Palaeobotanist 50 (2001) :141-152
0031-0174/2001/141-152 $2.00

A tree ring reconstruction of climatic extreme years since 1427 AD for Western Central Asia

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(Received 30 January 2001; revised version accepted 23 July 2001)

ABSTRACT

Esper J, Treydte K, Gärtner H & Neuwirth B 2001. A tree ring reconstruction of climatic extreme years since 1427 AD for Western Central Asia. Palaeobotanist 50(1) : 141-152.

Analyses of ring width values of 429 trees from twelve *Juniperus* sites and three mixed sites (*Juniperus, Picea, Pinus*) of the northwest Karakorum in Pakistan and seven *Juniperus* sites of the southern Tien Shan in Kirghizia enable the reconstruction of extreme years since 1427 AD. Extreme growth reactions are classified as (i) event years—reflecting extreme years of individual trees, (ii) site pointer years—reflecting common extreme years within a site, (iii) regional pointer years—reflecting common extreme years within the Karakorum or Tien Shan, and (iv) inter-regional pointer years—reflecting synchronous extreme years between the Karakorum and Tien Shan. A comparison between the Karakorum and Tien Shan results in eight positive inter-regional pointer years (1916, 1804, 1766, 1703, 1577, 1555, 1514, 1431 AD) and 17 negative inter-regional pointer years (1917, 1877, 1871, 1833, 1806, 1802, 1790, 1742, 1669, 1653, 1611, 1605, 1591, 1572, 1495, 1492, 1483 AD). These years are valid for Western Central Asia.

The extreme year reconstructions from the Karakorum and Tien Shan Mountains are dominated by regional pointer years. Regional pointer years result from climatic conditions limiting tree growth independent of site ecology, from the lower, arid, to the upper, humid timberlines, and in different exposures. The seasonal climatic forcing of regional pointer years changes from year-to-year, but temperature variation predominantly limits tree growth. Additional analyses of selected site pointer years, which do *not* belong to regional pointer years, prove temperature signals from sites near the upper timberlines, and precipitation signals from sites near the lower timberlines.

Key-words—Dendrochronology, Climate, Extreme years, Pointer years, Site ecology, Karakorum, Tien Shan, Pakistan, Kirghizia, *Juniperus*.

पश्चिमी-मध्य एशिया हेतु विगत सन् 1427 ई. से आज तक के जलवायुविक चरम वर्षों का वृक्ष वलयी पुनर्सृजन

जान एस्पर, केर्स्टिन ट्रेइट, होल्गर गार्टनर एवं बर्खार्ड न्यूविर्थ

सारांश

पाकिस्तान के उत्तर-पश्चिमी कराकोरम के बारह *जूनीपेरस* स्थलों तथा तीन सम्मिश्र स्थलों के 429 वृक्षों (*जूनीपेरस, पाइसिया, पाइनस*) एवं किर्गिज़िया के दक्षिण तिएन शान के सात *जूनीपेरस* स्थलों के वलय चौड़ाई मानों का विश्लेषण विगत सन् 1427 ई. से आज तक के चरम वर्षों का पुनर्सृजन करने हेतु सहायक है। चरम वृद्धि प्रतिक्रियाओं को (I) वृक्ष विशेष के चरम वर्षों को प्रदर्शित करने वाले घटना वर्षों (II) एक स्थल के भीतर उभयनिष्ठ चरम वर्षों को प्रदर्शित करने वाले स्थल संकेतक वर्षों (III) कराकोरम एवं तिएन शान के भीतर उभयनिष्ठ चरम वर्षों को प्रदर्शित करने वाले क्षेत्रीय संकेतक वर्षों तथा (IV) कराकोरम एवं तिएन शान के मध्य समकालिक चरम वर्षों को प्रदर्शित करने वाले अन्तः क्षेत्रीय संकेतक वर्षों के रूप में वर्गीकृत किया गया है। कराकोरम एवं तिएन शान की तुलना करने से आठ सकारात्मक अन्तः क्षेत्रीय संकेतक वर्ष (सन् 1916, 1804, 1766, 1703, 1577, 1555, 1514, 1431 ई.) तथा सत्रह नकारात्मक अन्तः क्षेत्रीय संकेतक वर्ष (सन् 1917, 1877, 1871, 1833, 1806, 1802, 1790, 1742, 1669, 1653, 1611, 1605, 1591, 1572, 1495, 1492, 1483 ई.) परिणामस्वरूप प्राप्त हुए हैं। ये वर्ष पश्चिमी-मध्य एशिया हेतु वैध हैं।

कराकोरम एवं तिएन शान पर्वतश्रेणियों से प्राप्त चरम वर्ष पुनर्सृजन में क्षेत्रीय संकेतक वर्षों की प्रधानता है। जलवायुविक स्थितियों के परिणामस्वरूप प्राप्त क्षेत्रीय संकेतक वर्ष स्थल पारिस्थितिकी के इतर अधो शुष्क से उपरि आर्द्र वृक्षसीमाओं तथा विभिन्न अनावरणों में वृक्ष वृद्धि को सीमित कर देते हैं। क्षेत्रीय संकेतक वर्षों का मौसमी जलवायुविक प्रणोदन वर्ष दर वर्ष परिवर्तित होता है, किन्तु तापमान में भिन्नता प्रमुखतः वृक्ष वृद्धि को सीमित कर देती है। कुछ चयनित स्थल संकेतक वर्षों के अतिरिक्त विश्लेषणों, जो क्षेत्रीय संकेतक वर्षों से सम्बन्धित नहीं हैं, से अधो वृक्ष सीमा के समीप के स्थलों के वर्षण संकेत तथा उपरि वृक्ष सीमा के समीप के स्थलों के तापमान संकेत प्रमाणित होते हैं।

संकेत शब्द—वृक्षवलयकालानुक्रमिकीविज्ञान, जलवायु, चरम वर्ष, संकेतक वर्ष, स्थल पारिस्थितिकी, कराकोरम, तिएन शान, पाकिस्तान, किर्गिज़िया, *जूनीपेरस*.

