Climate change and variability in Poland from Copernicus‘s time to present

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Climate of northern Poland during the last 1000 years: Constraining the future with the past (CLIMPOL)

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Introduction

- **1. State of knowledge**

  - Instrumental period: quite good

for Poland we have dozen of long-term homogenise temperature series, the longest come from Warsaw (since 1779), Wrocław (since 1791) and Cracow (since 1792), however in the near future there will be also available series for Gdańsk since 1739.

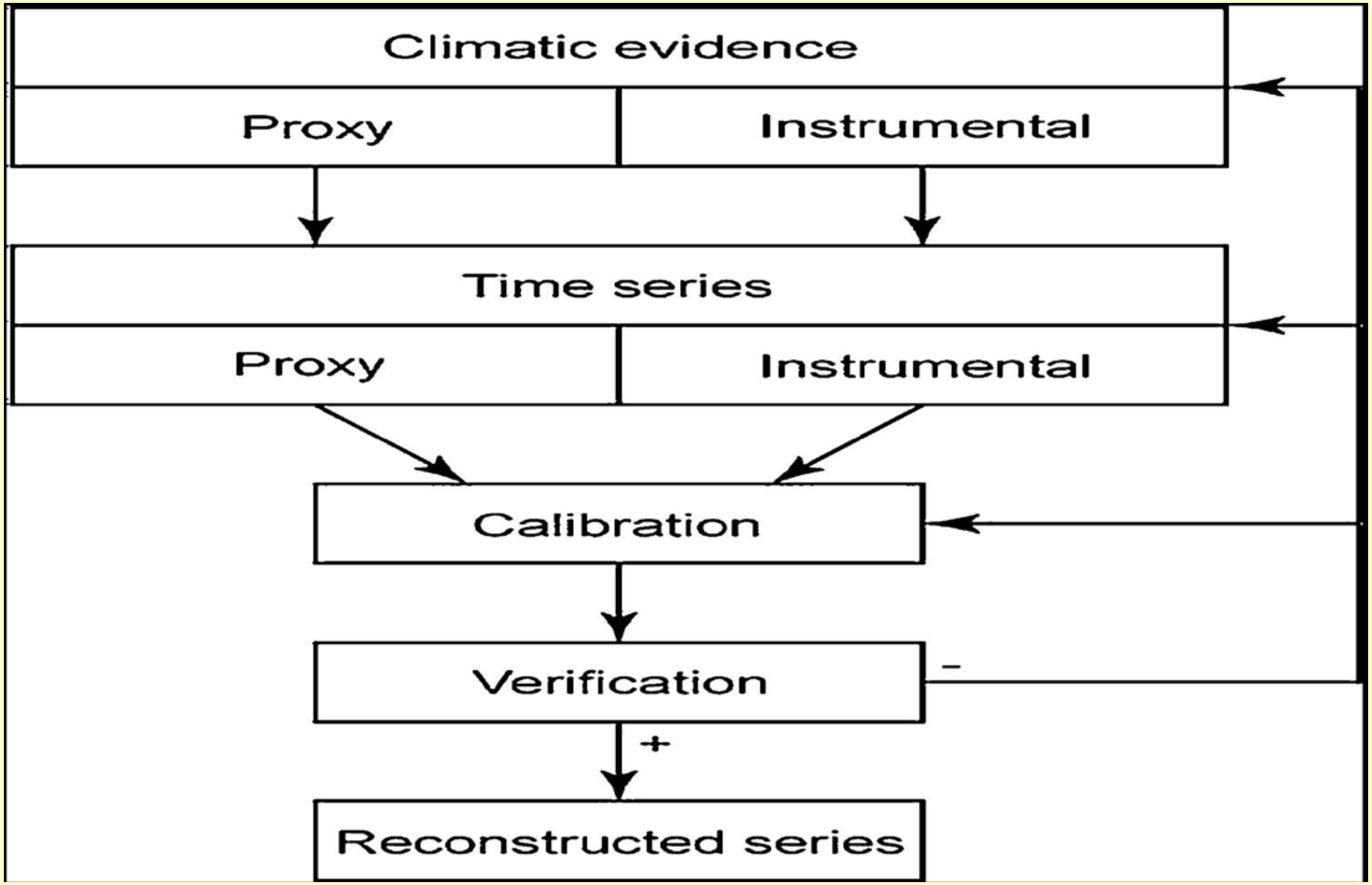
for Europe for comparison the longest series come from central England (so called Manley series since 1659), in addition very long series are available e.g. for the following places: Berlin (1701), de Bilt (1706), Uppsala (1722), St. Petersburg (1743), Geneva (1753), Stokholm (1756), Frankfurt (1757), Paris (1757), Vienna (1760), Prague (1771), Vilnius (1777); in about 30 places started meteorological observations in the 18th century.

Introduction cont.

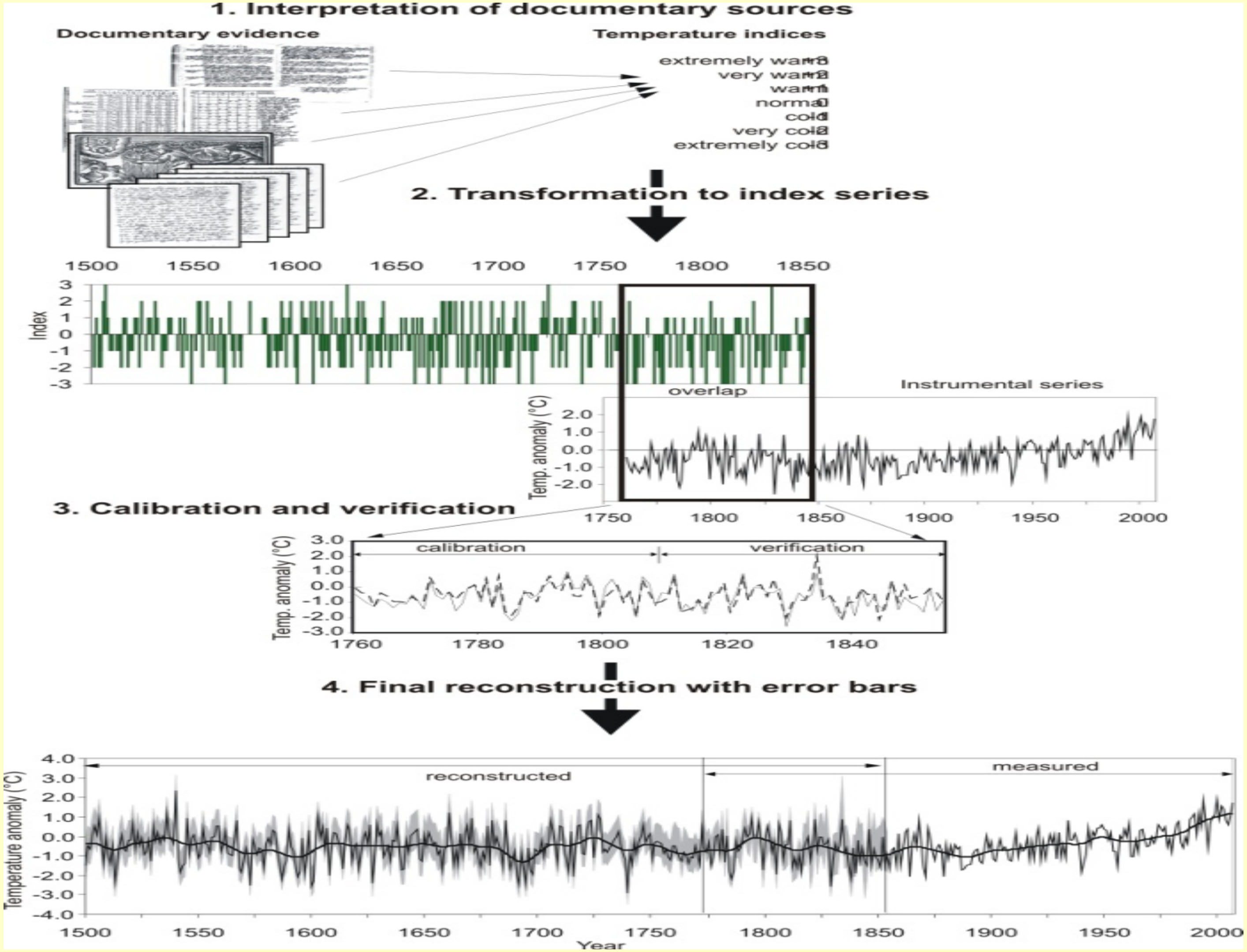
- **Pre-instrumental period: still limited**

However marked progress in Poland's climate history studies based on proxy data (documentary evidence, dendrochronological data, geophysical data) is noted since the beginning of the 1990s. Nonetheless, this does not extend back before the start of the last millennium (Przybylak et al. (eds), 2010; Przybylak 2011). Relatively better climate information is available since Nicolaus Copernicus's time and onwards.

Method of climate reconstruction (Brazdil 2002)



Schematic procedure of air temperature reconstruction based on documentary evidence (Brazdil 2010)



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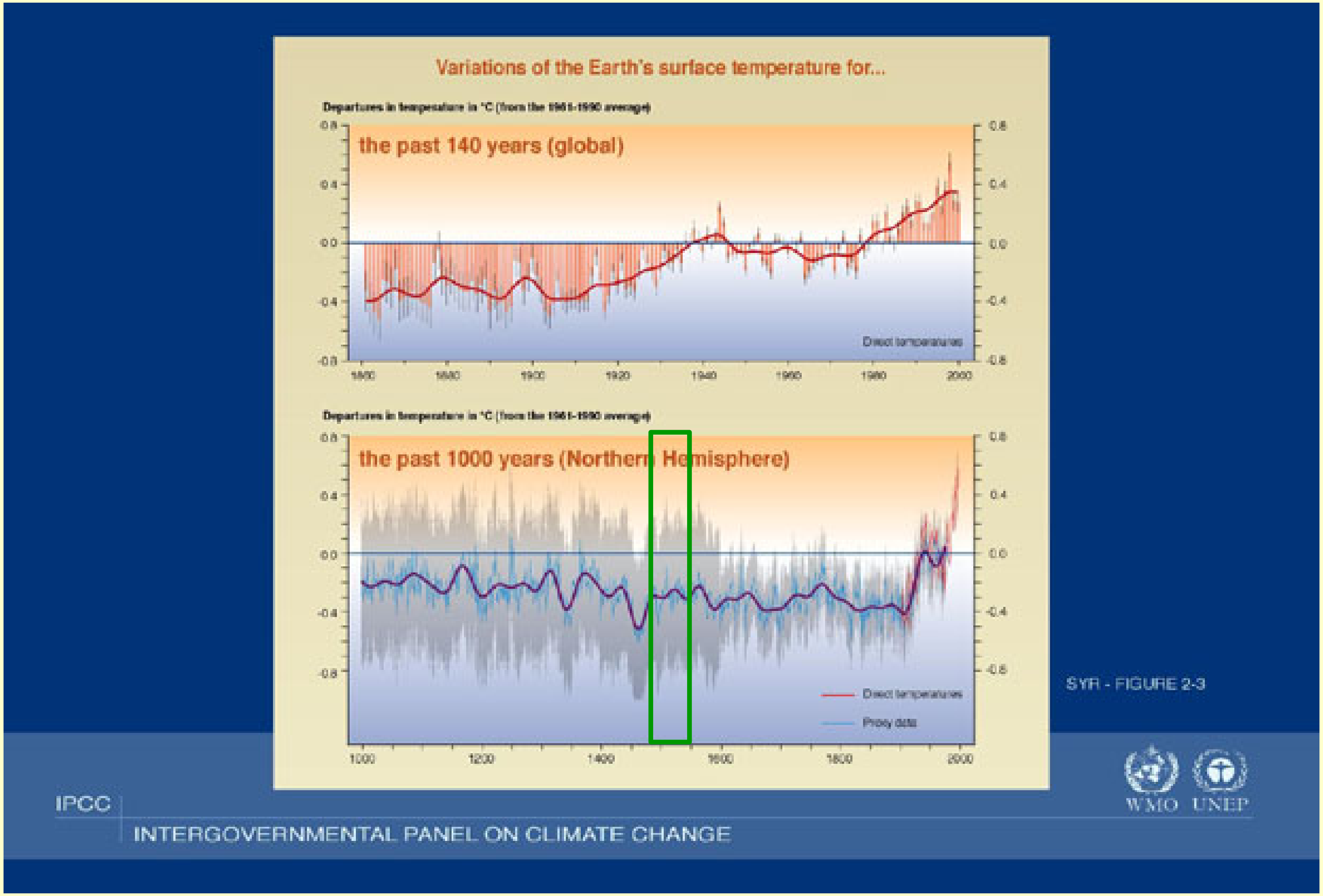
AIR TEMPERATURE

Annual Earth's surface air temperature changes in the last millennium (IPCC 2001)



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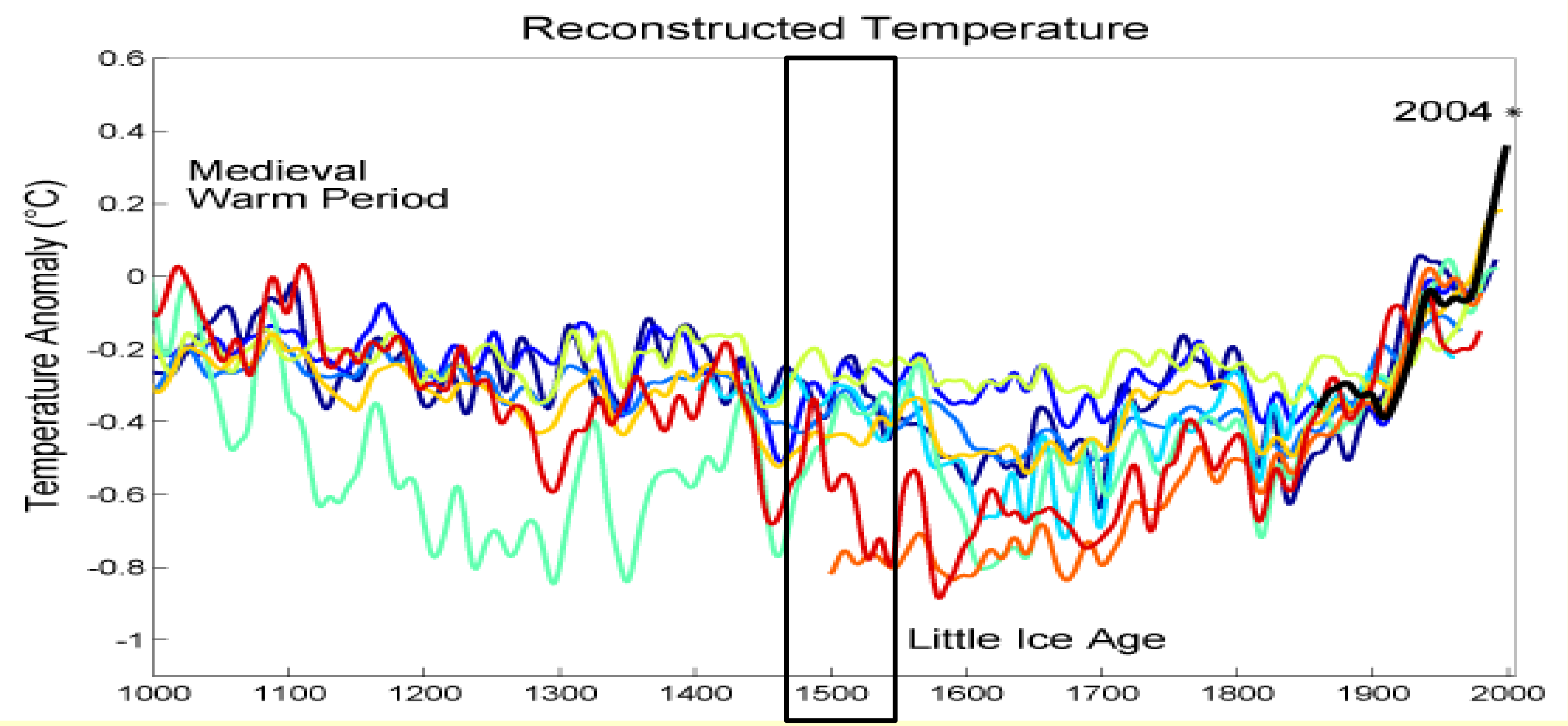
Changes of mean annual air temperature in the last millennium according to nine different reconstructions (red line – Moberg et al. 2005)



