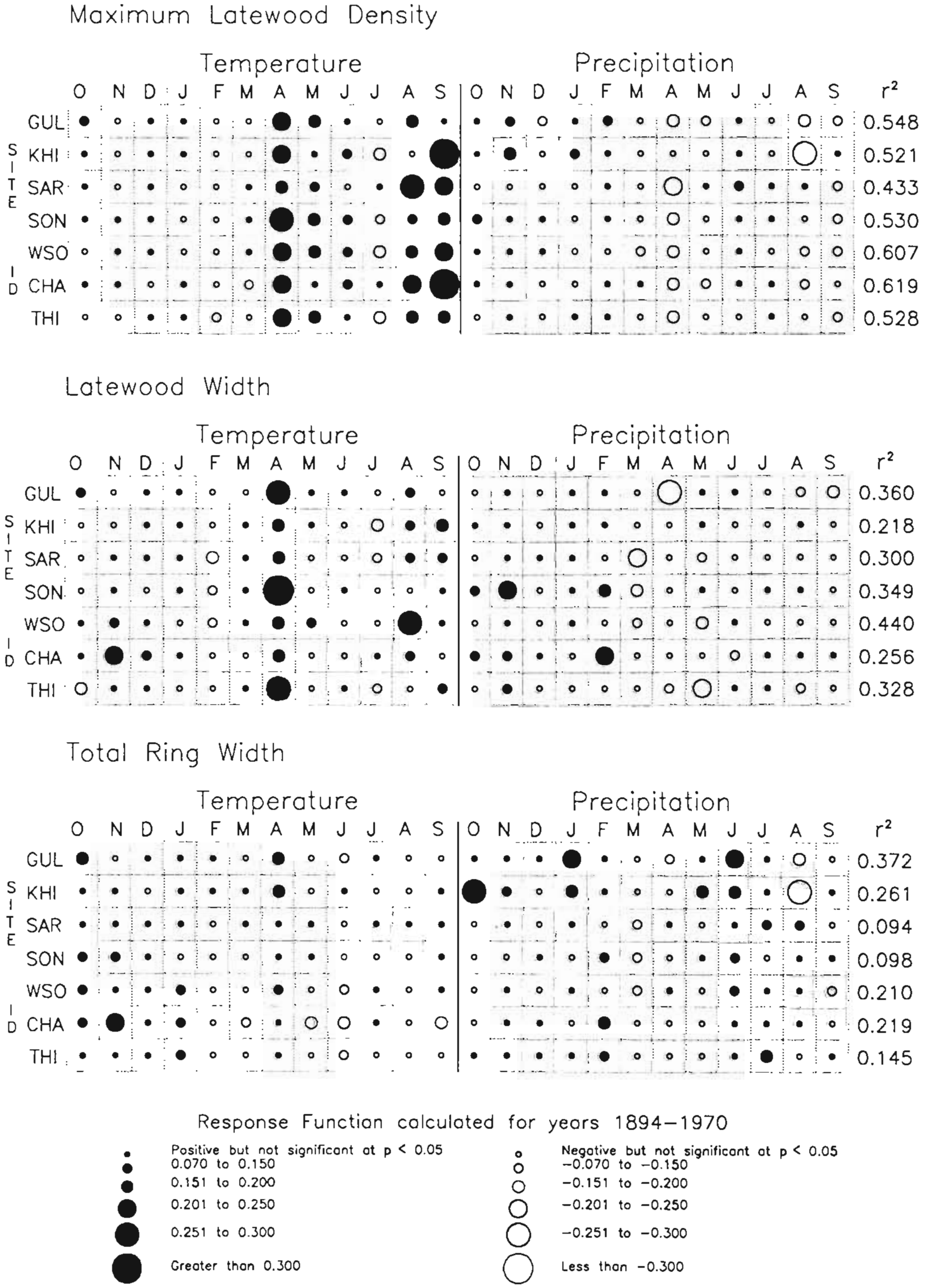

Fig. 5—Response function elements for Maximum latewood density (MXD) top panel; Latewood width (LWW) middle panel; Total ring width (TRW) lower panel.

Period	Calibration		Verification			
	r_a^2	F	r_a^2	ST	CE	RE
1893–1931	0.505	19.30***	0.516***	30/7***	0.343	0.478
1931–1970	0.647	34.44***	0.654***	29/7***	0.522	0.586
1893–1970	0.583	53.52***	0.560***	64/13***	–	–

*** p ≤ 0.0001 ST: Sign Test
** p ≤ 0.001 CE: Coefficient of Efficiency
* p ≤ 0.010 RE: Reduction of Error

Fig. 6—Split Summer Temperature.