INTRODUCTION

ANALYSES of tree ring variation enable the reconstruction of climate history on interannual to centennial time scales (overview in Dean *et al.*, 1996; Schweingruber, 1996). Tree ring width or density chronologies are usually transformed into temperature or precipitation series estimated by calibrating and verifying the proxy variation with climatic station data (Fritts & Guiot, 1990; Cook & Kairiukstis, 1990). A commonly used technique to calculate linear models between climatic and tree ring series is response function (Fritts, 1976). Since a tree ring chronology is a sequence of averages from individual trees, the signal strength of chronologies changes from year-to-year and decade-to-decade (Esper *et al.*, 2001a; Wigley *et al.*, 1984). It is widely known that the extreme years of a mean chronology have the highest signal strength (Schweingruber *et al.*, 1991). Analyzing extreme years is therefore an approach to better understand the climate/tree ring relationship.

The high mountain systems of Central Asia are poorly represented on the worldwide map of dendroclimatic reconstructions. There exists only some tree ring studies from Central Asia, a region that might be one of the key areas to understand global climate change (e.g., Bräuning, 1994, 1999; Zimmermann *et al.*, 1997 in Tibet; Cook & Krusic, 2001; Schmidt & Gruhle, 1995 in Nepal; Bhattacharyya *et al.*, 1988; Borgaonkar *et al.*, 1996; Hughes, 1992; Yadav & Bhattacharyya, 1992; Yadav *et al.*, 1997 in India; Graybill *et al.*, 1992 in Kirghizia; Jacoby *et al.*, 1996 in Mongolia). Earlier work showed the importance of decadal and centennial growth variation in Western Central Asia (Esper *et al.*, 1995; Esper, 2000a, b). Common decadal growth variation, observed in the Karakorum and Tien Shan Mountains, reflects mean, annual temperature variability within a range of -0·2 to +0·2°C (Esper *et al.*, 2001b). These mid-term fluctuations are superimposed on centennial trends verifying the existence of faster growth during the Medieval Warm Period, slower growth during the Little Ice Age, and increasing growth rates again in the most recent centuries. However, the growth level in the modern period does not reach the values recorded around 1000 AD (Esper, 2000b; Esper *et al.*, 2001b). To understand the reconstructed climatic variability on broader spatial scales, a group of cooperating scientists was recently established (Amalava Bhattacharyya, Hemant Borgaonkar, Achim Bräuning, Vandana Chaudhary, Edward Cook, Jan Esper, Paul Krusic, Kolli Rupa Kumar, Govind Pant, Amar Sikder, Limin Xiong) to develop a network of tree ring chronologies reaching from Kirghizia in the West to Central China in the East.

This paper focuses on extreme growth years of a tree ring network from the Karakorum (Pakistan) and Tien Shan Mountains (Kirghizia) in Western Central Asia. We present a reconstruction of extreme growth years since 1427 AD and explain the climatic information of extreme years in relation to the ecology of the sampling sites.

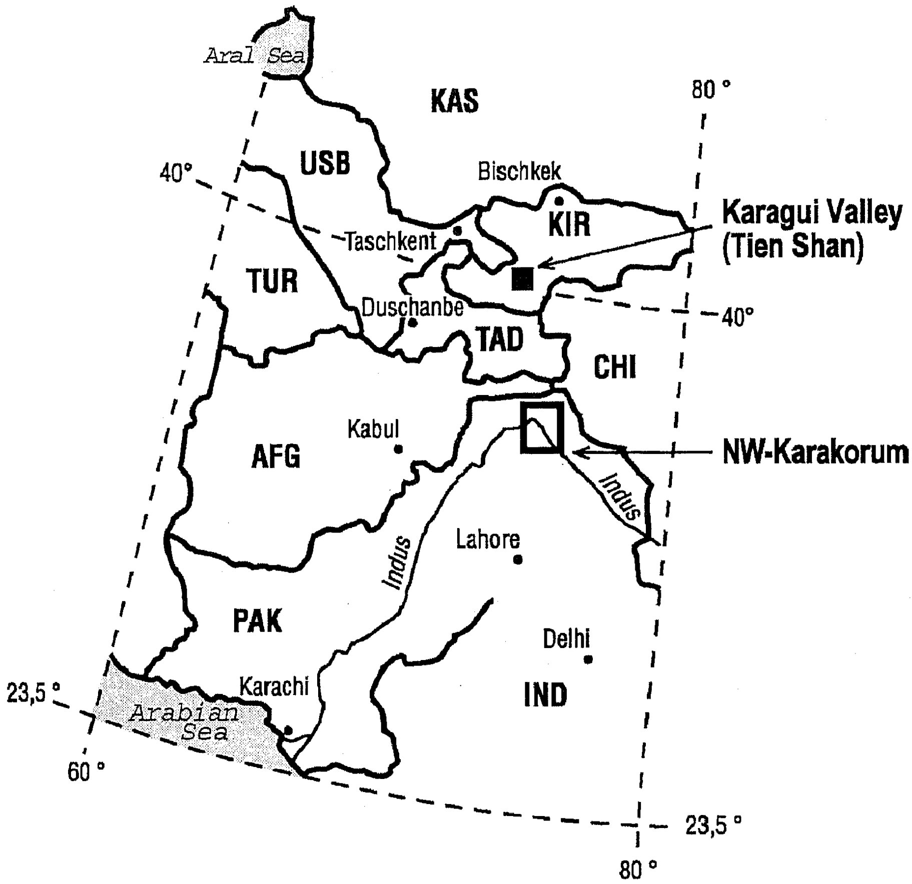


Fig. 1—Western Central Asia region and study areas in the Tien Shan and the Karakorum Mountains.