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Decadal frequencies of extreme events in Central and Eastern Europe (Sadowski 1991)

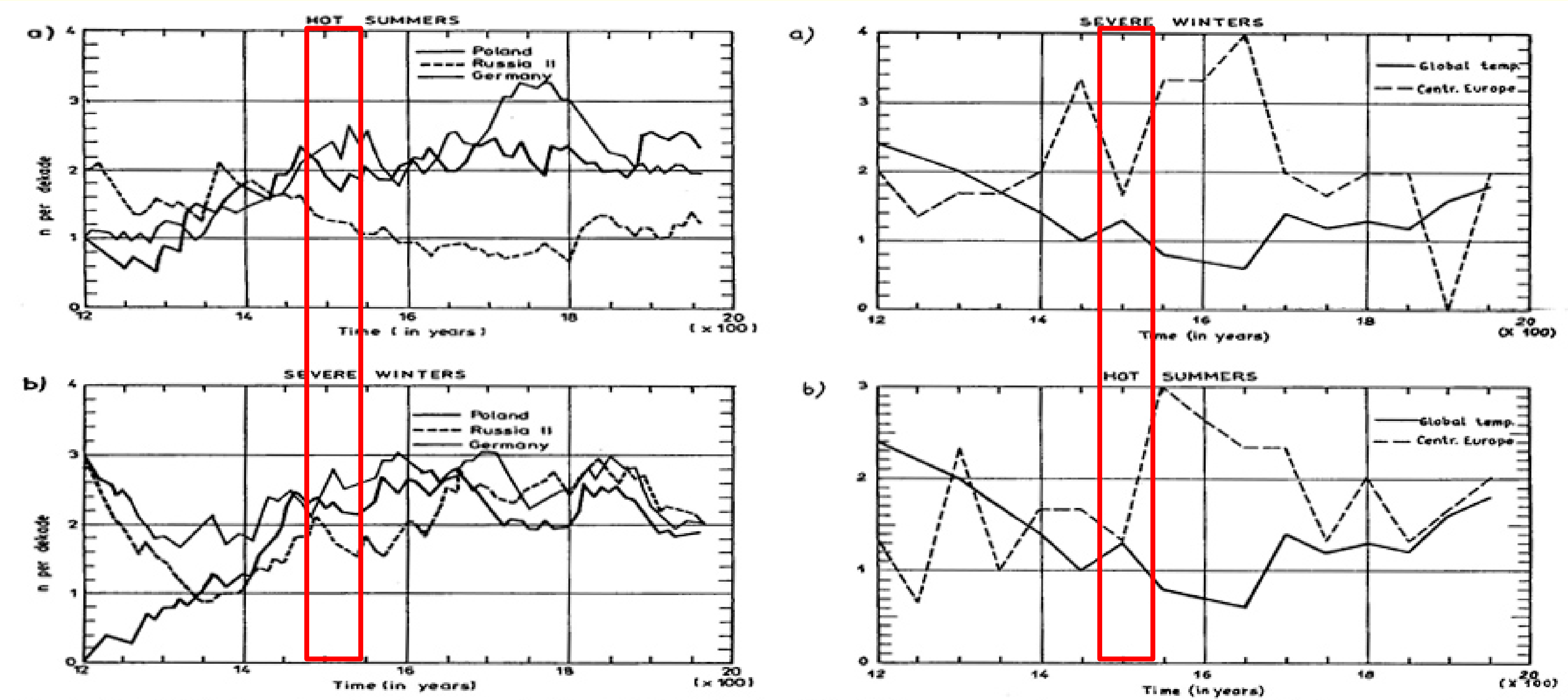


Fig. 1. Decadal frequencies of extreme events (smoothed values) for Central and Eastern Europe
Abb. 1. Denzennienhäufigkeiten extremer Ereignisse (geglättete Werte) für Mittel- und Osteuropa

Fig. 2. Frequency of severe winters and hot summers in Central and Eastern Europe vs global temperature changes
Abb. 2. Häufigkeit strenger Winter und heißer Sommer in Mittel- und Osteuropa im Vergleich zu globalen Temperaturänderungen

Jenkins 1983). A comparison between frequency series of both phenomena for the three above-mentioned parts of Europe was carried out using statistical, two-sample consistency tests: the *t*-test for the means and variances, and the Wilcoxon test of signed rank. Results of both tests are contained in Table 4. As is shown in the Table, assuming a statistical significance level of $\alpha = 0.05$, there is no reason to reject the hypothesis about the consistency of investigated series except the Russia II set for summer. More detailed investi-

Changes of mean continentality index (W), 1200-1970 (Sadowski 1991)

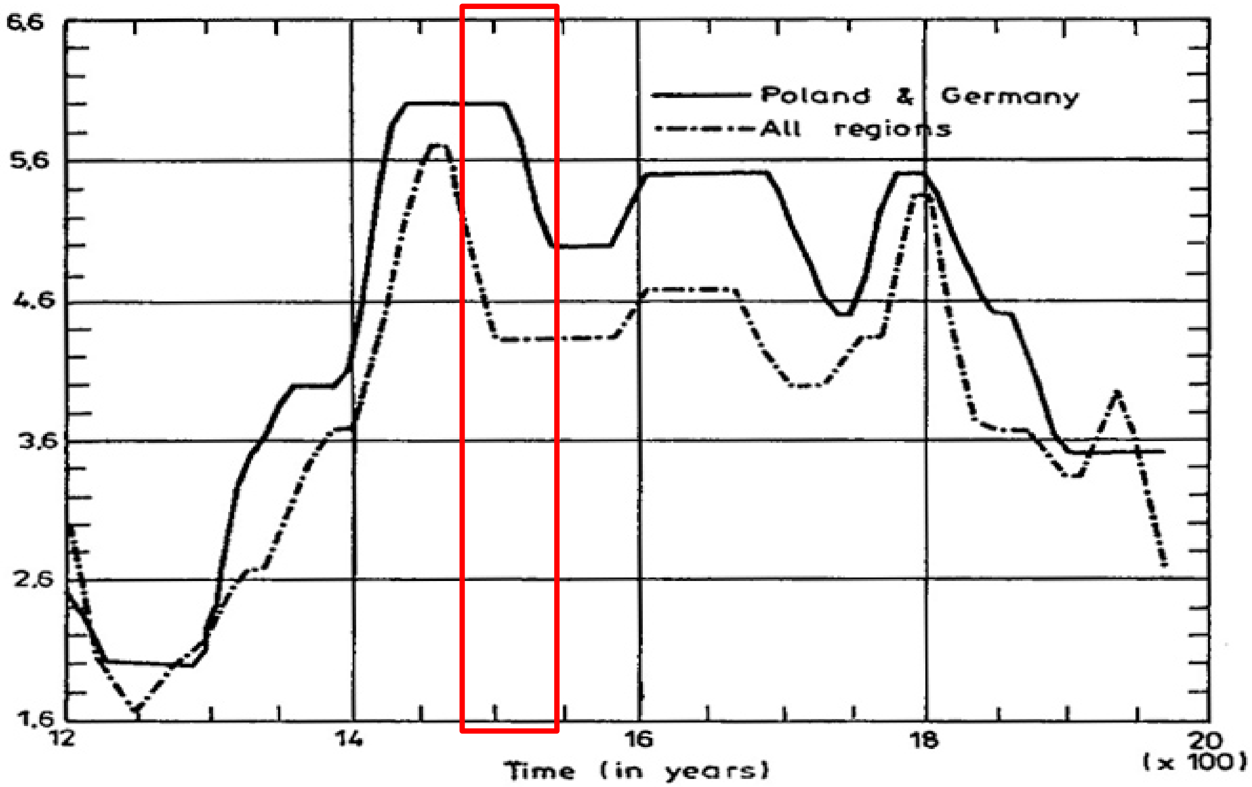
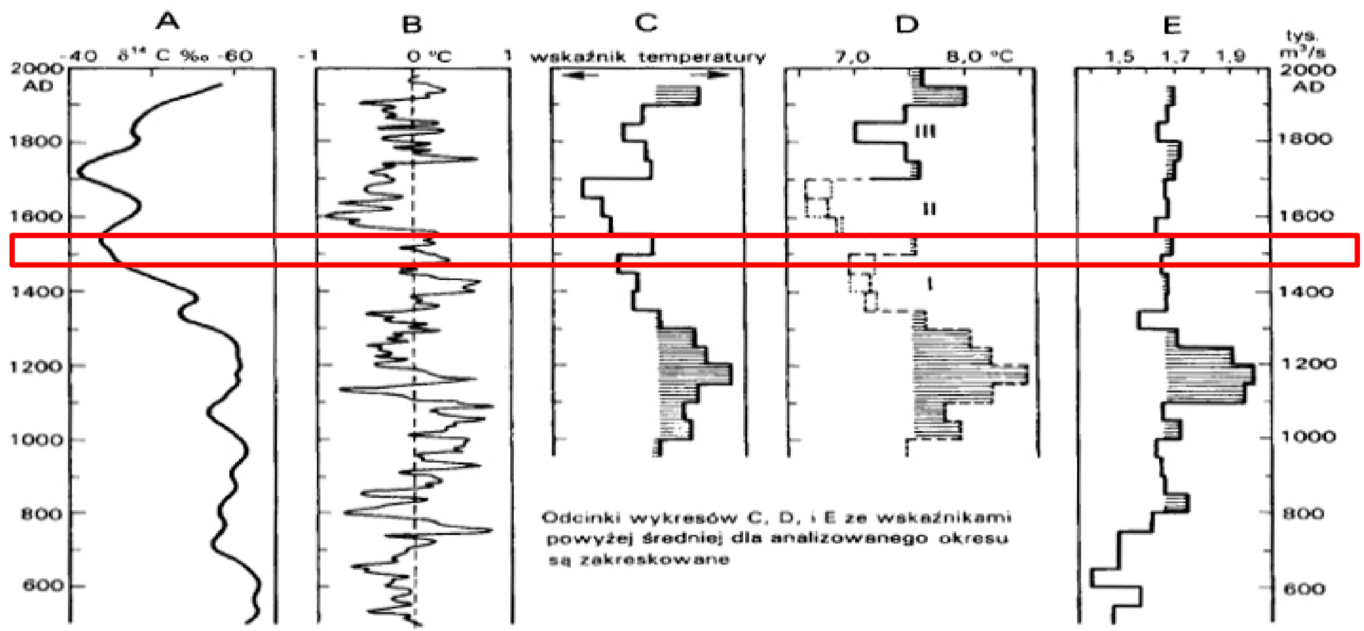


Fig. 6. Mean continentality index (*W*), variations 1200—1970
Abb. 6. Schwankungen des mittleren Kontinentalitätsindexes (*W*) 1200—1970

Climate changes in different regions of the Northern Hemisphere (A, B, C, and E) and in Poland (D) (after Maruszczak 1998)



RYC. 100. Tendencje sekularne zmian klimatu w ciągu ostatnich piętnastu stuleci według różnych wskaźników stosunków termicznych (B–D) i wilgotnościowych (E) (wg H. Maruszczaka 1998)

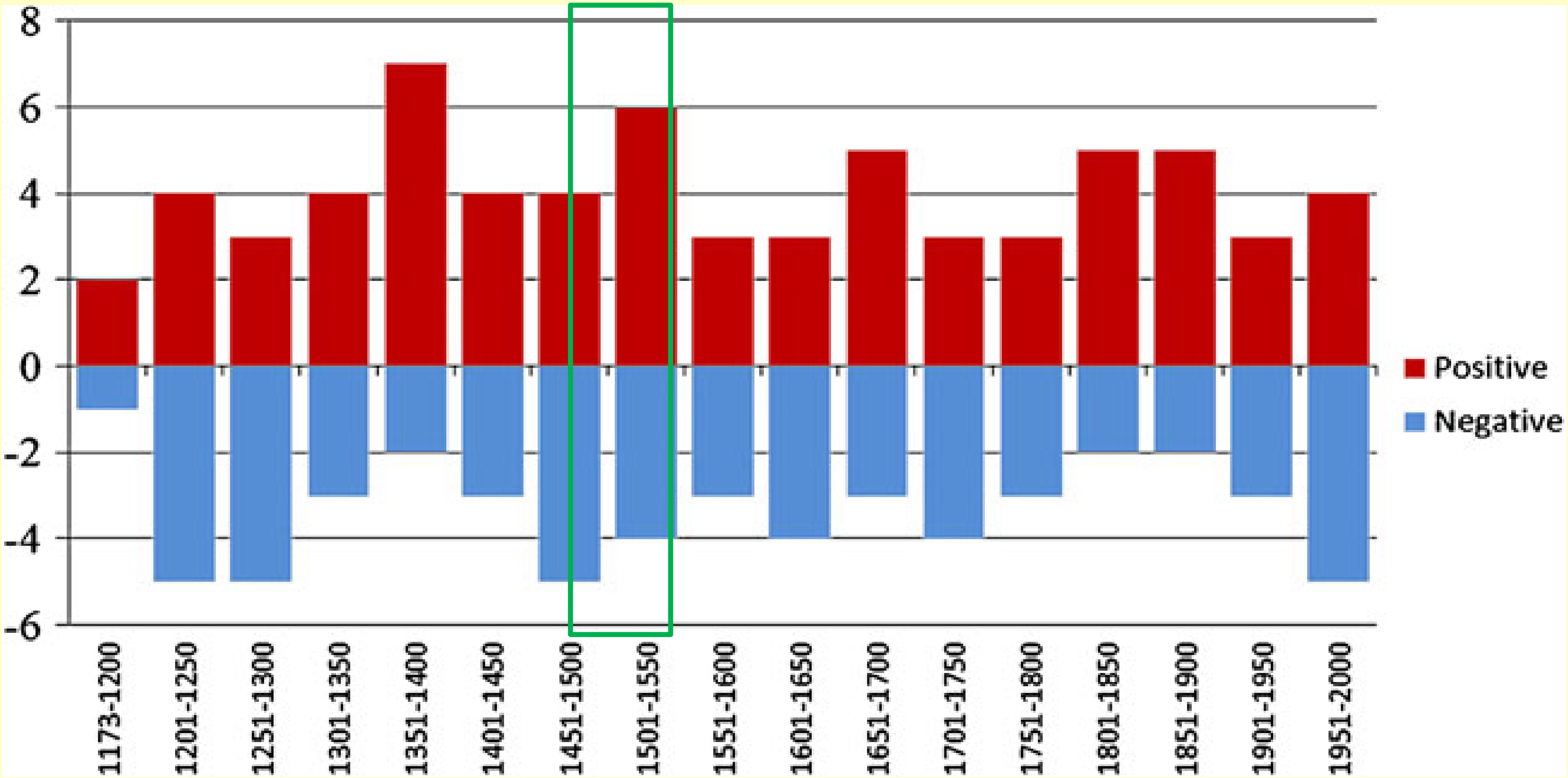
A — średnie 20-letnie wskaźniki δ ^{14}C wg dendrochronologicznych analiz pni drzew z Kalifornii, Irlandii i Niemiec W (wg Stuiver i Braziunas 1993); B — odchylenia średniej temperatury kwietnia–sierpnia w Skandynawii N na podstawie analizy pierścieni przyrostowych drzew (wg Briffa i in. 1992); C — kierunki zmian wskaźnika temperatur średnich i wyższych szerokości geograficznych półkuli północnej, ustalone na podstawie wykresów zmian temperatury w Anglii środkowej, pomiarów przyrostowych drzew w Kalifornii oraz wyników badań izotopowego składu tlenu w lodowcu na Grenlandii (wg Hammer i in. 1980); D — średnie, 50-letnie temperatury w Polsce środkowej na podstawie pomiarów instrumentalnych i obliczeń dla lat 1700–2000 oraz ekstrapolacji nawiązującej do wykresu „C" niniejszej ryciny (linia przerywana) lub wykresu cen artykułów spożywczych w Krakowie (linia kropkowana), z oznaczonymi trzema falami ochłodzenia małej epoki lodowej (wg Maruszczaka 1994); E — średnie, 50-letnie przepływy dolnego Dniepru wg danych pomiarów z XIX–XX w., danych historycznych oraz wyników analiz rocznych warstw osadów jeziornych z północnego Krymu (wg danych Shveca z 1978 r., zestawił Maruszczak w 1997 r.).