DISCUSSION

Why should the correlations between MXD and LWW on the one hand and temperature on the other be strongest at the beginning and end of the growth season, but weak or even negative in July? The strength of correlation between MXD and early growth season temperatures is, at first sight, puzzling. Vaganov (1996), however, has pointed out the crucial role played in ring formation by conditions just after the initiation of cambial activity, including the predetermination of the size of latewood cells. This is also the time at which the size of the new needle mass is determined, which must influence the amount of photosynthate available for cell wall thickening at the end of the season. Similarly, it can be argued that a warm August-September will permit the production of excess photosynthate which could be available for increased thickening of latewood tracheid walls, leading to higher maximum latewood density. It is difficult to find a process of similar importance to the amount and density of latewood taking place in the middle of the season. It should also be borne in mind that, although the climate of the Vale of Kashmir is not strongly influenced by the summer monsoon, July is usually a time of major changes in circulation over this region, and July conditions are generally less strongly correlated with June and August than are other adjacent months in the year.

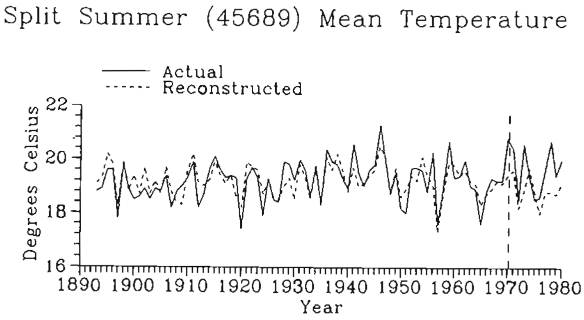

Fig. 7—Split summer temperature as observed at Srinagar (solid line) and as reconstructed in this paper (broken line).

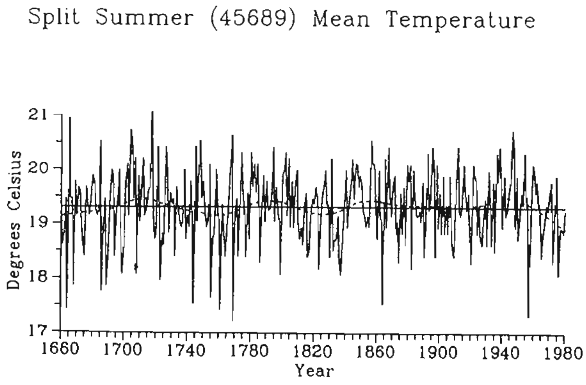

Fig. 8—Split summer temperature at Srinagar since 1660 AD, as reconstructed in this paper.

Since the first reconstructions for Kashmir based on TRW and MXD were published (Hughes, 1992), it has been reported that the relationship between many high-latitude MXD chronologies and temperature has weakened and changed, especially on decadal time scales, starting in the mid-20th century (Briffa *et al.*, 1998b). Is the weakened relationship seen in Kashmir since 1970 the result of the same phenomenon, or is there a problem with the instrumental data? This is an important topic for future research.

There are decadal-to-multidecadal features in the reconstruction, but no evidence of long-term trend. Given the shortness of many of the segments making up the chronologies used, this does not necessarily mean that such trends have not occurred. There is a tendency for a higher frequency of cool summers to be reconstructed before 1770 than after. There is no clear relationship between these cool summers and known explosive volcanic eruptions. There is evidence of large-scale spatial coherence between summer temperature in Kashmir and spring temperature several hundreds of kilometers to the southeast in Uttar Pradesh (Yadav *et al.*, 1997), at least on the decadal timescale. Examples of this include periods of cool conditions around 1750 and in the 1810s, and warmth in the 1850s.

Acknowledgements—*Special thanks are due to Shao Xuemei and G. Garfin for extensive help in the preparation of this manuscript. Fenbiao Ni helped with the preparation of graphs and maps. A.C. Davis conducted the densitometric work, and G.B. Pant, R. Ramesh, S.K. Bhattacharya and P. Mayes helped in the field collections. The field collection and original laboratory analyses were supported by the U.K. Natural Environment Research Council. Support for the reanalysis was provided by Award No. NA90AA-D-AC514 from the United States National Oceanographic and Atmospheric Administration. At the time of writing the author was in receipt of a Bullard Fellowship at Harvard University.*

REFERENCES

Bhattacharyya A, Telewski FW & LaMarche VC 1988. Dendrochronological reconnaissance of the conifers of North-West India. Tree-Ring Bulletin 48: 334-343.

Bhattacharyya A & Yadav RR 1989. Growth and climate relationship in *Cedrus deodara* from Joshimath, Uttar Pradesh. Palaeobotanist 38 : 411-414.

Bhattacharyya A & Yadav RR 1996. Dendrochronological reconnaissance of *Pinus wallichiana* to study glacial behavior in the Western Himalaya. Current Science 70 : 739-744.