DATA AND METHODS

More than 2,00,000 ring width values were measured from core samples of 429 *Juniperus* (*J. turkestanica* Kom., *J. seravchanica* Komarov. and *J. semiglobosa* Regel), *Pinus wallichiana* A.B. Jackson and *Picea smithiana* (Wallich) Boiss. trees from the northwest Karakorum of Pakistan and the southern Tien Shan of Kirghizia (Fig. 1). Seven sites were sampled in the Karagui Valley of Kirghizia (K1-K7) and 15 sites from four valleys (P1-P4) in Pakistan. The NNW-facing sites P1a-P1c of the Bagrot Valley are the only mixed sampling locations of *Juniperus*, *Pinus* and *Picea*. All other sites represent pure *Juniperus* samplings (Fig. 2).

Sampling sites reach from 2,700 to 3,900 m asl. in the Karakorum and from 2,550 to 3,200 m asl. in the Tien Shan between the lower, arid, and upper, humid timberlines. Site ecology is also determined by exposure and the distance to monsoonal air masses. The Bagrot Valley (P1) receives the highest amount of rainfall, followed by the Chaprot (P2), the Morkhun (P3) and the Satpara valleys (P4). Elevation, exposure and valley positions enable a classification of the sites within an ecogram (Kaennel & Schweingruber, 1995), such as shown in Fig. 3 for the Karakorum. We presume that tree growth at cold-wet sites is predominantly limited by temperature and at warm-dry sites by precipitation. Tree age at low elevation sites is generally lower than at high elevation sites (Fig. 2).

Even though the distance between the northwest Karakorum (35-37°N/74-76°E) and southern Tien Shan (40°10'N/72°35'E) is only 500 km, different synoptic weather patterns influence each region. The Karakorum sites are affected by westerlies and monsoonal depressions, and the Tien Shan sites by a strong continental climate, without precipitation transport from the Arabian Sea (Böhner, 1996; Flohn, 1958; Reimers, 1992; Weiers, 1998).

Extreme growth reactions within a sequence of i years are classified as follows. Extreme years of individual trees are named »event years« (e_i) (Schweingruber *et al.*, 1990). Synchronous event years of one site result in »site pointer years« (sp_i). Synchronous site pointer years result in »regional pointer years« (rp_i), reflecting common extreme years within the Karakorum region or the Tien Shan region. Synchronous regional pointer years between the Karakorum *and* the Tien Shan result in »inter-regional pointer years« (ip_i).

Event years (e_i) are calculated following a two-step-procedure (Cropper, 1979). First, the residuals (r_i) from a 5-year digital filter, fitted to each individual ring width series, are calculated. This technique removes any low frequency signal. The r_i values are then divided by the standard deviation within a five-year moving-window. This second step scales

Chrono	Valley	Elevation	Exposition	No. of Trees	Max. Age	Aver. Age [yr.]
K1	Karagui	3200 m	SW	30	AD1316	346
K2	40°10'N/72°35'E	3000 m	SSW	25	AD1157	422
K3		2900 m	N	20	AD1346	326
K4		2900 m	SSW	18	AD1591	221
K5		2800 m	W	43	AD1378	227
K6		2600 m	SSW	27	AD1839	93
K7		2550 m	N	13	AD1781	82
P1a	Bagrot	3100 m	NNW	26	AD1535	189
P1b	36°02'N/74°35'E	3300 m	NNW	19	AD1369	268
P1c		3750 m	NNW	5	AD1679	224
P1d		3050 m	S	21	AD1438	236
P1e		3750 m	S	17	AD1240	218
P2a	Chaprot	2700 m	S	14	AD1587	173
P2b	36°20'N/74°02'E	3500 m	S	19	AD1032	481
P2c		3900 m	S	11	AD1144	459
P3a	Morkhun	3900 m	SW	13	AD 476	517
P3b	36°35'N/75°05'E	3800 m	ENE	15	AD 968	510
P3c		3600 m	ENE	20	AD 554	632
P3d		3900 m	SSE	18	AD1069	398
P4a	Satpara	3300 m	NW	13	AD1412	343
P4b	35°10'N/75°30'E	3700 m	S	18	AD 736	755
P4c		3900 m	S	17	AD 388	581
P5	Hunza	single trees		7	AD 568	774

Fig. 2—Western Central Asia tree ring chronologies.

the variance between different periods and series. The resulting e_i values are multiplied by 1000. The highest and lowest e_i values indicate the outliers of individual series. e_i values are then averaged for each site to calculate sp_i sequences. Site pointer years are again classified by ranking the highest and lowest sp_i values of each century, for example, outstanding sp_i values are only reached if e_i values of individual trees are synchronous. The classification of regional and inter-regional pointer years follow the same procedure.

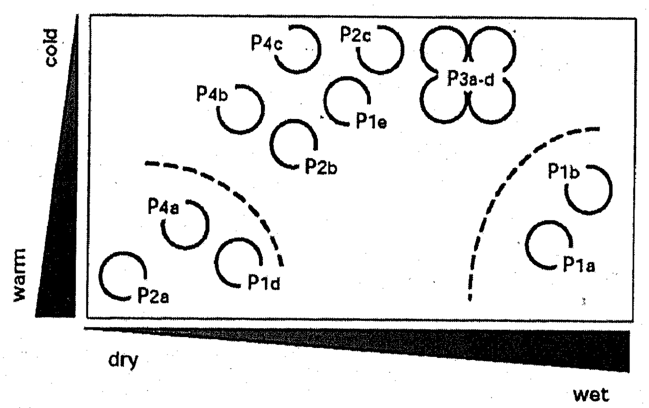


Fig. 3—Classification of the Karakorum sampling sites in an ecogram. Sites near the lower timberlines are »warm and dry«, sites near the upper timberlines are »cold and wet«. Site exposure and valley position likewise specify the location of the sites in the ecogram.

For calibration purposes the monthly mean temperature and precipitation series from the stations Peshawar, Lahore, Murree and Gilgit in Pakistan, and Simla and Ludhiana in India are used. The normalized annual precipitation amounts and annual temperature means of the six stations are shown in Fig. 4. Averaging these stations to regional mean curves is suitable to estimate the conditions at high mountainous tree ring sampling sites. Mountainous climate stations alone are generally less representative and too short to calibrate tree ring variation (Esper, 2000b). This is particularly true for rainfall. While the total average, annual precipitation at Gilgit is only 131 mm, rainfall near the upper timberline of the nearby Bagrot Valley is estimated 800 mm/a and more (Cramer, 2000). The signals in common, recorded by mean, annual precipitation and temperature series (Fig. 4, thick curve), are lower for precipitation than for temperature. The significant rainfall variability over space and with elevation needs to be considered when pointer years are calibrated (Böhner, 1996; Reimers, 1992).