Frequency of occurrence of extreme warm and wet as well as cold and dry winters (DJF) and summers (JJA) in Poland from 1501 to 1840 (after Przybylak et al. 2004)

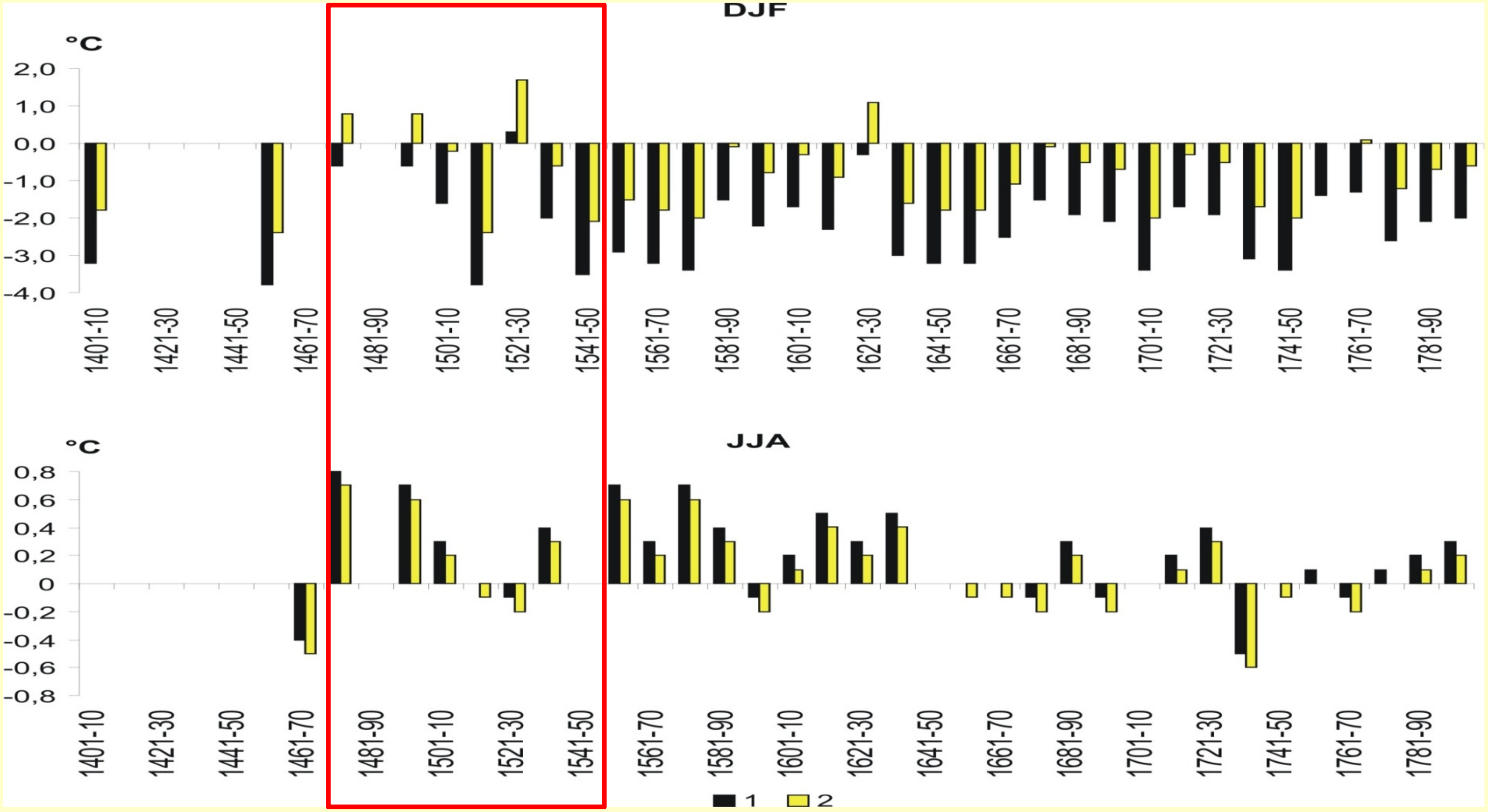
Period	Air temperature				Precipitation				Extreme situations	
	DJF		JJA		DJF		JJA			
	2 i 3	-2 i -3	2 i 3	-2 i -3	2 i 3	-2 i -3	2 i 3	-2 i -3	Total	%
1501-1550	**7**	12	2	0	**7**	**7**	**17**	4	56	24,2
1551-1600	1	**14**	7	0	1	3	10	**9**	45	19,5
1601-1650	0	11	**10**	0	0	0	3	0	24	10,4
1651-1700	4	11	3	1	1	0	4	3	27	11,7
1701-1750	2	12	1	**3**	6	0	9	3	36	15,6
1751-1800	0	10	0	0	1	0	1	0	12	5,2
1801-1840	0	9	7	2	2	1	4	6	31	13,4
1501-1840	14	79	30	6	18	11	48	25	231	
%	6,1	34,2	13,0	2,6	7,8	4,8	20,7	10,8		100,0

The greatest frequency of occurrence of extreme warm and wet as well as cold and dry winters and summers in the 50-year periods is shown in bold

The occurrence of pointer years in 50-year intervals, based on Scots pine widths, central Poland, 1173-2000 (after Koprowski et al. 2012)



Reconstructions of mean 10-year air temperatures (oC) in Poland from 1501 to 1840: a) winter (DJF) and b) summer (JJA). 1 and 2 – anomalies with respect to 1901–1960 and 1789–1850 means, respectively (after Przybylak 2011)



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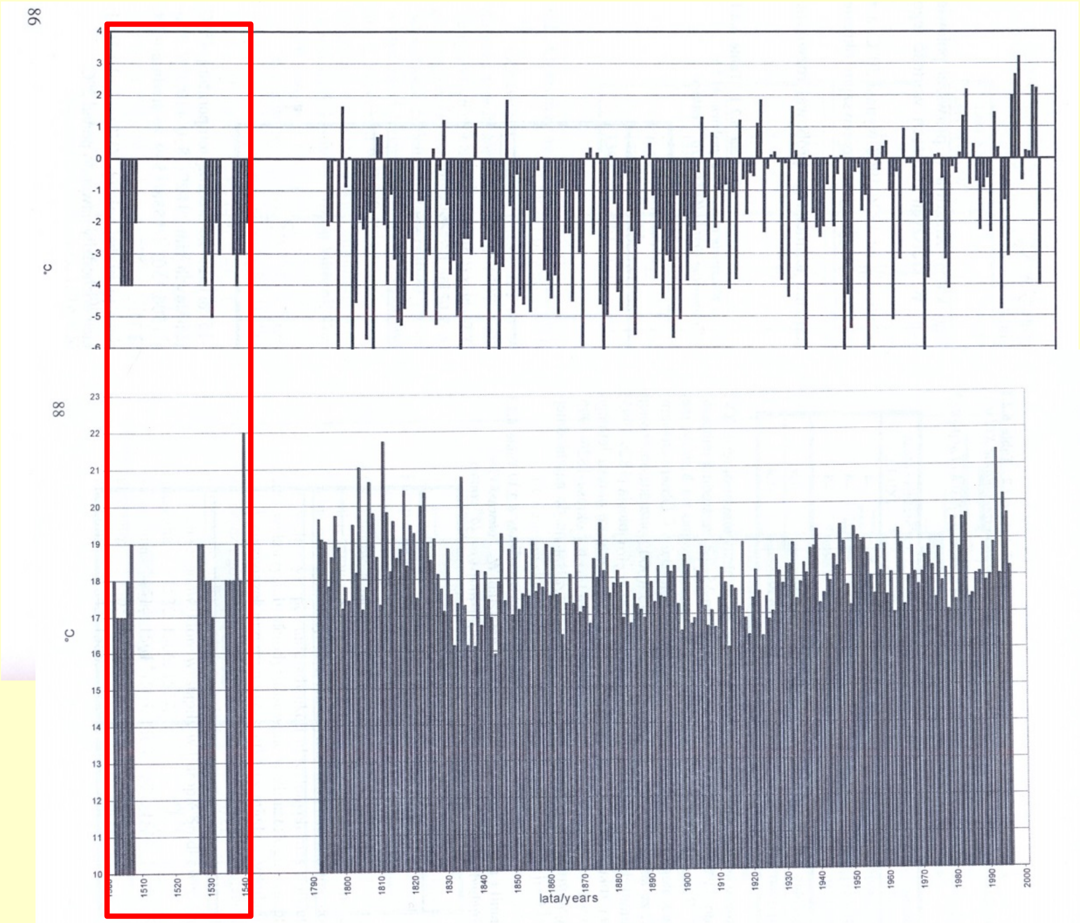
Mean winter (upper figure) and summer (lower figure) air temperature in Cracow in periods: 1502-1507, 1527-1531, 1535-1540 (based on Biem's weather notes) and 1792-1996 (instrumental data) (after Limanówka 2001)



Ryc. 6.2.2. Przebieg średniej temperatury powietrza w lecie w latach 1502-1507, 1527-1531, 1535-1540 (zrekonstruowane wg zapisków Biema) oraz 1792-1996 (obserwacje instrumentalne) w Krakowie
Fig. 6.2.2. Mean air temperature in summer in the years 1502-1507, 1527-1531, 1535-1540 (reconstructed from the notes of Biem) and 1792-1996 (instrumental observations) in Cracow

Long-term means of summer temperature in Cracow in historical periods (after Limanówka 2001)

Tabela 6.2.4 / Table 6.2.4

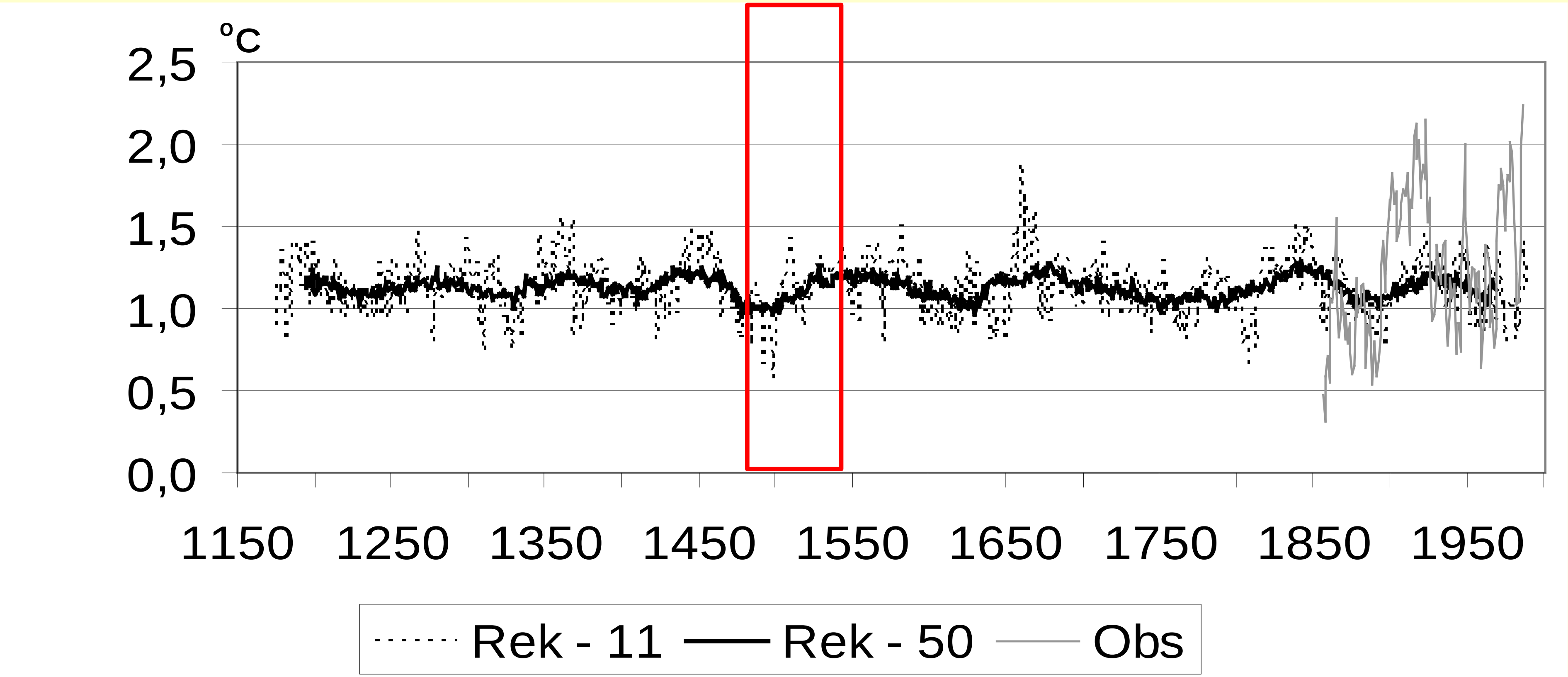
Średnie wieloletnie wartości temperatury lata (°C) w Krakowie w pierwszej połowie XVI w. oraz w XIX-XX w.

