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

JAN ESPER¹, KERSTIN TREYDTE², HOLGER GÄRTNER³ AND BURKHARD NEUWIRTH⁴

¹Tree-Ring Laboratory, Lamont-Doherty Earth Observatory of Columbia University, 61 Route 9W, Palisades, New York 10964, USA.
²Institute for Chemistry and Dynamics of the Geosphere, ICG 4, Research Center Juelich, Leo-Brandt-Str., 52425 Juelich, Germany.
³Department of Geosciences, Geography, University of Fribourg, Perolles, 1700 Fribourg, Switzerland.
⁴Department of Geography, University of Bonn, Meckenheimer Allee 166, 53115 Bonn, Germany.

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

ABSTRACT


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, 1853, 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 सदी 1427 ई. से आज तक के जलवायुविक चरम वर्षों का वृक्ष वल्ली पुनरुत्साहन
जान एसपर, केरस्टिन ट्रेंडेट, होलर गार्टनर एवं बर्कहार्ड न्यूवर्थ
INTRODUCTION

A

NALYSES 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., Brüning, 1994, 1999; Zimmermann et al., 1997 in Tibet; Cook & Krusic, 2001; Schmidt & Gruhle, 1995 in Nepal; Bhattacharyya et al., 1988; Bhaonkar 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 Bhaonkar, Achim Brüning, Vandana Chaudhary, Edward Cook, Jan Esper, Paul Krusic, Koll 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.
DATA AND METHODS

More than 2,000,000 ring width values were measured from core samples of 429 Juniperus (J. turkestana 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« ($e$) (Schweingruber et al., 1990). Synchronous event years of one site result in »site pointer years« ($sp$). Synchronous site pointer years result in »regional pointer years« ($rp$), 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« ($ip$).

Event years ($e$) 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
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 \( s_p \) sequences. Site
pointer years are again classified by ranking the highest and lowest \( s_p \) values of each century, for example, outstanding \( s_p \),
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.

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,
normal 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).

<table>
<thead>
<tr>
<th>Chrono</th>
<th>Valley</th>
<th>Elevation</th>
<th>Exposition</th>
<th>No. of Trees</th>
<th>Max. Age</th>
<th>Aver. Age [yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>Karagui</td>
<td>3200 m</td>
<td>SW</td>
<td>30</td>
<td>AD1316</td>
<td>346</td>
</tr>
<tr>
<td>K2</td>
<td></td>
<td>3000 m</td>
<td>SSW</td>
<td>25</td>
<td>AD1157</td>
<td>422</td>
</tr>
<tr>
<td>K3</td>
<td></td>
<td>2900 m</td>
<td>N</td>
<td>20</td>
<td>AD1346</td>
<td>326</td>
</tr>
<tr>
<td>K4</td>
<td></td>
<td>2900 m</td>
<td>SSW</td>
<td>18</td>
<td>AD1591</td>
<td>221</td>
</tr>
<tr>
<td>K5</td>
<td></td>
<td>2800 m</td>
<td>W</td>
<td>43</td>
<td>AD1378</td>
<td>227</td>
</tr>
<tr>
<td>K6</td>
<td></td>
<td>2600 m</td>
<td>SSW</td>
<td>27</td>
<td>AD1839</td>
<td>93</td>
</tr>
<tr>
<td>K7</td>
<td></td>
<td>2550 m</td>
<td>N</td>
<td>13</td>
<td>AD1781</td>
<td>82</td>
</tr>
<tr>
<td>P1a</td>
<td>Bagrot</td>
<td>3100 m</td>
<td>NNW</td>
<td>26</td>
<td>AD1535</td>
<td>189</td>
</tr>
<tr>
<td>P1b</td>
<td></td>
<td>3300 m</td>
<td>NNW</td>
<td>19</td>
<td>AD1369</td>
<td>268</td>
</tr>
<tr>
<td>P1c</td>
<td></td>
<td>3750 m</td>
<td>NNW</td>
<td>5</td>
<td>AD1679</td>
<td>224</td>
</tr>
<tr>
<td>P1d</td>
<td></td>
<td>3050 m</td>
<td>S</td>
<td>21</td>
<td>AD1438</td>
<td>236</td>
</tr>
<tr>
<td>P1e</td>
<td></td>
<td>3750 m</td>
<td>S</td>
<td>17</td>
<td>AD1240</td>
<td>218</td>
</tr>
<tr>
<td>P2a</td>
<td>Chaprot</td>
<td>2700 m</td>
<td>S</td>
<td>14</td>
<td>AD1587</td>
<td>173</td>
</tr>
<tr>
<td>P2b</td>
<td></td>
<td>3600 m</td>
<td>S</td>
<td>19</td>
<td>AD1032</td>
<td>481</td>
</tr>
<tr>
<td>P2c</td>
<td></td>
<td>3900 m</td>
<td>S</td>
<td>11</td>
<td>AD1144</td>
<td>459</td>
</tr>
<tr>
<td>P3a</td>
<td>Morkhun</td>
<td>3900 m</td>
<td>SW</td>
<td>13</td>
<td>AD476</td>
<td>517</td>
</tr>
<tr>
<td>P3b</td>
<td></td>
<td>3800 m</td>
<td>ENE</td>
<td>15</td>
<td>AD968</td>
<td>510</td>
</tr>
<tr>
<td>P3c</td>
<td></td>
<td>3600 m</td>
<td>ENE</td>
<td>20</td>
<td>AD554</td>
<td>652</td>
</tr>
<tr>
<td>P3d</td>
<td></td>
<td>3900 m</td>
<td>SSE</td>
<td>18</td>
<td>AD1069</td>
<td>398</td>
</tr>
<tr>
<td>P4a</td>
<td>Satpara</td>
<td>3300 m</td>
<td>NW</td>
<td>13</td>
<td>AD1412</td>
<td>343</td>
</tr>
<tr>
<td>P4b</td>
<td></td>
<td>3700 m</td>
<td>S</td>
<td>18</td>
<td>AD736</td>
<td>755</td>
</tr>
<tr>
<td>P4c</td>
<td></td>
<td>3900 m</td>
<td>S</td>
<td>17</td>
<td>AD388</td>
<td>581</td>
</tr>
<tr>
<td>P5</td>
<td>Hunza</td>
<td>single trees</td>
<td></td>
<td>7</td>
<td>AD568</td>
<td>774</td>
</tr>
</tbody>
</table>