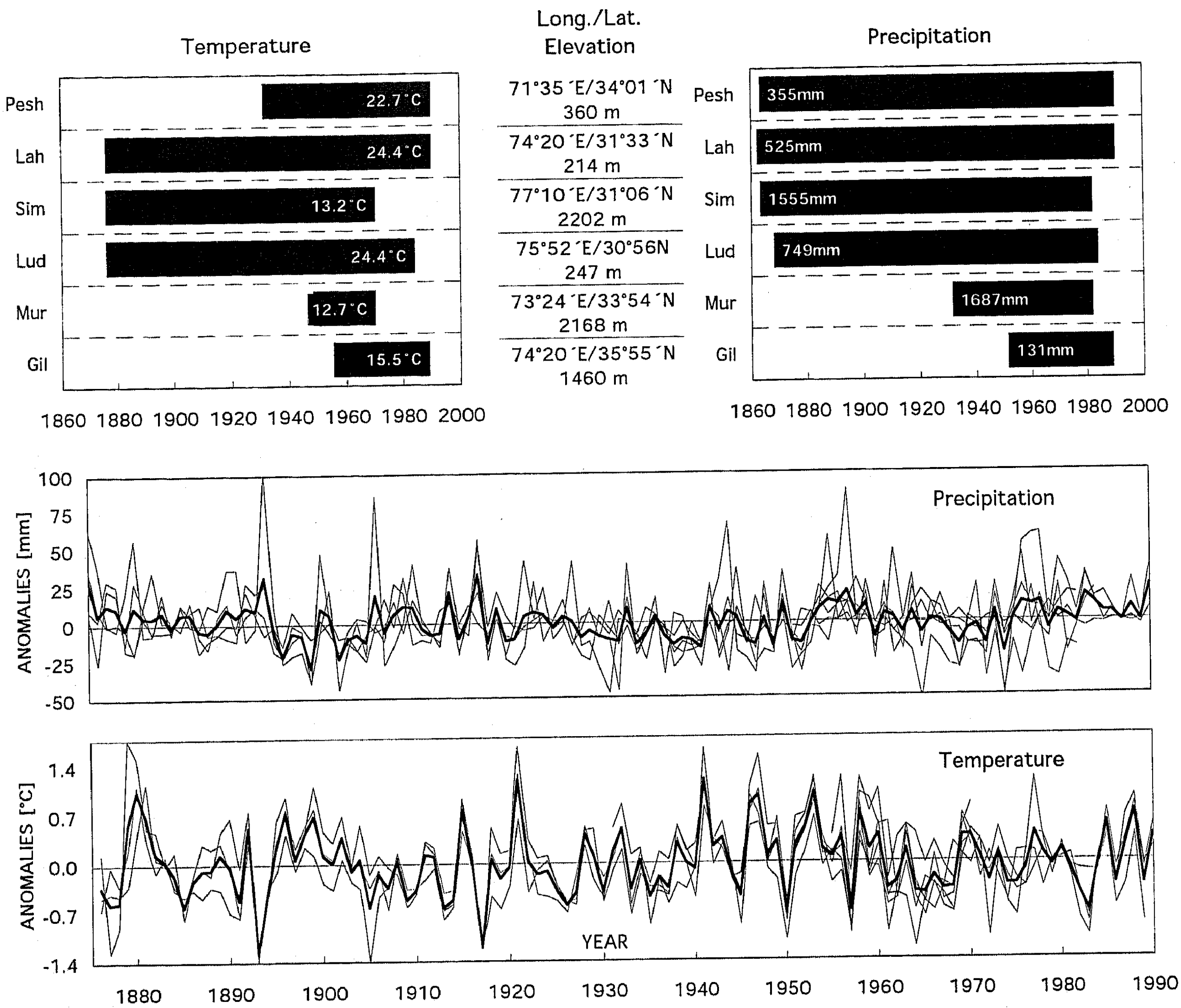


Fig. 4—Length, location and mean values of six climatic station data sets. The curves show the normalized, mean annual precipitation and temperature series (thin curves), and the regional averages (thick curves).

RESULTS

a. Regional and inter-regional pointer years

Fig. 5 shows the reconstruction of regional pointer years of the Karakorum and Tien Shan since 1800 AD. The individual site pointer values (gray and white planes) were divided by the number of sites in each region (Pakistan = 16, Kirghizia = 7), before adding them to regional pointer years. 10 regional pointer years per century are labeled at the top and bottom of the histograms. They only occur, if individual site pointer years appear synchronously. The numbers of trees contributing to regional pointer years are 232 in 1990 AD (221 in 1899 AD) for the Karakorum, and 173 in 1990 AD (145 in 1899 AD) for the Tien Shan.

Regional pointer years refer to climatic conditions forcing the trees of most sites to extreme growth reactions. These reactions are synchronous, even though the sites are located in different exposures, and reach from the lower to the upper timberlines with altitudinal differences of more than 1000 m. Regional pointer years result from climatic conditions limiting tree growth independently of site ecology. Note that the site pointer years are also synchronous between the four sampled valleys of the Karakorum (P1-P4). The distance of these valleys is more than 100 km.