Mean multi-annual values of the summer air temperature (in °C) in Cracow the first half of the 16th and 19th-20th century

Okresy Periods	Miesiąc / Month			Średnia / Mean (VI-VIII)
	VI	VII	VIII	
1502-1507	17	18	18	18
1527-1531	17	20	18	18
1535-1540	19	19	19	19
1826-1995	17,1	18,7	17,9	17,9
1901-1960	17,0	18,8	17,9	17,9

A reconstruction of mean January–April air temperature in Poland for the period 1170–1994 using a standardised chronology of tree-ring widths for Scots pine (Pinus sylvestris L.) (after Przybylak et al. 2001, modified)

Key: Rek-11, Rek-50 – 11- and 50-year running means; reconstruction using areally-averaged air temperatures from Warsaw, Bydgoszcz and Gdańsk for calibration, Obs – mean January–April areally-averaged air temperature from Warsaw, Bydgoszcz and Gdańsk



Reconstruction of mean air temperature for periods Dec-Mar (Aa) and Feb-Mar (Ps) based on chronologies of fir and Pinus sylvestris L., respectively (after Szychowska-Krąpiec 2010)

Key: capital letters W, S, M and D denote minimum solar activity periods Wolf, Sporer, Maunder and Dalton, respectively

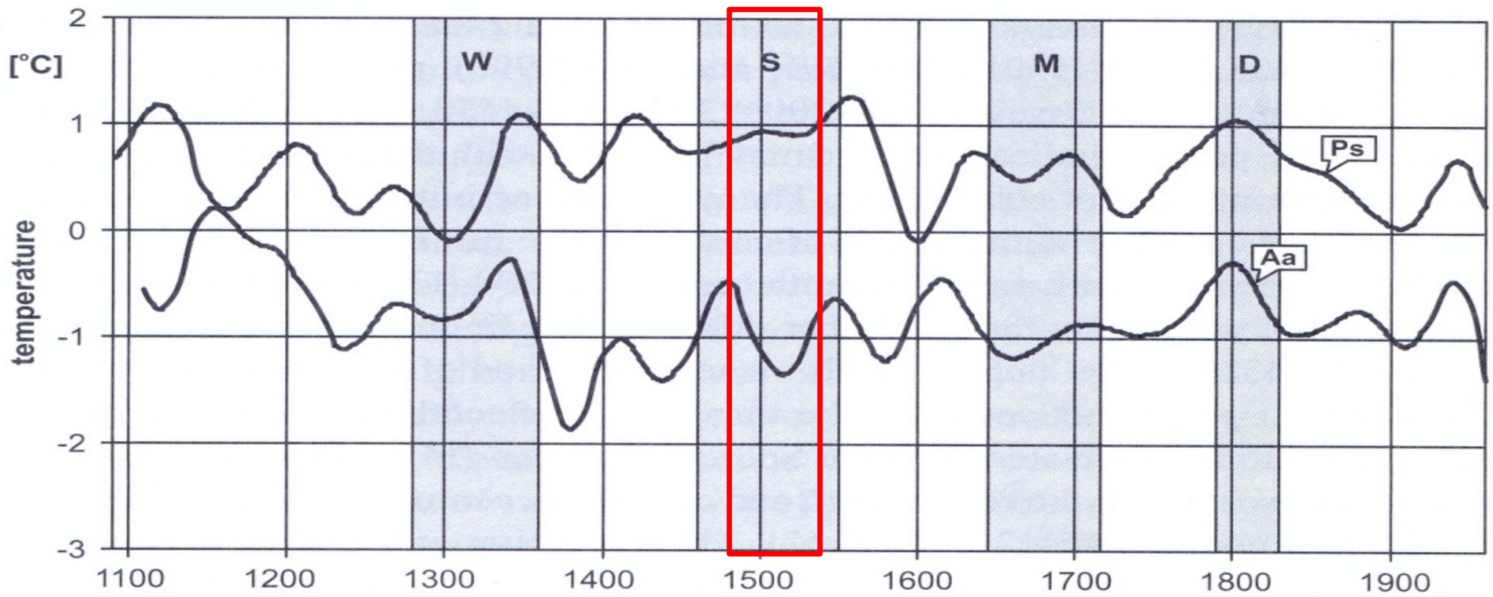
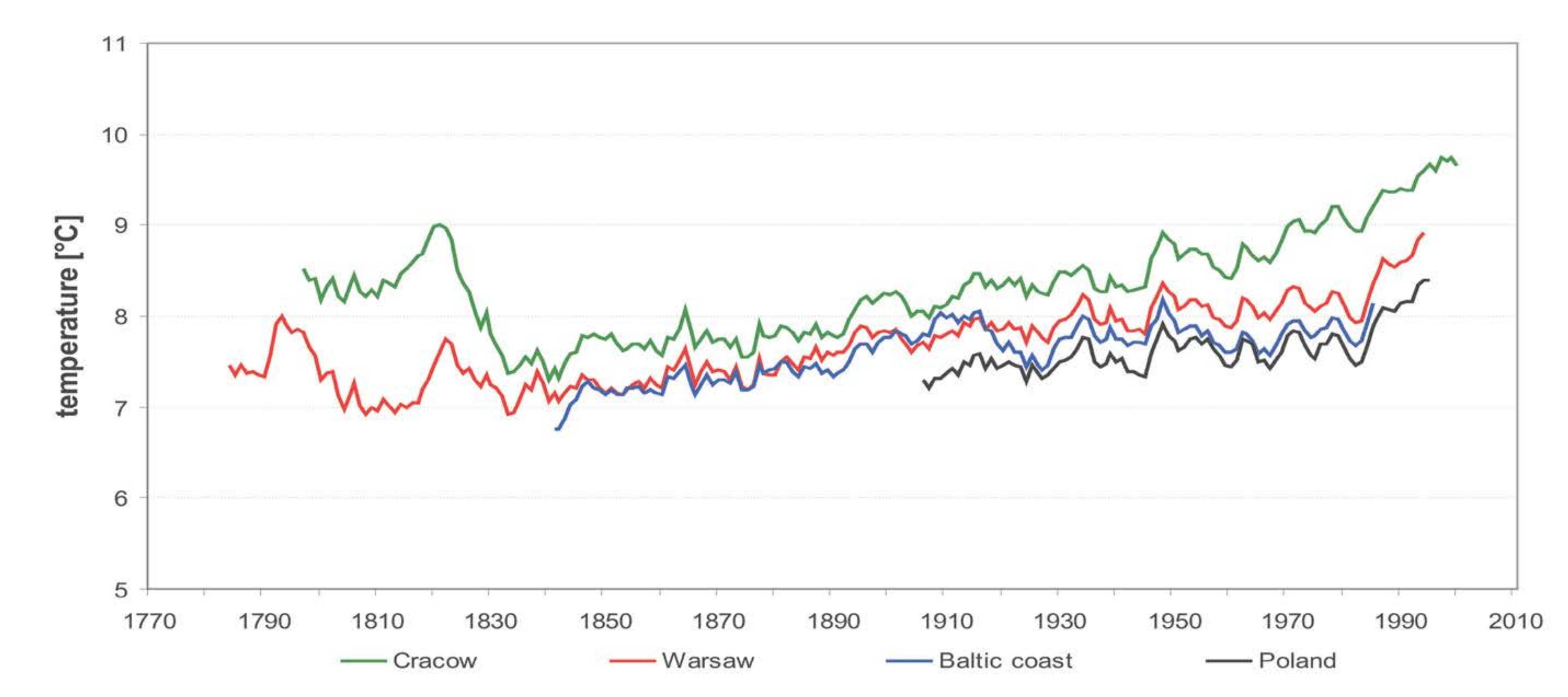


Fig. 57. Comparison of the reconstructed temperatures of December, January, February, and March (Aa) and the reconstructed temperatures of February and March (Ps) with the periods of the weakened solar activity (W – the Wolf Minimum, S – the Spörer Minimum, M – the Maunder Minimum, D – the Dalton Minimum), Ps – the reconstructed temperatures of February and March on the basis of the pine chronology, (Aa) the reconstructed temperatures of December, January, February, and March on the basis of the fir chronology

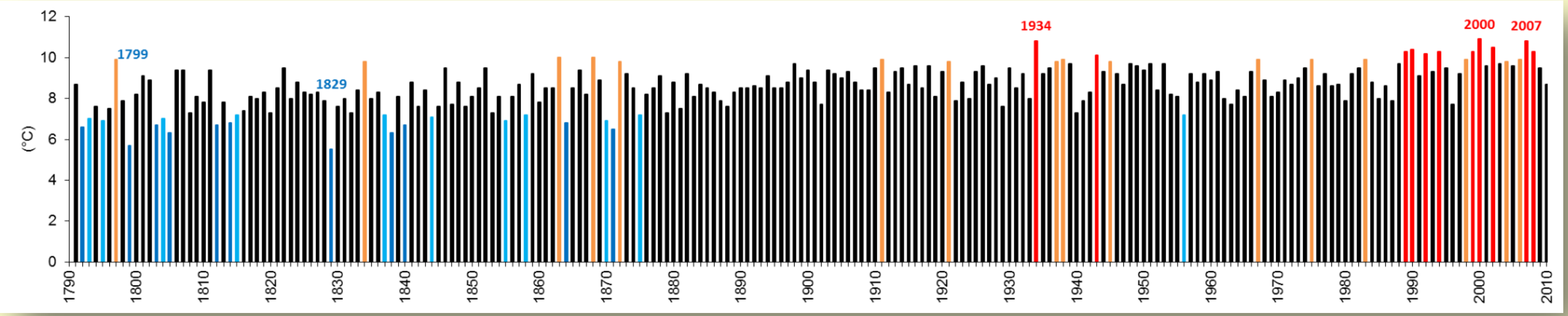
Long-term changes of 11-years running mean annual values of air temperature in the period of instrumental observations (after Przybylak 2010, modified)

Key: Data from Cracow after Trepińska (1971) and Matuszko (2007, ed.), from Warsaw after Lorenc (2000), from coast of Baltic after Miętus (1996) and for Poland (after Żmudzka 2008).

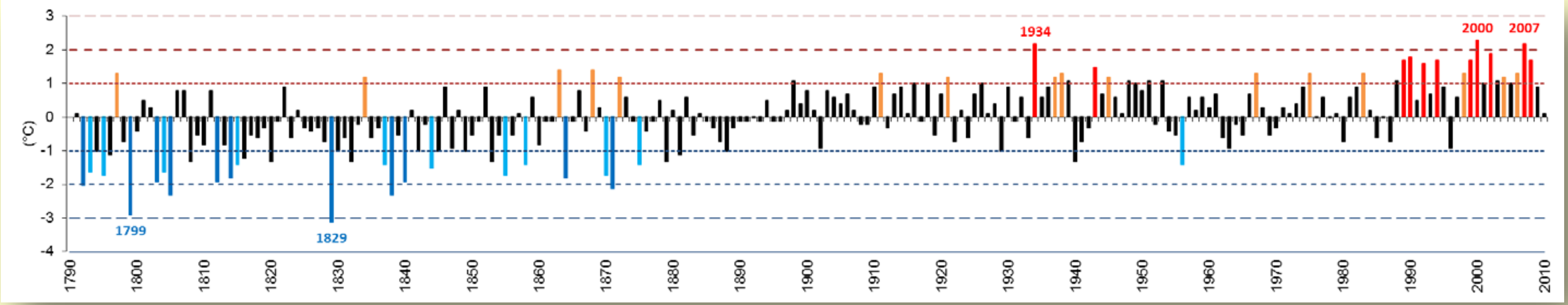


Extremely warm and cold years in Wrocław, 1791-2010

based on mean annual values (after Przybylak et al. 2013)



Extremely warm and cold years (≥99% - red with label, ≥95% - red, ≥90% - orange and ≤10% - light blue, ≤5% - dark blue, ≤1% - dark blue with label) in Wrocław, 1791-2010
Values of thresholds: 1% = 5,7°C; 5% = 6,8°C; 10% = 7,2°C; 90% = 9,8°C; 95% =10,1°C; 99% =10,8°C
Percentiles calculated for annual values



Mean annual temperature anomalies in Wrocław, 1791-2010. Reference period 1791-2010. Standard deviations (±1σ - dots, ±2σ – short dashed lines, ±3σ – long dashed lines, ±4σ – solid line) calculated for the reference period
Extremely warm and cold years (≥99% - red with label, ≥95% - red, ≥90% - orange and ≤10% - light blue, ≤5% - dark blue, ≤1% - dark blue with label) in Wrocław, 1791-2010

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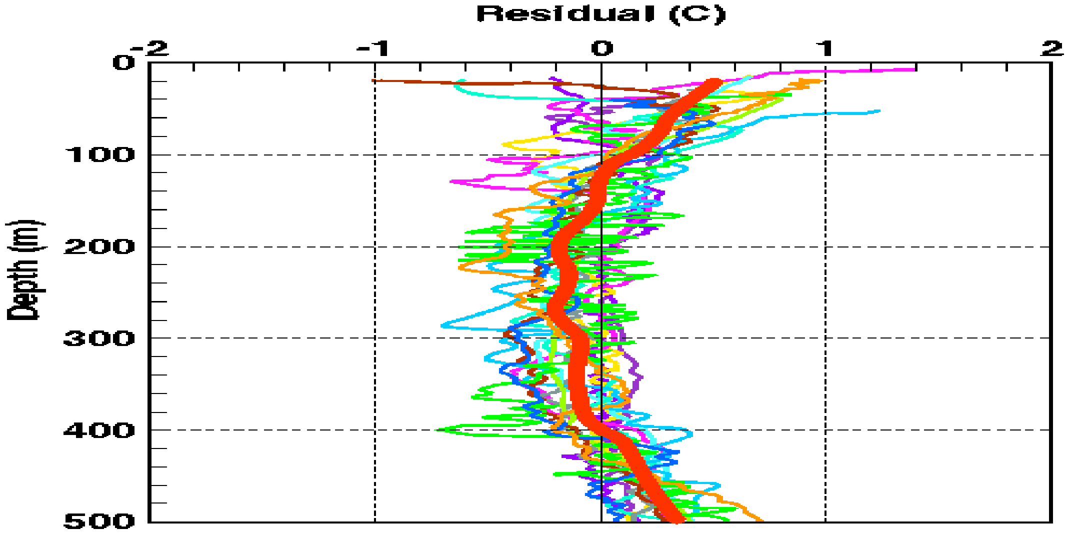
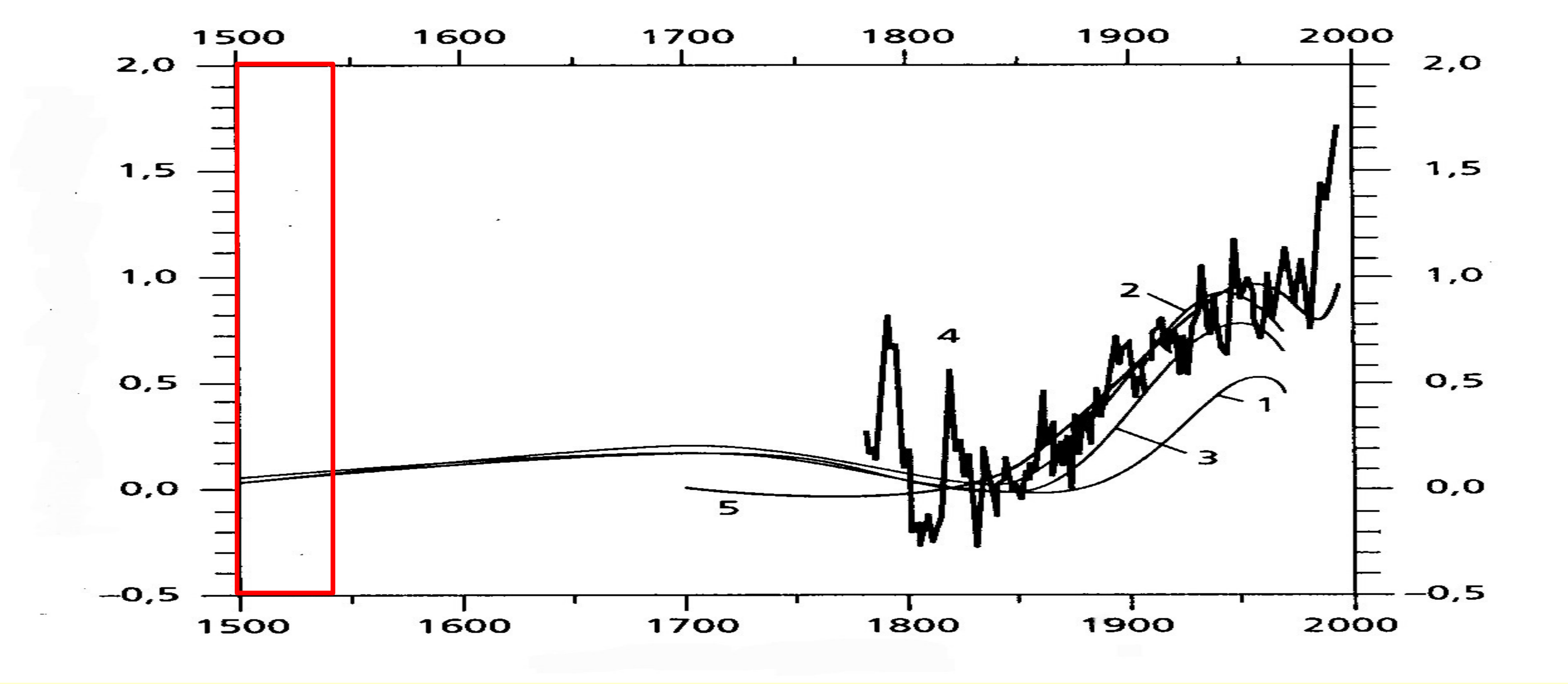
SURFACE GROUND TEMPERATURE

Anomalies of temperature with depth for 13 boreholes located in Poland and their mean anomaly (red line) (after Majorowicz et al. 2001)



Reconstructions of the ground-surface temperature history in Poland (curves 1–3) and their comparison with the analogical reconstruction (curve 5) based on the deepest point temperature profile with depth in the Grodziec borehole, as well as with air temperature (curve 4) (after Majorowicz et. al. 2001).