Fig. 2—Western Central Asia tree ring chronologies.

![Ecogram](image)

Fig. 3—Classification of the Karakoram 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 like-
wise specify the location of the sites in the ecogram.
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.
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

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.
1917

1950

1895

1877

1921

1942

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. 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
| YEAR | NEGATIVE   | POSITIVE  | ELEV./EXP.   | TEMPERATURE AND PRECIPITATION | EXPLANATION | Fig. 8—Temperature and precipitation anomalies in site pointer years of the Karakoram 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. |
| 1988 | P3d (III)  | 3900 m/SSE | Nov-Feb & Apr-May warm Mar wet | high elevation S-site reacts to T | 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 | low elevation S-site reacts to P | high elevation S-site reacts to T (may be summer drought) |
| 1983 | P4a (I)    | 3300 m/NE  | Feb-Jul cold  | low elevation S-site reacts to P | ? |
| 1982 | P4b (I)    | 3700 m/S   | Feb-Jul cold  | high elevation S-site reacts to T | ? |
| 1978 | P2c (IV)   | 3900 m/S   | Mar & Jul cold, May warm Mar & Jun-Jul wet | high elevation S-site reacts to T | ? |
| 1949 | P2b (III)  | 3500 m/S   | Apr-May & Sep warm Aug dry | high elevation S-site likely reacts to spring T | low elevation S-site reacts to P |
| 1947 | P1d (IV)   | 3050 m/S   | Feb-Aug warm  | low elevation S-site reacts to P | ? |
| 1938 | P3b (II)   | 3800 m/ENE | Mar-Sep warm  | high elevation N-site reacts to T | ? |
| 1933 | P2b (II)   | 3500 m/S   | Apr-May & Aug-Sep cold Mar-Sep dry | high elevation site reacts to T | ? |
| 1932 | P3b (I)    | 3800 m/ENE | Aug-Sep wet  | high elevation S-site reacts to T | ? |
| 1931 | P3a (I)    | 3900 m/SW  | Jan-Apr & Jun warm Jan-Feb & Apr & Jun-Jul dry | high elevation S-site reacts to T | ? |
| 1930 | P1d (II)   | 3050 m/S   | Feb cold, Apr & Aug warm | high elevation S-site reacts to T | ? |
| 1927 | P2a (I)    | 2700 m/S   | Jan-Apr & Jun-Jul dry, Aug-Sep wet | high elevation S-site reacts to T | ? |
| 1914 | P1e (III)  | 3750 m/S   | Jul wet, Aug dry | high elevation S-site reacts to T | ? |
| 1909 | P4a (IV)   | 3100 m/NNW | Apr-Jun-Jul cold Jan-Mar cold  | high elevation N-site likely reacts to P | low elevation N-site reacts to P |
| 1904 | P4c (III)  | 3900 m/S   | Dec-Feb & Apr-Sep cold Mar & Aug dry, Apr & Jun-Jul wet | high elevation S-site reacts to T | ? |
| 1903 | P3c (III)  | 3600 m/ENE | Apr-Aug warm  | high elevation S-site reacts to T | ? |
| 1905 | P1b (III)  | 3300 m/NNW | Mar-May cold, Jun-Jul warm Mar wet, Apr-Sep dry | high elevation N-site reacts to T | ? |
| 1892 | P3d (IV)   | 3900 m/S   | Feb & Jun-Jul dry  | high elevation S-site likely reacts to spring T | ? |
| 1885 | P4b (III)  | 3700 m/S   | Jan-May, Aug-Sep cold  | high elevation S-site likely reacts to spring T | low elevation N-site reacts to P |
| 1884 | P2c (IV)   | 3900 m/S   | Jan & Apr-May wet, Jun & Sep dry | high elevation S-site likely reacts to spring T | low elevation N-site reacts to P |
| 1883 | P1a (IV)   | 3100 m/NNW | Dec-Jun, Aug-Sep wet  | high elevation S-site likely reacts to spring T | low elevation N-site reacts to P |
| 1882 | P1b (IV)   | 3300 m/NNW | Apr-Aug warm  | high elevation S-site likely reacts to spring T | 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 | ? |
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 Karakoram 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.

Acknowledgments—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.

REFERENCES