Regional pointer years that are synchronous between the Karakorum and the Tien Shan are labelled bold in Fig. 5. Following this criteria, five positive inter-regional pointer years (1916, 1910, 1878, 1832, 1804 AD) and 10 negative inter-regional pointer years (1936, 1917, 1911, 1877, 1871, 1858, 1833, 1810, 1806, 1802 AD) are reconstructed since

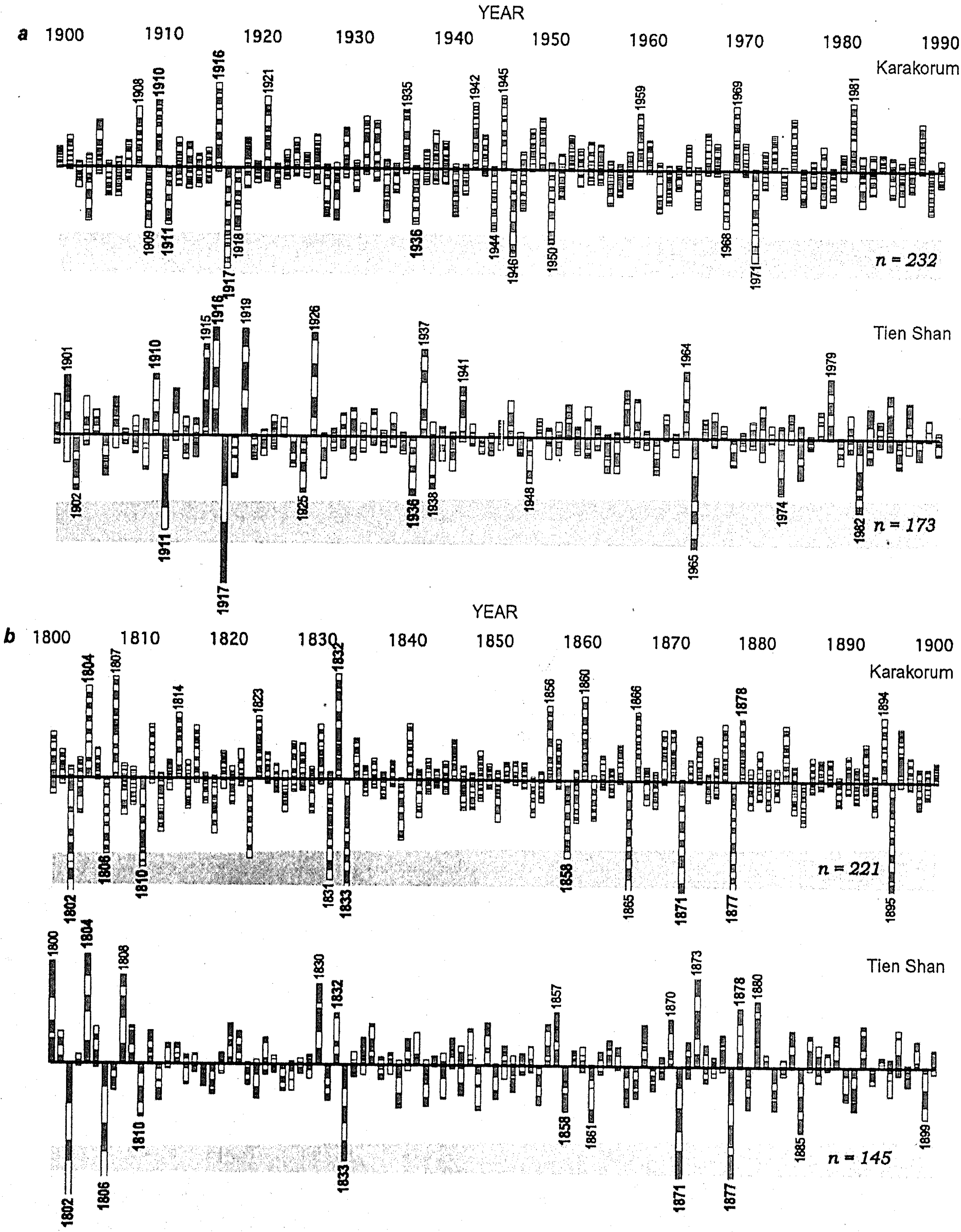


Fig. 5—Pointer year values of 16 Karakorum and seven Tien Shan sampling sites (gray and white planes) AD1900-1990 (*a*) and AD1800-1899 (*b*). Regional pointer years are labeled at the top and bottom of the histograms. Inter-regional pointer years are labeled bold.