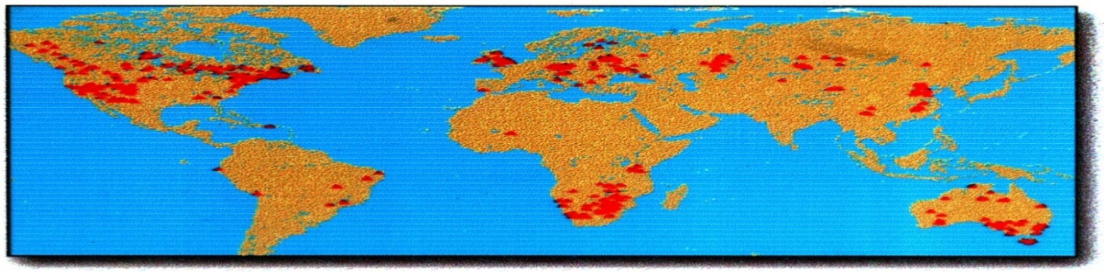
Key: curve 1 – reconstruction from the continuous temperature logs which indicate minor ground-surface temperature warming, curve 2 – reconstruction derived from continuous temperature logs indicative of major warming, curve 3 – average based on the above two groups, curve 4 – homogeneous air temperature series from Warsaw (11–year running mean) (Lorenc 2000).



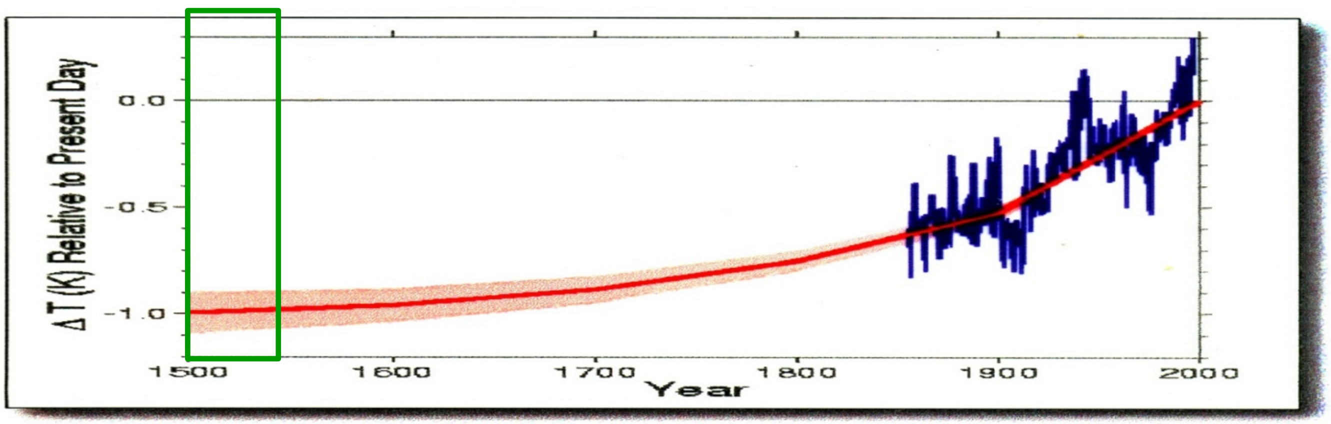
Reconstructions of the mean global ground-surface temperature history (lower figure) based on data from 616 boreholes (for location see upper map, red dots)

(after Pollack et al., 1998)

Borehole Data and Derived Climatic Parameters



The map above shows the location of borehole sites in the database that we have analyzed to date. The diagram below is a global perspective of surface temperature change over the last five centuries, averaged from 616 indivisual reconstructions. The thick red line represents the mean surface temperature since 1500 relative to the present-day. The shading represents ± one standard error of the mean. Shown in blue for comparision is the global mean surface air temperature (five year running average) derived from instrumental records by P.D. Jones and colleagues at the University of East Anglia (http://www.cru.uea.ac.uk/).



ATMOSPHERIC

PRECIPITATION

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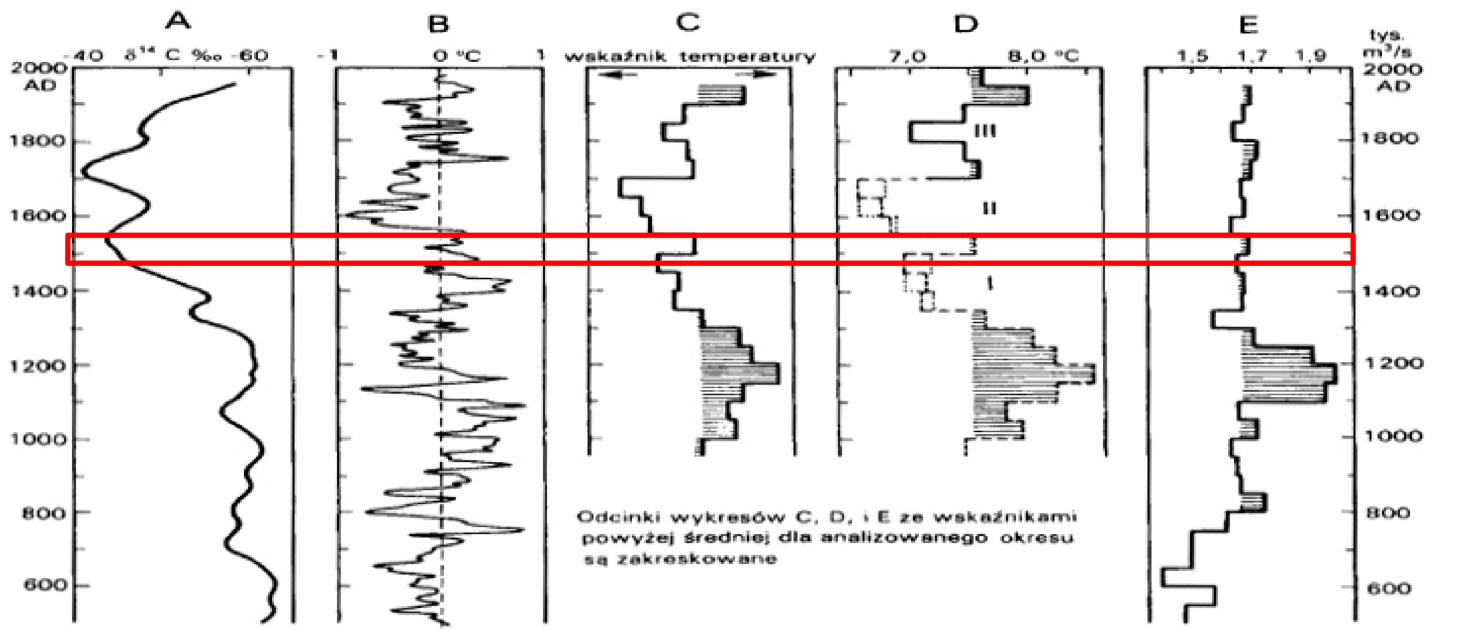
Climate changes in different regions of the Northern Hemisphere (A, B, C, and E) and in Poland (D) (after Maruszczak 1998)



Ryc. 100. Tendencje sekularne zmian klimatu w ciągu ostatnich piętnastu stuleci według różnych wskaźników stosunków termicznych (B–D) i wilgotnościowych (E) (wg H. Maruszczaka 1998)

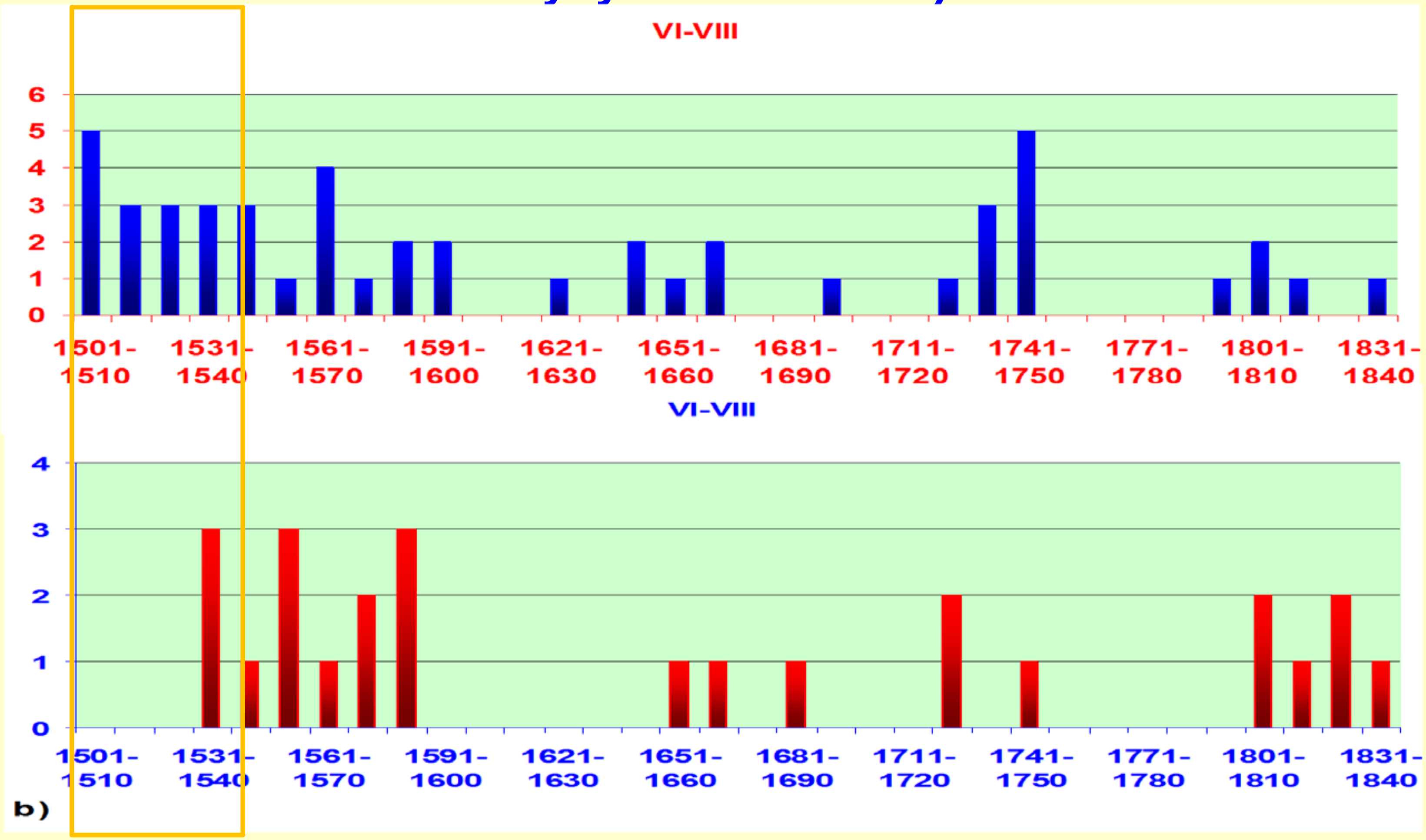
A — średnie 20-letnie wskaźniki $\delta\ ^{14}C$ wg dendrochronologicznych analiz pni drzew z Kalifornii, Irlandii i Niemiec W (wg Stuiver i Braziunas 1993); B — odchylenia średniej temperatury kwietnia–sierpnia w Skandynawii N na podstawie analizy pierścieni przyrostowych drzew (wg Briffa i in. 1992); C — kierunki zmian wskaźnika temperatur średnich i wyższych szerokości geograficznych półkuli północnej, ustalone na podstawie wykresów zmian temperatury w Anglii środkowej, pomiarów przyrostowych drzew w Kalifornii oraz wyników badań izotopowego składu tlenu w lodowcu na Grenlandii (wg Hammer i in. 1980); D — średnie, 50-letnie temperatury w Polsce środkowej na podstawie pomiarów instrumentalnych i obliczeń dla lat 1700–2000 oraz ekstrapolacji nawiązującej do wykresu „C" niniejszej ryciny (linia przerywana) lub wykresu cen artykułów spożywczych w Krakowie (linia kropkowana), z oznaczonymi trzema falami ochłodzenia małej epoki lodowej (wg Maruszczaka 1994); E — średnie, 50-letnie przepływy dolnego Dniepru wg danych pomiarów z XIX–XX w., danych historycznych oraz wyników analiz rocznych warstw osadów jeziornych z północnego Krymu (wg danych Shveca z 1978 r., zestawił Maruszczak w 1997 r.).

Frequency of occurrence of extreme warm and wet as well as cold and dry winters (DJF) and summers (JJA) in Poland from 1501 to 1840 ((after Przybylak et al. 2004)

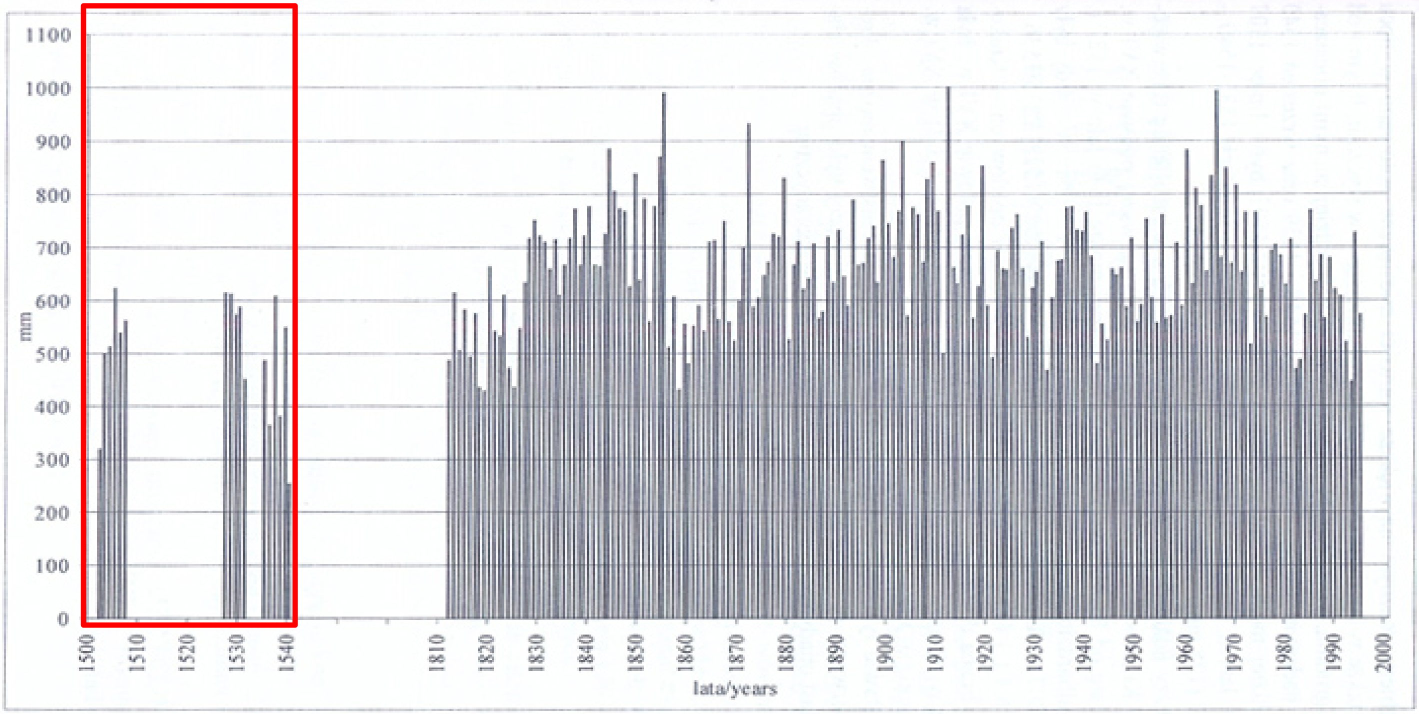
Period	Air temperature				Precipitation				Extreme situations	
	DJF		JJA		DJF		JJA			
	2 i 3	-2 i -3	2 i 3	-2 i -3	2 i 3	-2 i -3	2 i 3	-2 i -3	Total	%
1501-1550	**7**	12	2	0	**7**	**7**	**17**	4	56	24,2
1551-1600	1	**14**	7	0	1	3	10	**9**	45	19,5
1601-1650	0	11	**10**	0	0	0	3	0	24	10,4
1651-1700	4	11	3	1	1	0	4	3	27	11,7
1701-1750	2	12	1	**3**	6	0	9	3	36	15,6
1751-1800	0	10	0	0	1	0	1	0	12	5,2
1801-1840	0	9	7	2	2	1	4	6	31	13,4
1501-1840	14	79	30	6	18	11	48	25	231	
%	6,1	34,2	13,0	2,6	7,8	4,8	20,7	10,8		100,0