Borgaonkar HP, Pant GB & Kumar KR 1994. Dendroclimatic reconstruction of summer precipitation at Srinagar, Kashmir, India, Since the Late-Eighteenth Century. The Holocene 4 : 299-306.

Borgaonkar HP, Pant GB & Kumar KR 1996. Ring-width variations in *Cedrus deodara* and its climatic response over the Western Himalaya. International Journal of Climatology 16 : 1409-1422.

Briffa KR, Jones PD & Schweingruber FH 1988. Summer temperature patterns over Europe: a reconstruction from 1750 A.D. based on Maximum Latewood Density indices of conifers. Quaternary Research 30 : 36-52.

Briffa KR, Jones PD & Schweingruber FH 1992. Tree-ring density reconstructions of summer temperature patterns across Western North America since 1600. Journal of Climate 5 : 735-754.

Briffa KR, Jones PD, Schweingruber FH & Osborn TJ 1998a. Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years. Nature 393 : 450-455.

Briffa KR, Schweingruber FH, Jones PD, Osborn TJ, Shiyatov SG & Vaganov EA 1998b. Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. Nature 391 : 678-682.

Conkey LE 1986. Red spruce tree-ring widths and densities in Eastern North America as indicators of past climate. Quaternary Research 26 : 232-243.

Fritts HC 1976. *Tree rings and climate*. London: Academic Press.

Fritts HC, Blasing TJ, Hayden BP & Kutzbach JE 1971. Multivariate techniques for specifying tree-growth and climate relationships and for Reconstructing Anomalies in Paleoclimate. Journal of Applied Meteorology 10 : 845-864.

Hughes MK 1992. Dendroclimatic evidence from the Western Himalaya. *In:* Bradley RS & Jones PD (Editors)—*Climate since 1500 A.D.* : 415-431. London: Routledge.

Hughes MK & Davis AC 1987. Dendroclimatology in Kashmir using tree ring widths and densities in subalpine conifers. *In:* Bednarz Z & Kairiukstis EFL (Editors)—*Methods in Dendrochronology: East-West approaches* : 163-176. IIASA/Polish Academy of Sciences.

Hughes MK, Vaganov EA, Shiyatov S, Touchan R & Funkhouser G 1999. Twentieth-Century summer warmth in Northern Yakutia in a 600-year context. The Holocene 9 : 629-634.

Lenz O, Schär E & Schweingruber FH 1976. Methodische probleme Bei Der Radiographisch-Densitometrischen Bestimmung Der Dichte Und Der Jahrringbreiten Von Holz. Holzforschung 30 . 114-123.

Pant G 1983. Climatological signals from the annual growth-rings of selected tree species of India. *Mausam* 34 : 251-256.

Pant GB & Borgaonkar HP 1984. Climate of the hill regions of Uttar Pradesh. Himalayan Research and Development 3 : 13-20.

Ramesh R 1995. Isotope-Dendroclimatological studies in India. *In:* Ohta S, Fujii T, Okada N, Hughes MK & Eckstein D (Editors)—*Tree rings from the past to the future* : 187-192. Tsukuba, Japan: Forestry and Forest Supply Research Institute.

Ramesh R, Bhattacharya SK & Gopalan K 1985. Dendroclimatological implications of isotope coherence in trees from Kashmir Valley. Nature 317 : 802-804.

Ramesh R, Bhattacharya SK & Gopalan K 1986a. Climatic correlations in the stable isotope records of Silver Fir (*Abies Pindrow*) trees from Kashmir, India. Earth and Planetary Science Letters 79 : 66-74.

Ramesh R, Bhattacharya SK & Gopalan K 1986b. Stable Isotope systematics in tree cellulose as palaeoenvironmental indicators- A review. Journal of the Geological Society of India 27 : 154-167.

Vaganov EA 1996. Analyses of seasonal tree-ring formation and modelling in dendrochronology. *In:* Dean JS, Meko DM & Swetnam TW (Editors)—*Tree rings, environment and Humanity* : 73-87. Tucson, AZ: Radiocarbon.

Yadav RR & Bhattacharyya A 1992. A 745 years chronology of *Cedrus deodora* from Western Himalaya. Dendrochronologia 10 : 53-61.

Yadav RR, Won-Kyu Park & Bhattacharyya A 1997. Dendroclimatic reconstruction of April-May temperature fluctuations in the Western Himalaya of India since 1698 AD Quaternary Research 48 : 187-191.

Yadav RR, Won-Kyu Park & Bhattacharyya A 1999. Spring-temperature variations in Western Himalaya, India, as reconstructed from tree-rings : 1390-1987 AD. The Holocene 9 : 85-90.