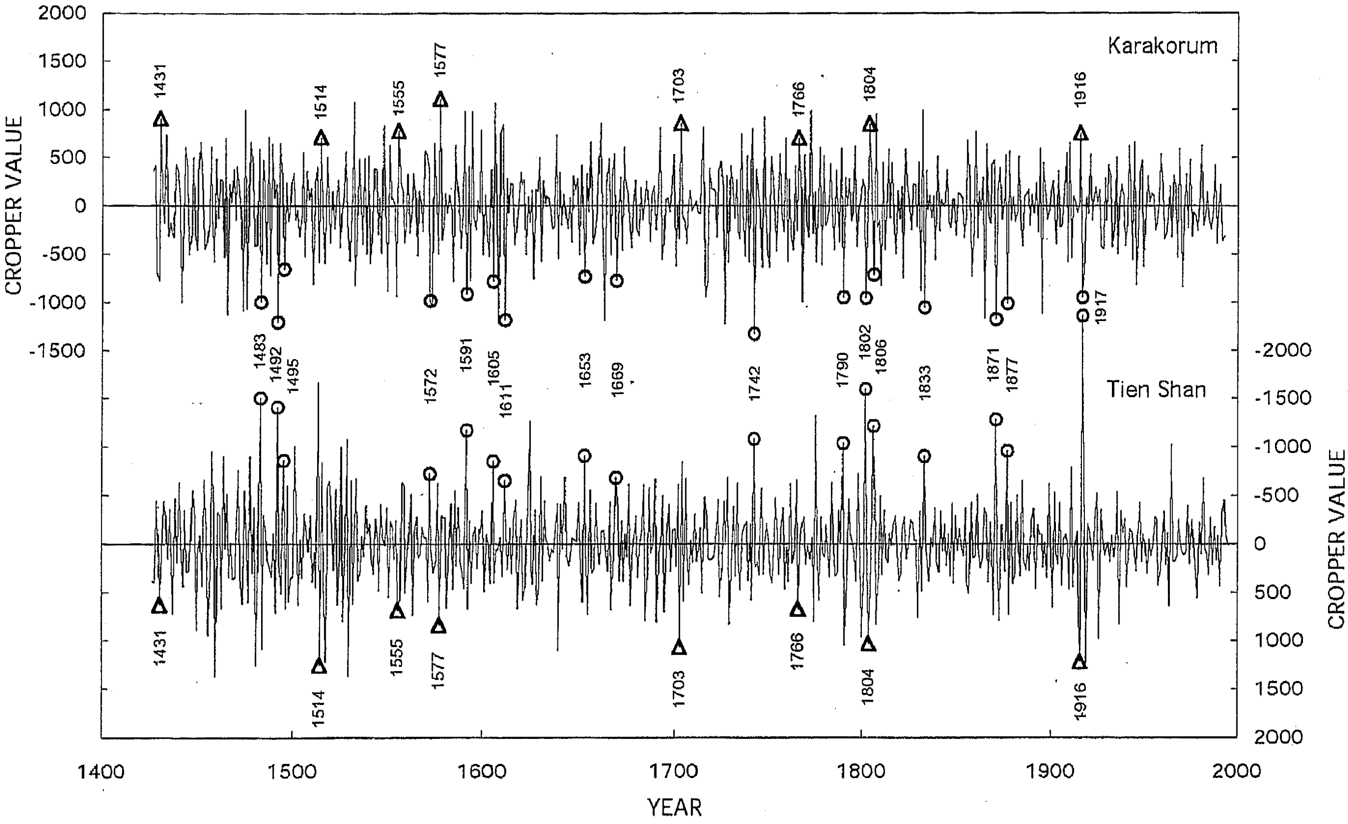


Fig. 6—Inter-regional pointer year reconstruction for Western Central Asia since AD1427. Extreme high and low curve values indicate regional pointer years in the Karakorum and Tien Shan. Synchronous, inter-regional pointer years are labeled with triangles (positive) and circles (negative). Inter-regional pointer years must be among the 50 strongest regional pointer years observed in both the Karakorum and the Tien Shan Mountains.

1800 AD. Negative pointer years are more synchronous within the sites, the regions and in between the regions. Accordingly, they have a higher potential to reconstruct climatic extreme years.

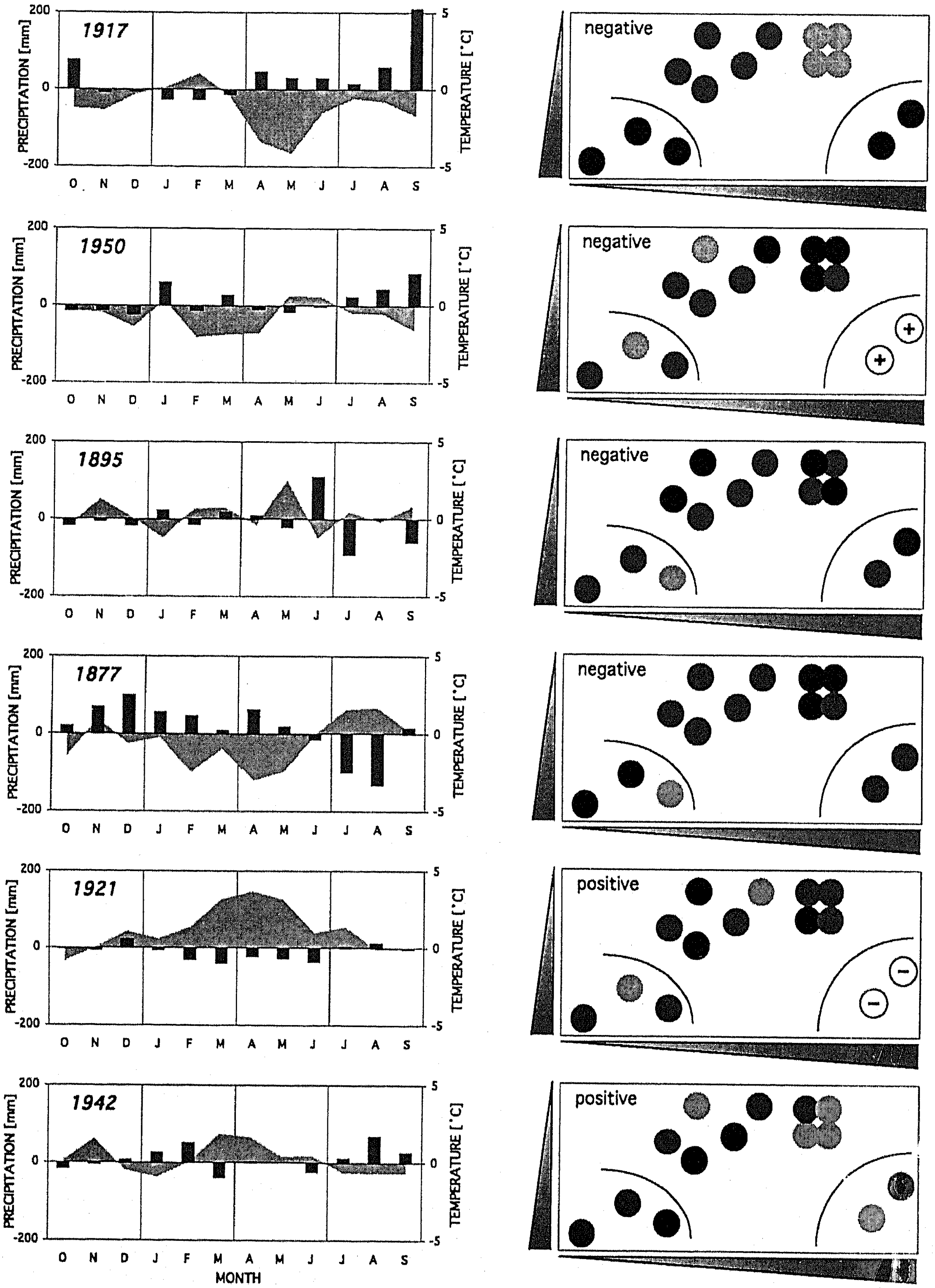
A different, more rigorous approach to reconstruct inter-regional pointer years for Western Central Asia since 1427 AD is shown in Fig. 6. The curves represent regionally averaged pointer values after Cropper (1979) for the Karakorum and the Tien Shan Mountains. Synchronous, inter-regional pointer years from the 50 highest and lowest regional pointer year values are labeled with triangles (positive) and circles (negative). This method is more rigorous than the reconstruction shown in Fig. 5 (less years are labeled in the 19th and 20th centuries), and we recommend using the years labeled in Fig. 6 for calibration purposes with other work, from Nepal, India, or Tibet, for example. Following this strict technique, eight significant positive and 17 negative inter-regional pointer years are reconstructed over the last 564 years. In other words, the chance for a positive pointer year in the Karakorum is increased, if a positive pointer year is reconstructed from the Tien Shan, and vice versa. This chance is again significantly higher for negative regional pointer years.