The greatest frequency of occurrence of extreme warm and wet as well as cold and dry winters and summers in the 50-year periods is shown in bold

Decadal frequencies of occurrence of summers (JJA) that were: a) extremely wet and very wet (indices 3 and 2) and b) extremely dry and very dry (indices –3 and –2) in Poland between 1501 and 1840 (after Przybylak et. al. 2004)



Annual totals of precipitation in Cracow (1502-1507, 1527-1531 and 1535-1540 - reconstruction based on annual number of days with precipitation), 1814-1849 reconstruction by Twardosz (1999), 1850-1995 – instrumental observations (after Limanówka 2001)



Ryc. 6.3.2. Przebieg sum rocznych opadów w Krakowie (1501-1507, 1527-1531, 1535-1540 – rekonstrukcja wg Twardosza bazująca na liczbie dni z opadem, 1814-1849 – rekonstrukcja Twardosza (1999), 1850-1995 – obserwacje instrumentalne)

Fig. 6.3.2. Annual totals of precipitation in Cracow (1502-1507, 1527-1531, 1535-1540 – recontruction after Twardosz method basing on the number of days with precipitation, 1814-1849 – reconstruction by Twardosz (1999), 1850-1995 – instrumental observations)

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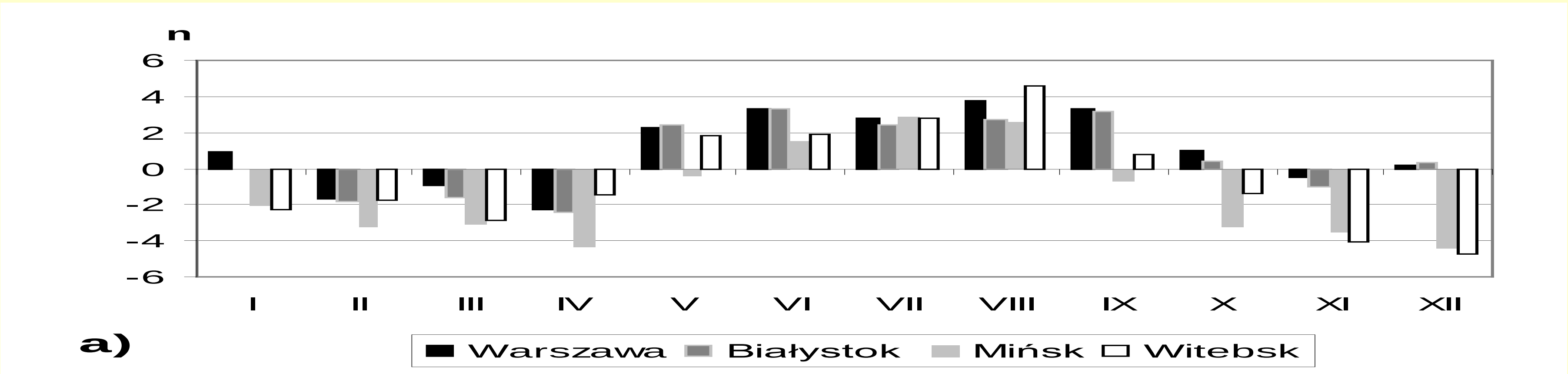
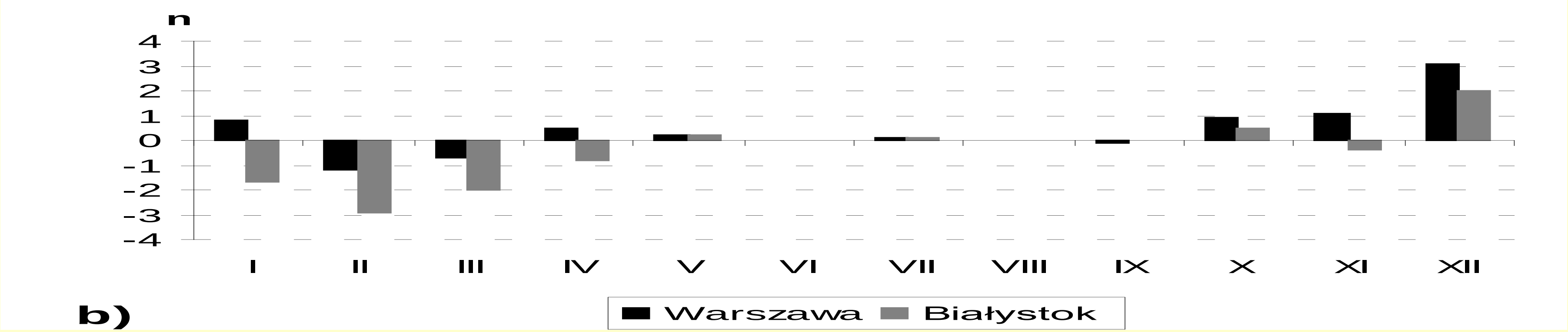
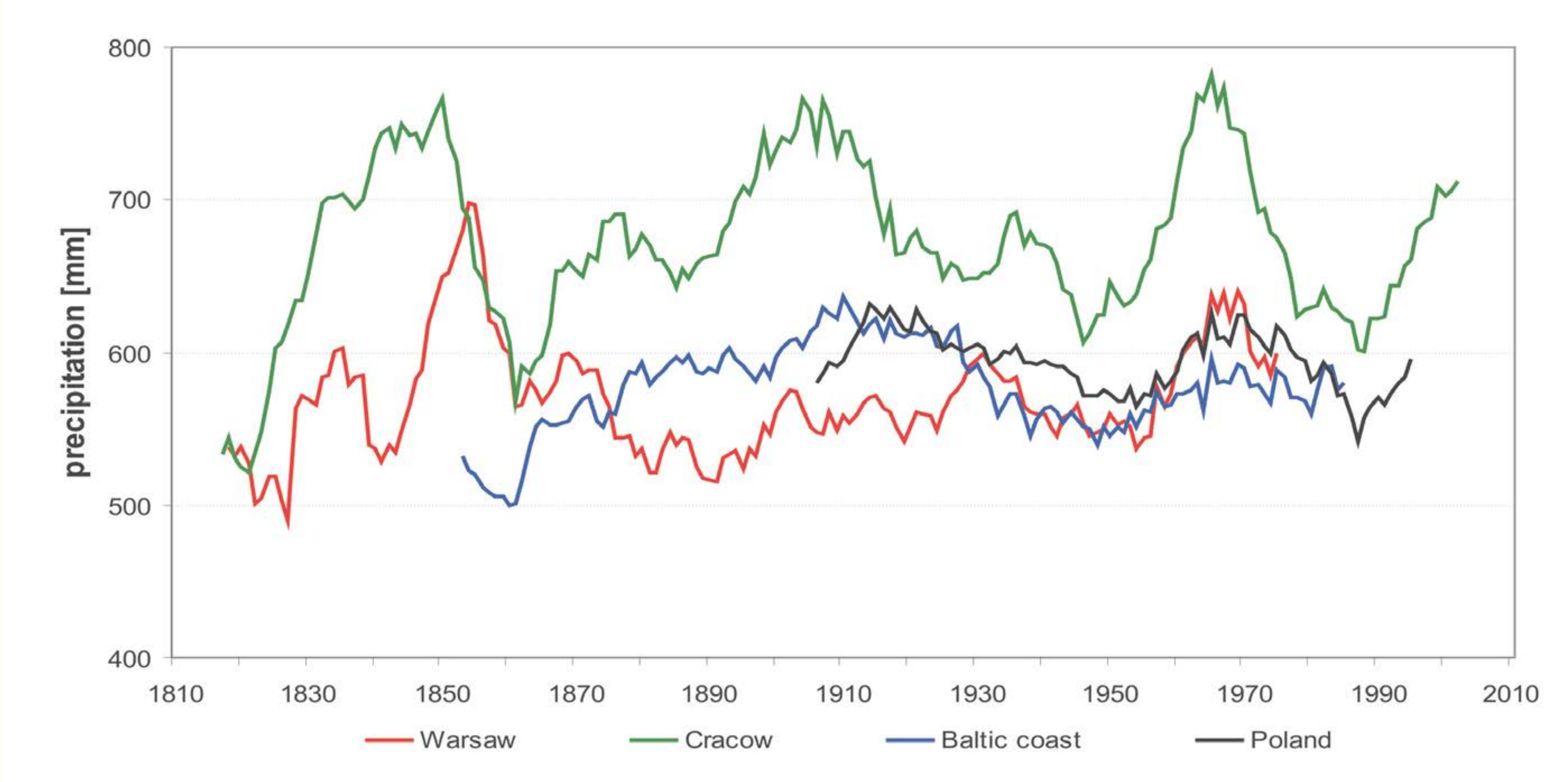
Differences in number of days with precipitation (a) and snowfall (b) between period 1656-1667 (diary of J. A. Chrapowicki) and contemporary (meteorological stations' data) period 1931-1960 (after Nowosad et al. 2006)





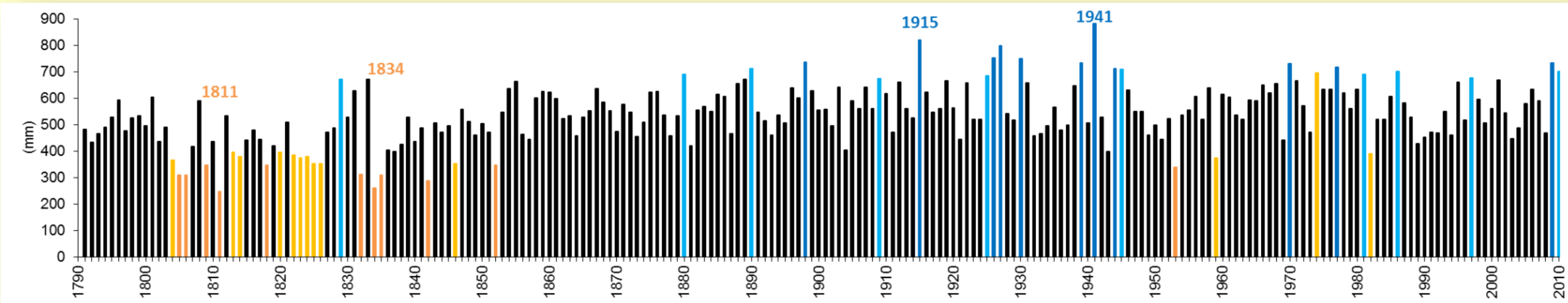
Long-term changes of 11-years running mean annual totals of precipitation in the period of instrumental observations (after Przybylak 2010, modified)

Key: Data from Warsaw after Kożuchowski (1990, ed.), from Cracow after Twardosz (1999, updated), from coastal part of Baltic after Miętus (1996) and from Polski (after Kożuchowski and Żmudzka 2003)



Extremely wet and dry years **in Wrocław, 1791-2010**

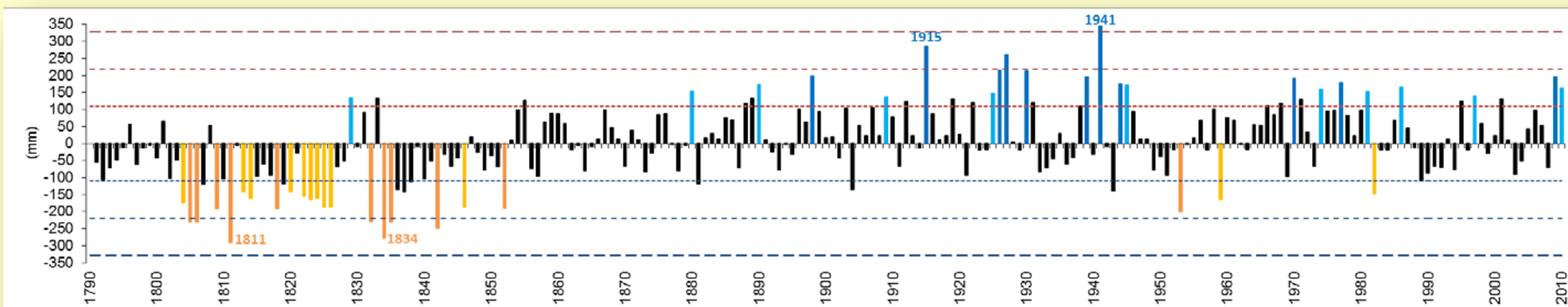
(after Przybylak et al. 2013)



Extremely wet and dry years (≥99% - black blue with label, ≥95% - black blue, ≥90% - light blue and ≤10% - yellow, ≤5% - orange, ≤1% - orange with label) in Wrocław, 1791-2010

Threshold values: 1% = 261 mm; 5% = 348 mm; 10% = 397 mm; 90% = 673 mm; 95% = 713 mm; 99% =822 mm.