b. Climatic signals of pointer years

We applied two different techniques to calibrate extreme growth reactions in the Karakorum, (i) analyses of regional pointer years, and (ii) analyses of site pointer years that do *not* belong to regional pointer years.

Fig. 7 shows the site pointer years of the Karakorum in relation to site ecology (right column) together with the temperature and precipitation anomalies from the preceding October to the current September (left column). Site names and ecological parameters are listed in Fig. 2 and Fig. 3. Since negative pointer years are more common within and between the sites, four negative (1917, 1950, 1895, 1877 AD) and only two positive regional pointer years (1921, 1942 AD) are illustrated. The temperature and precipitation anomalies were derived from a maximum of six stations representing regional climatic variability of the northwest Karakorum (see Fig. 4). Site pointer years are ranked by standard deviation units from »reaction«, to »strong reaction«, »extremely strong reaction«, and »reverse reaction«.

1917 AD is one of the most severe negative regional pointer years recorded for the Karakorum. All sampling sites show a negative pointer year, forced by cold conditions during



LEGEND:

Precipitation
Temperature

Extremely strong reaction (> 2 standard deviations)
Strong reaction (> 1 standard deviation)
Reaction (< 1 standard deviation)
⊕⊖ Reverse reaction
(classification related to the AD1876-1990 standard deviation at each site)

the growing season. Temperatures were extremely cold in May. The cambial activity at the sampling sites was reduced, even if the amount of rainfall was sufficient. The reactions were strongest at the wet NNW-facing sites of the Bagrot Valley (ecogram, right corner) and the dry, low elevation sites of the Bagrot, Chaprot and Satpara valleys (left corner). An unexpected result was the strong response of the second group, located close to the arid lower timberline. Prominent work, done along comparable altitudinal transects in the US (e.g., La Marche, 1974), verified a changing response with elevation: drought near the lower timberlines, and cold near the upper timberlines. This conclusion does not hold for the regional pointer years from the Karakorum. The result is confirmed by the low elevation sites of the Tien Shan, which frequently have a missing ring in 1917 AD.

A comparison of the temperature and precipitation anomalies in all four negative regional pointer years indicates that the seasonal climatic forcing is different from year-to-year. Synchronous site pointer years of the Karakorum result from different climatic constellations, a characteristic feature of pointer year analyses (Schweingruber *et al.,* 1991). For example, the temperature and precipitation regimes in 1950 and 1895 AD are very different, but in both years most of the sampled tree ring sites react strongly. In 1950 AD a cold winter with a late start of the vegetation period, and in 1895 AD extreme rainfall conditions in June and July are responsible. The impact of extreme rainfall changes is verified by density fluctuations recorded in the 1895 AD tree ring. 1877 AD is a regional pointer year, caused by severe changes from cold-wet conditions in the pre-season, to warm-dry conditions in the vegetation period.

Even though changing climatic conditions might be responsible for some negative regional pointer years, low temperatures seem to limit tree growth predominantly. This assumption is supported by the positive regional pointer years. 1921 AD is the warmest year of the entire climatic record, and in 1942 AD warm conditions reach from early spring to early summer. In addition, sufficient rainfall is recorded during the generally hot summers of the Karakorum Mountains.

Conspicuous, reverse growth reactions are recorded at the mixed *Juniperus*, *Picea* and *Pinus* sites in 1950 AD and 1921 AD (ecogram, right corner). These years prove the different response of the mixed sampling sites in comparison to the pure *Juniperus* sites sampled elsewhere. Interestingly enough, the mixed sites deviate frequently from the homogenous *Juniperus* sites in years with significant precipitation anomalies (without figure). This result confutes the contention that the NNW-facing, mixed sampling sites of the wet Bagrot Valley are predominantly limited by cold conditions.

To understand the effects of site ecology in greater detail, Fig. 8 lists the pointer years of each Karakorum site that does *not* belong to regional pointer years (column 1). This strategy excludes regional pointer years like 1917 AD, where all sites reacted commonly. Columns 2 and 3 name the sites and, in brackets, the rank of the site pointer year. »III« in row one, for example, means that 1988 AD is the third strongest pointer year at site P3d. The site pointer years ranking first and second belong to regional pointer years. Column 5 discusses significant temperature and precipitation anomalies, and column 6 explains the climatic forcing in relation to site exposure and elevation.

According to Fig. 8, 14 out of 23 site pointer years can be explained, i.e., high elevation sites are limited by temperature and low elevation sites by precipitation, and only nine years do not fit. The site pointer years 1985, 1978, 1931, and 1903 AD can not be readily explained by climatic variation. 1949, 1927, 1892, and 1885 AD are only likely understood, and in 1883 AD a low elevation site apparently reacts to temperature. The analysis shows that the predicted limitation of high elevation sites by temperature and of low elevation sites by precipitation holds only, if different climatic seasons are considered. This evidence limits the obvious tendency that site pointer years near the upper timberline reflect temperature and near the lower timberline precipitation variation.

DISCUSSION

Many of the observed site pointer years are synchronous within one region, causing a frequent occurrence of regional pointer years since 1427 AD. Additional comparison of regional pointer years between the Karakorum and Tien Shan Mountains resulted in eight positive and 17 negative inter-regional pointer years reflecting extreme growth conditions uniform for Western Central Asia. Both results were not expected, since the site ecology changes dramatically within the regions, and the regions belong to different climatic zones. The recorded uniform growth reactions (regional and inter-regional pointer years) question the concept of changing climatic signal strength with changing elevation (e.g., La Marche, 1974) for Western Central Asia, and the differences between the climatic zones outlined in climate atlases (e.g., Köppen, 1918; Troll, 1943).

Even though the analyses of selected site pointer years proved a predominant response to temperature variation at

←

Fig. 7—Temperature and precipitation variation in regional pointer years of the Karakorum. Intensity and sign of the site pointer years reach from »extremely strong reaction« to »reverse reaction«. Ecology of the sampling sites is classified by the location of the sites in the ecogram (see Fig. 3).

YEAR	NEGATIVE	POSITIVE	ELEV./EXP.	TEMPERATURE AND PRECIPITATION	EXPLANATION
1988		P3d (III)	3900 m/SSE	Nov-Feb & Apr-May warm Mar wet	high elevation S-site reacts to **T**
1986	P3c (VI)		3600 m/ENE	Mar-Sep cold	high elevation N-site reacts to **T**
1985	P4a (III)		3300 m/NE	Nov-Apr warm	?
1983		P4a (I)	3300 m/NE	Feb-Jul cold Mar-Apr & Aug wet	low elevation S-site reacts to **P**
1982	P4b (I)		3700 m/S	Feb-Jul cold Mar-May wet, Jul & Sep dry	high elevation S-site reacts to **T** (may be summer drouth)
1978		P2c (IV)	3900 m/S	Mar & Jul cold, May warm Mar & Jun-Jul wet	?
1949		P2b (III)	3500 m/S	Apr-May & Sep warm Aug dry	high elevation S-site likely reacts to spring **T**
1947	P1d (IV)		3050 m/S	Feb-Aug warm Feb-Aug dry, Sep wet	low elevation S-site reacts to **P**
1938		P3b (II)	3800 m/ENE	Mar-Sep warm Mar-Sep dry	high elevation N-site reacts to **T**
1933	P2b (II) P3b (I)		3500 m/S 3800 m/ENE	Apr-May & Aug-Sep cold Aug-Sep wet	high elevation site reacts to **T**
1932		P3a (I)	3900 m/SW	Jan-Apr & Jun warm Jan-Feb & Apr & Jun-Jul dry	high elevation S-site reacts to **T**
1931		P1d (II) P2a (I)	3050 m/S 2700 m/S	Feb cold, Apr & Aug warm Jan-Apr & Jun-Jul dry, Aug-Sep wet	? ?
1930	P1e (III)		3750 m/S	Apr & Jun-Jul cold Jul wet, Aug dry	high elevation S-site reacts to **T**
1927	P2a (II)		2700 m/S	Jan-Mar cold Jan & Mar-Jun dry, Aug wet	low elevation N-site likely reacts to **P**
1914		P1a (IV)	3100 m/NNW	Feb-Jun cold Apr-Jul & Sep wet	low elevation N-site reacts to **P**
1909	P4c (III)		3900 m/S	Dec-Feb & Apr-Sep cold Mar & Aug dry, Apr & Jun-Jul wet	high elevation S-site reacts to **T**
1904		P3c (III)	3600 m/ENE	Apr-Aug warm Mar wet, Apr-Sep dry	high elevation N-site reacts to **T**
1903	P1b (III) P3a (VIII) P3d (IV)		3300 m/NNW 3900 m/SW 3900 m/S	Mar-May cold, Jun-Jul warm Feb & Jun-Jul dry	? ? ?
1892		P4b (III)	3700 m/S	Jan-May warm, Aug-Sep cold Jan-Jun dry, Aug-Sep wet	high elevation S-site likely reacts to spring **T** (or summer **P**)
1885	P2c (IV)		3900 m/S	Feb & May cold Jan & Apr-May wet, Jun & Sep dry	high elevation S-site likely reacts to extreme conditions in May
1884	P1a (IV)		3100 m/NNW	Jan warm Dec-Jun dry, Aug-Sep wet	low elevation N-site reacts to **P**
1883		P1b (IV)	3300 m/NNW	Apr-Aug warm Jan & May & Sep wet, Aug dry	low elevation N-site reacts to **T**
1880		P4c (IV)	3900/S	Mar-Jun & Aug-Sep warm Mar-Apr dry, Mai-Jul wet, Aug-Sep dry	high elevation S-site reacts to **T**

Fig. 8—Temperature and precipitation anomalies in site pointer years of the Karakorum that do not belong to regional pointer years. Column 1 lists the site pointer years, column 2 and 3 the sites, column 4 the elevation and exposure, column 5 the climatic anomalies, and column 6 the tree ring response.

high elevation sites, and to precipitation at low elevation sites, the climatic forcing is not completely understood. Characteristic of the climatic signals in pointer years is the changing forcing seasonality from year-to-year. Some pointer years are caused by climatic anomalies in the pre-season, some in the vegetation period. And even at the low elevation sites, some pointer years are caused by temperature anomalies. This result confirms findings of comparable analyses (e.g.

Schweingruber *et al.*, 1991), which showed that similar pointer years were caused by drought in one year and by cold in another year.

Schweingruber *et al.* (1991) also indicated that single climatic events, like frosts, trigger pointer years as well. These findings point to the climatic data sets available for the Karakorum and Tien Shan region. Single, mountainous stations are not representative to calibrate tree growth at high elevation sites. They are generally located on the arid valley bottoms, and the length of these data sets is limited. Analyses of the impact of single frost events, for example, are not possible on the basis of monthly mean climatic data sets. Calculating regional averages from several climatic stations is the only, but limited, chance to calibrate ring width variation from the Mountains of Pakistan and Kirghizia.

Acknowledgements—*This work was supported by the German Science Foundation (Grant No. Wi-937-1/5) [Jan Esper]. We thank David Frank and two anonymous reviewers for valuable comments on an earlier draft of this paper.*

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