Percentiles calculated for annual totals



Annual precipitation anomalies in Wrocław, 1791-2010. Reference period, 1791-2010. Standard deviations (±1σ - dots, ±2σ – short dashed lines, ±3σ – long dashed lines) calculated for the reference period

Extremely wet and dry years (≥99% - black blue with label, ≥95% - black blue, ≥90% - light blue and ≤10% - yellow, ≤5% - orange, ≤1% - orange with label) in Wrocław, 1791-2010

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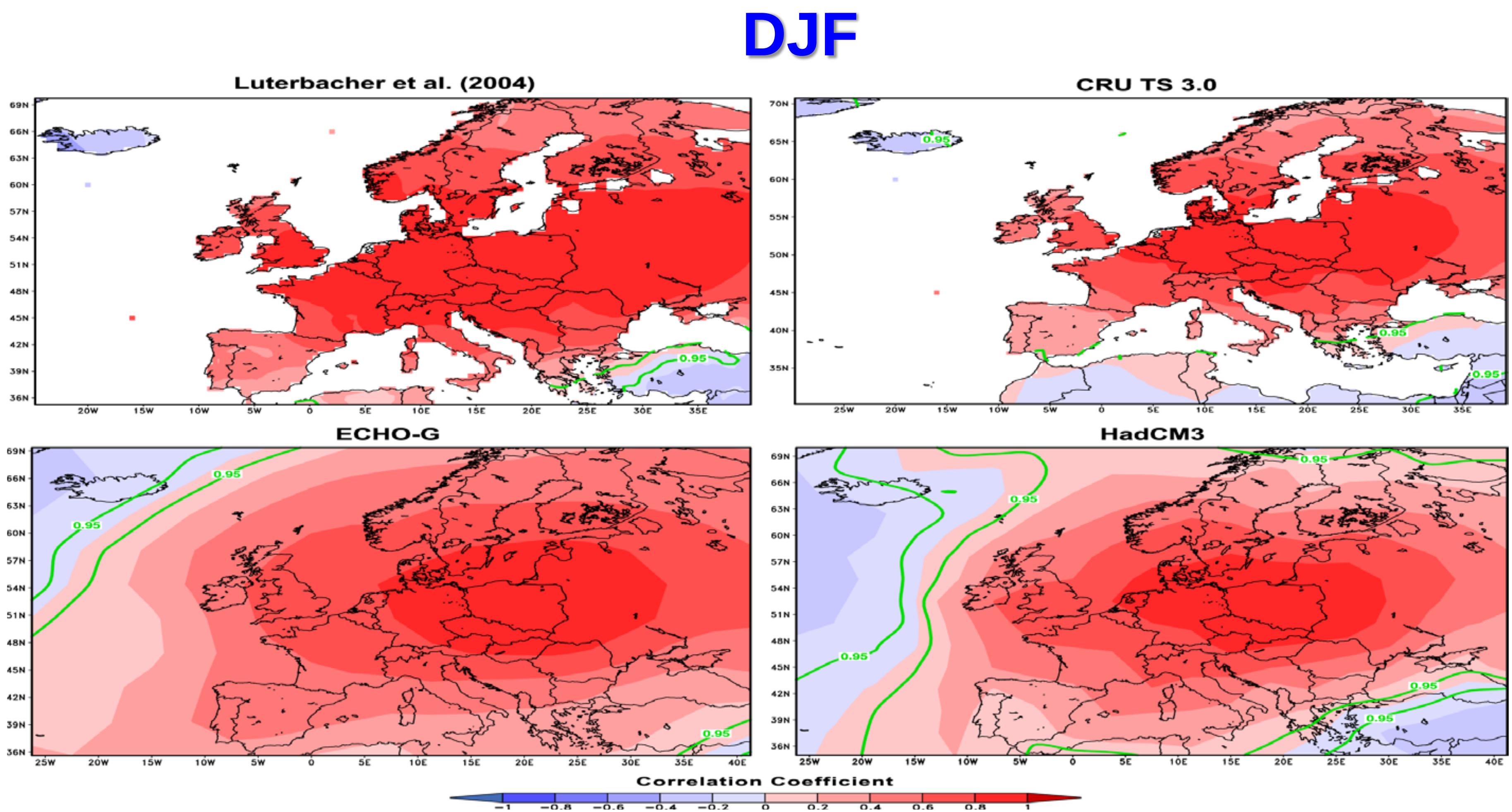
POLAND-EUROPE WEATHER AND CLIMATE LINKS

(top left) Spatial correlation maps between winter temperature averaged over Poland (14.25°E–24.25°E; 49.25°N–54.75°N) and European land areas over the past 500 years (Luterbacher et al. 2004), (top right), as top left but for the instrumental period 1901–2006 (Phil Jones pers. comm.); (bottom left) Spatial correlation maps between winter temperature averaged over Poland (15°E–22.5°E; 50.625°N–54.375°N) and Europe for the period 1500–1990 within the ECHO-G model (von Storch et al. 2004; Gonzalez-Rouco et al. 2006); (bottom right) as bottom left but for 15°E–22.5°E; 50°N–55°N, the period 1500–1999 and the HadCM3 model (Tett et al. 2006). The significant areas (95% level) are marked in green contours (after Luterbacher et al. 2010)



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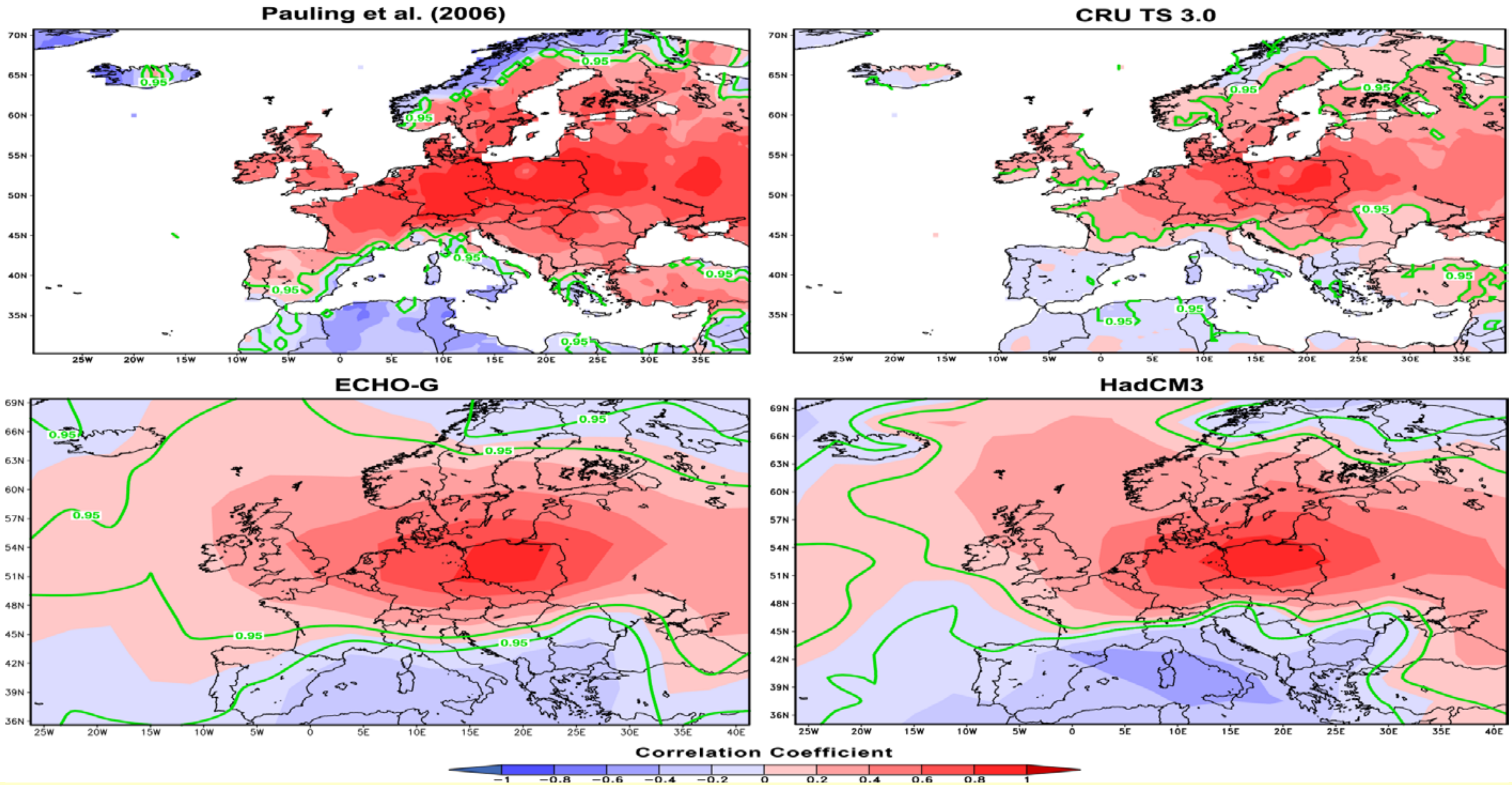
(top left) Spatial correlation maps between winter precipitation averaged over Poland (14.25°E–24.25°E; 49.25°N–54.75°N) and European land areas over the past 500 years (Pauling et al. 2006), (top right), as top left but for the instrumental period 1901–2006 (Phil Jones, pers. comm.); (bottom left) Spatial correlation maps between winter precipitation averaged over Poland (15°E–22.5°E; 50.625°N–54.375°N) and Europe for the period 1500–1990 within the ECHO-G model (von Storch et al. 2004; Gonzalez-Rouco et al. 2006); (bottom right) as bottom left but for 15°E–22.5°E; 50°N–55°N, the period 1500–1999 and the HadCM3 model (Tett et al. 2006). The significant areas (95% level) are marked in green contours (after Luterbacher et al. 2010)

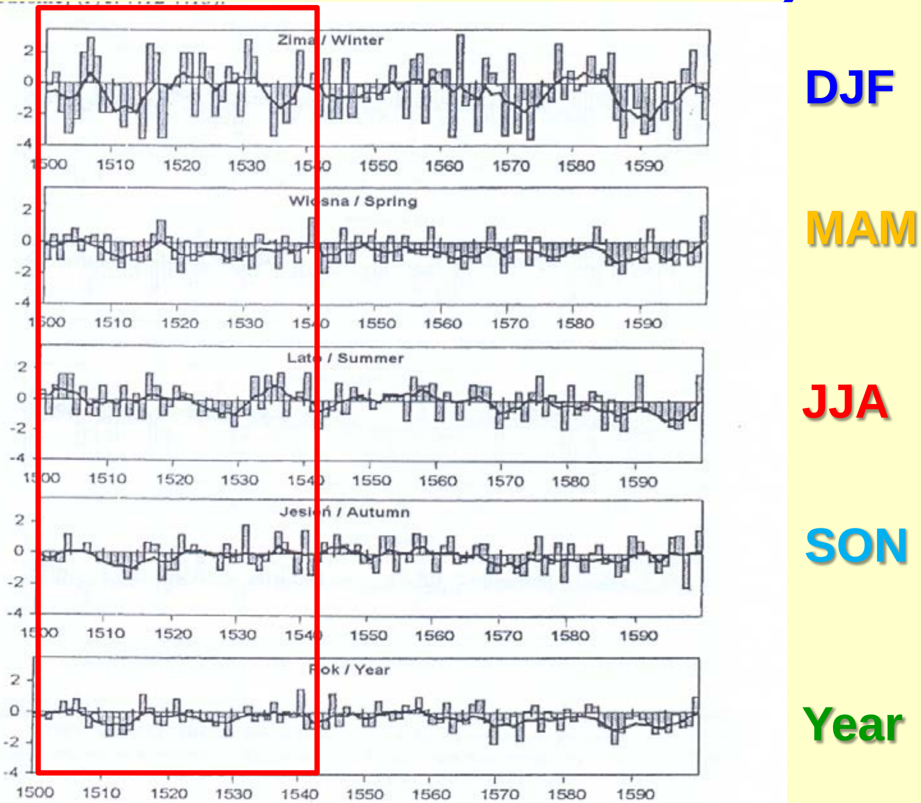
DJF



Poland's and European (in particular Central Europe) climate variables are very well correlated, thus for description of Poland's climate reconstructions made for the Central Europe can also be used

Air temperature

Fluctuation of seasonal and annual air temperature anomalies in Central Europe (reference period 1901-1960) in the 16th century smoothed by 10-year Gaussian filter (after Pfister and Brazdil 1999)



Ryc. 7.12. Sezonowe i roczne fluktuacje anomalii TACE (°C, okres porównawczy 1901-1960), wygładzone za pomocą 10-letniego filtra Gaussa, dla XVI w. (wg Pfistera i Brázdila 1999)
Fig. 7.12. Fluctuations of seasonal and annual TACE anomalies (°C, reference period 1901-1960) smoothed by a 10-year Gaussian filter in the 16th century (after Pfister and Brázdil 1999)

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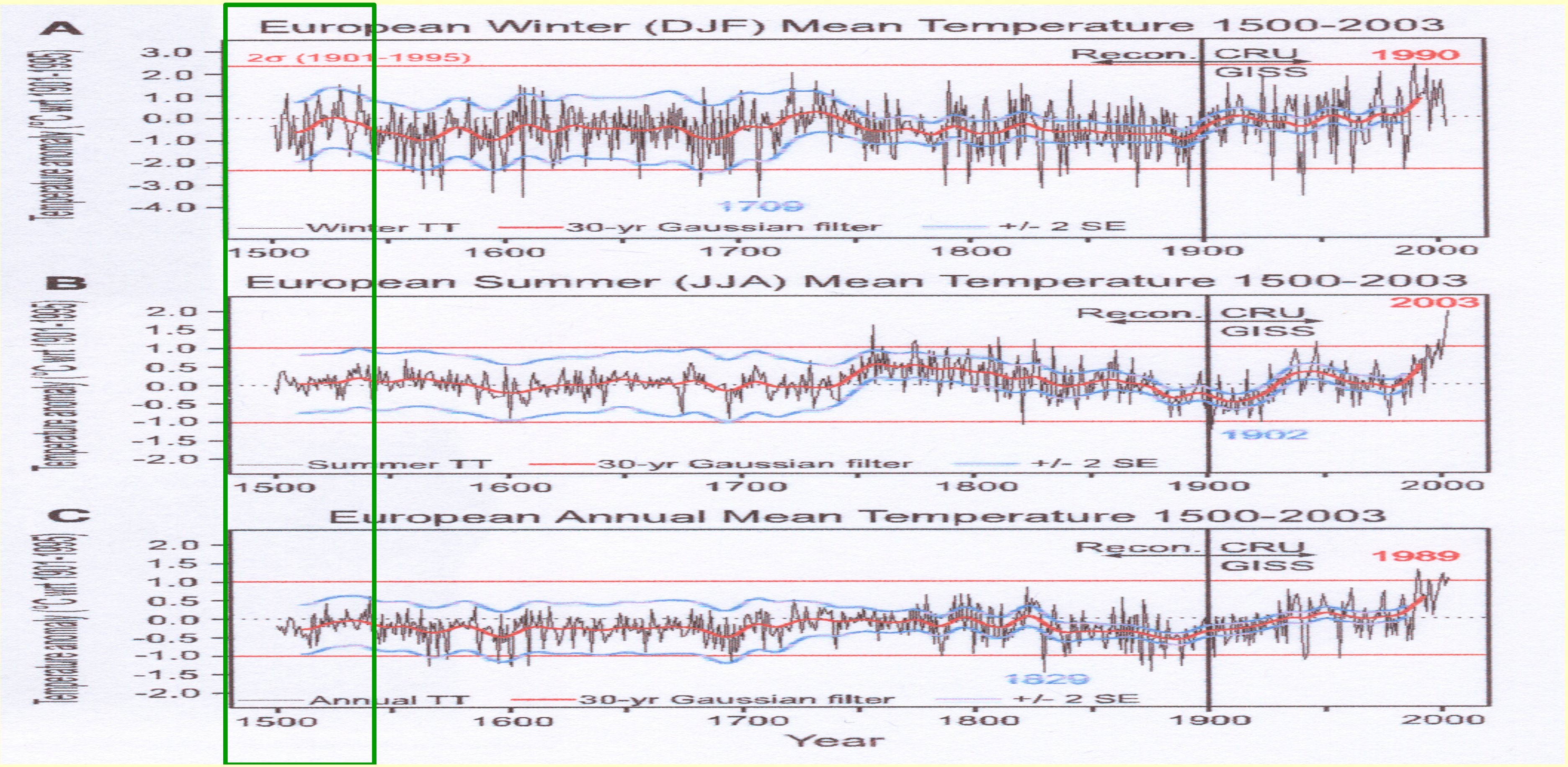
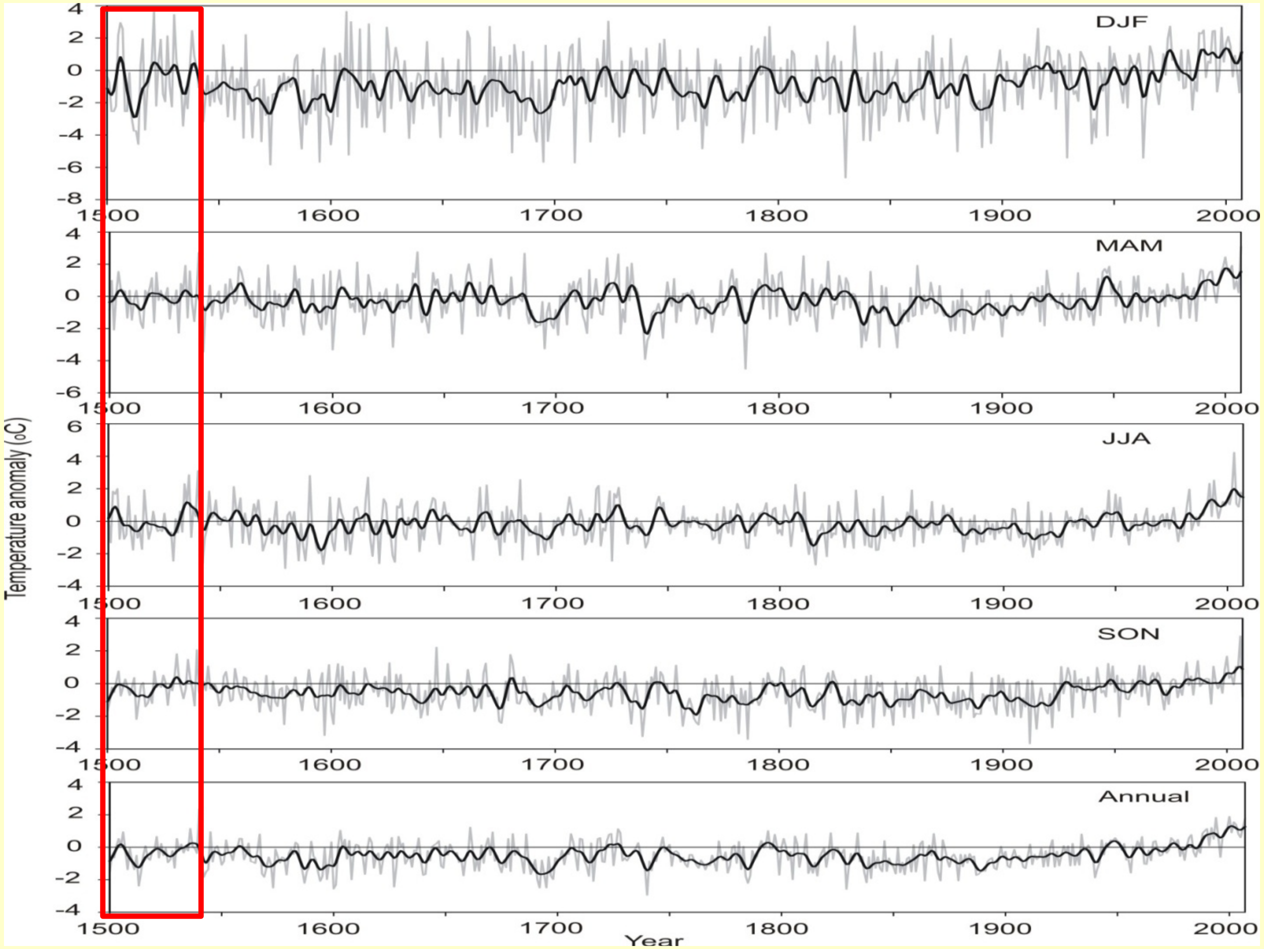
Mean anomalies (reference period 1901-1995) of air temperature in Europe for winter (upper figure), summer (middle figure) and year (lower figure) (after Luterbacher et al. 2004)



Fluctuation of seasonal and annual air temperature anomalies (reference period 1961-1990) in Central Europe, 1500-2007 (thick line – 10-year Gaussian filter) (after Dobrovolny et al. 2009)



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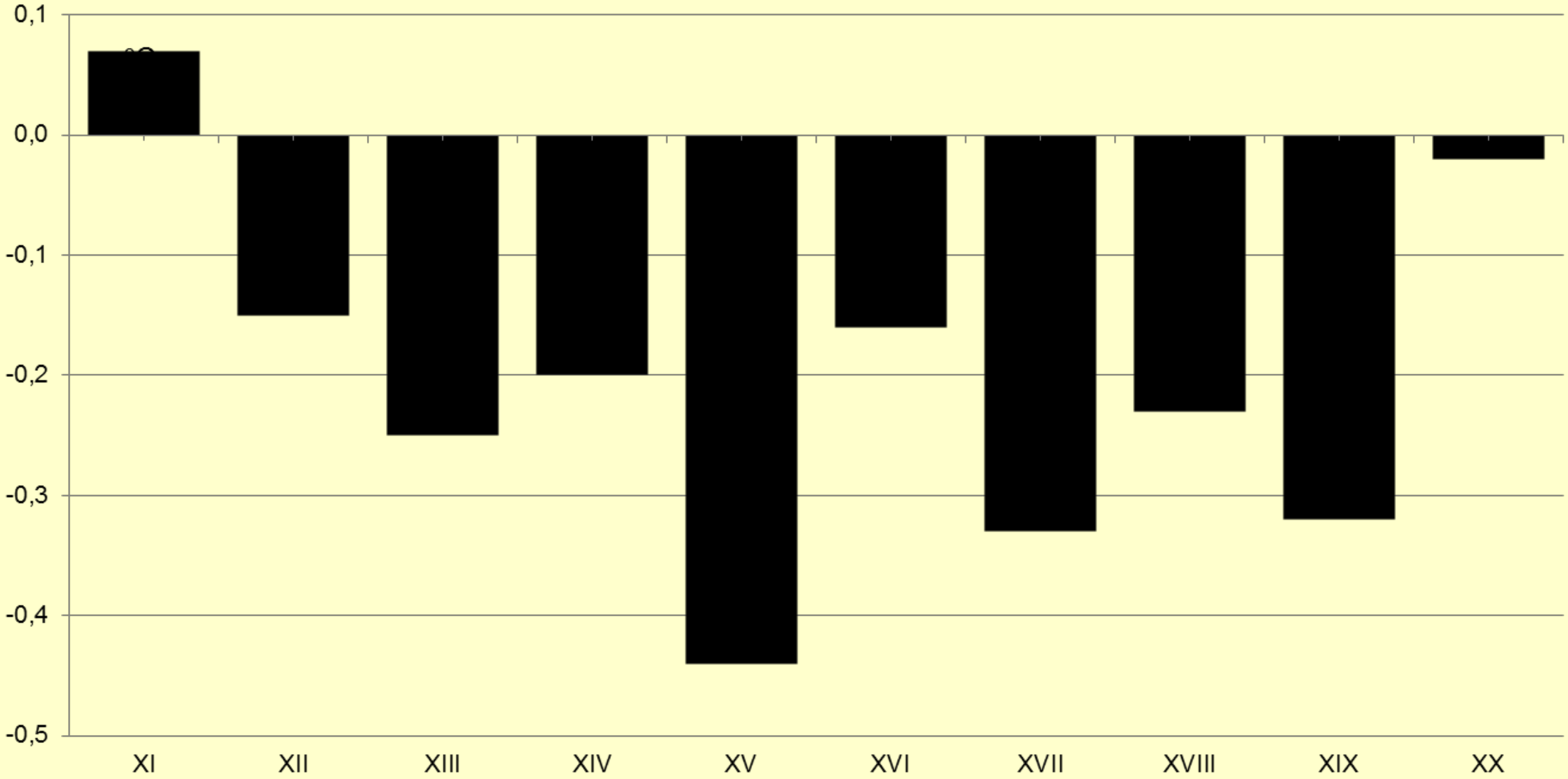
Annual air temperature anomalies (°C) in Eastern Europe, 1001-2000

centennial anomalies in reference to period 1951-1980 (after Klimenko and Solomina 2010)



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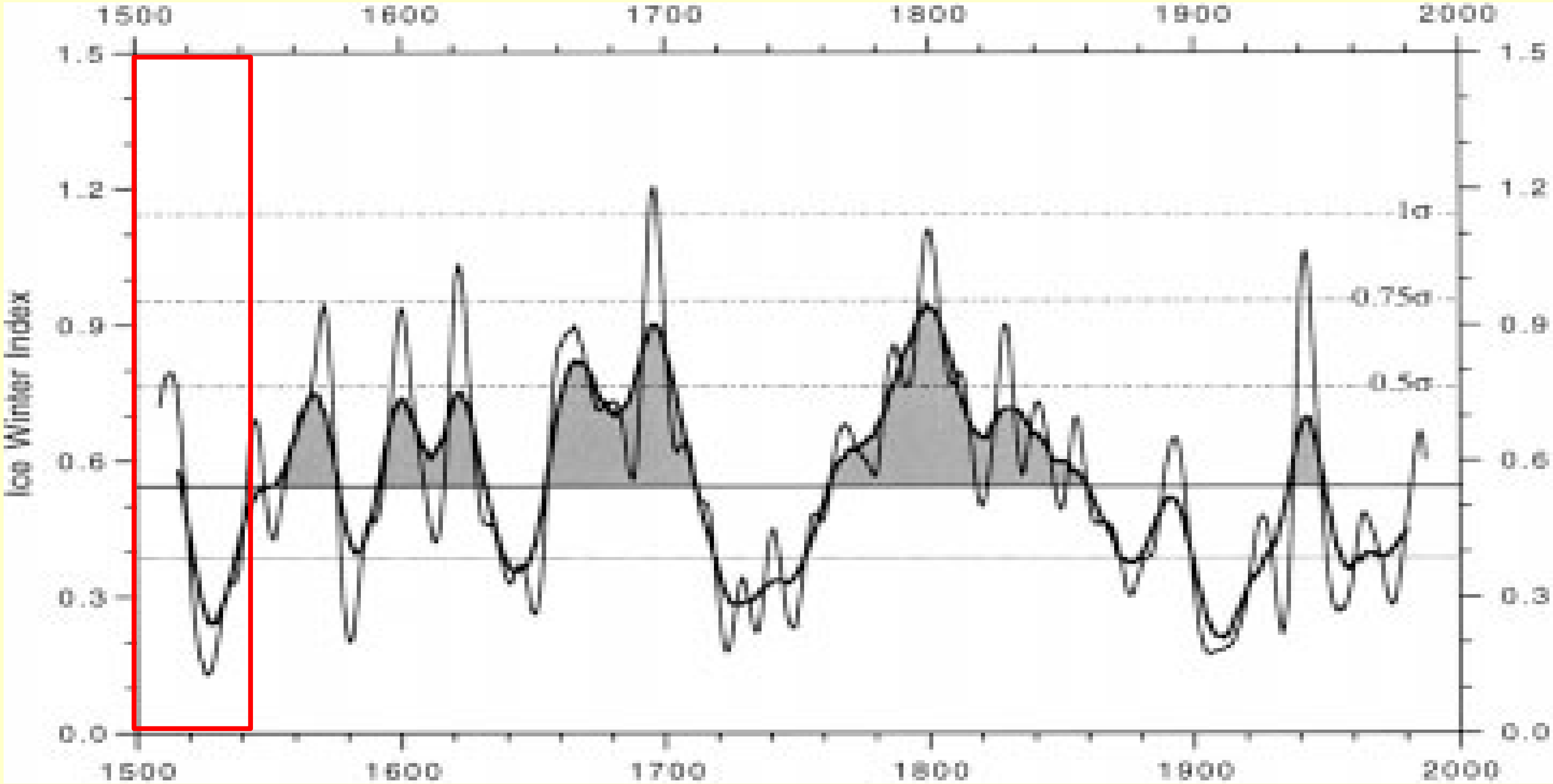
Baltic, ice winter index, 1501-1995

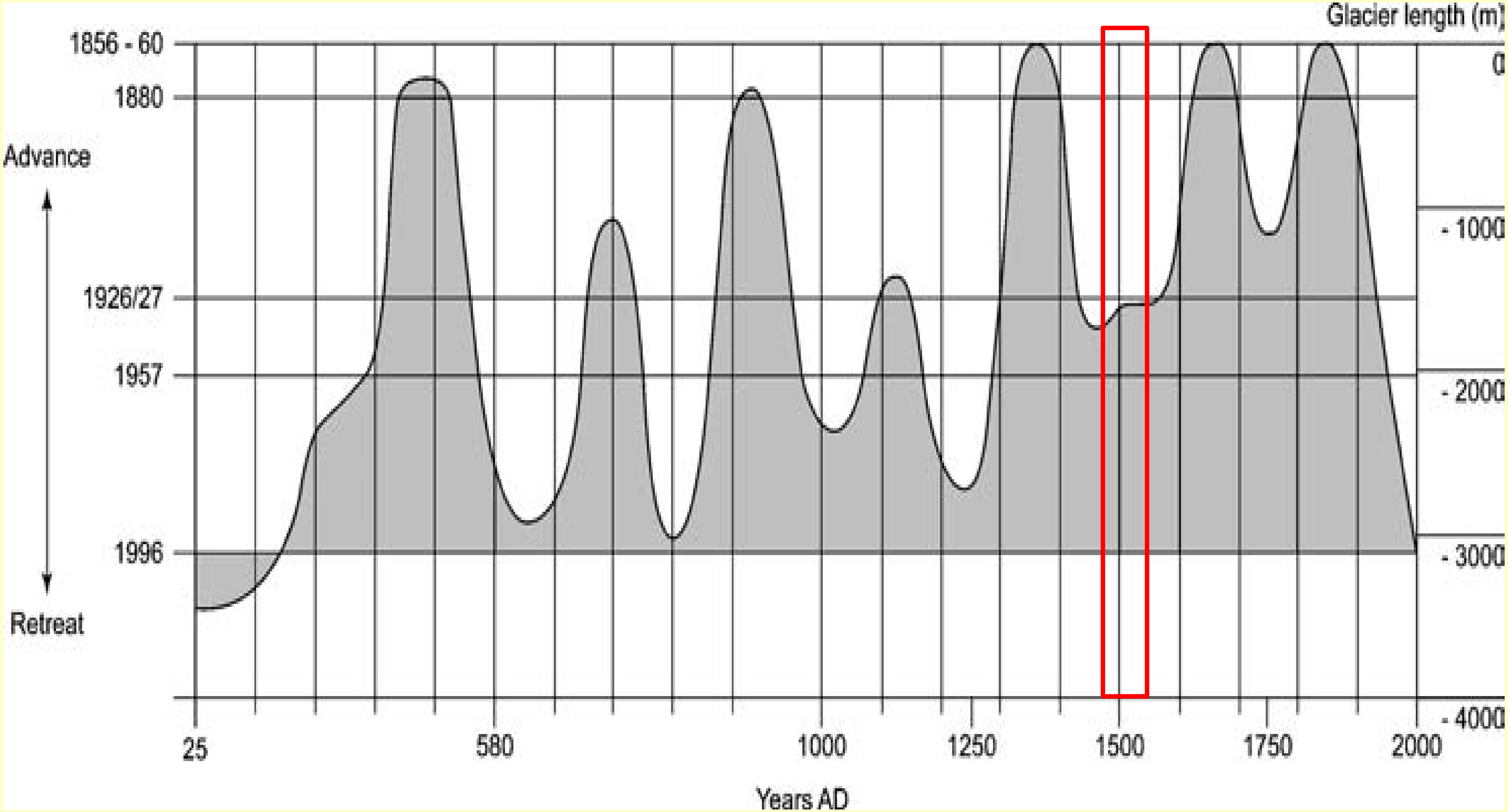
(after Koslowski and Glaser, 1999)



Variations of the ice winter index since 1501. The thin and the heavy solid curves represent the smoothed ice winter numerals obtained by applying a Gaussian lowpass filter with a 20- and a 40-year cutoff period, respectively. The dark areas denote the periods of increased ice winter severity

Fluctuations of length of Grosser Aletsch glacier (Swiss Alps) in the last 2000 years

(after Holzhauser and Zumbuhl, 1999)



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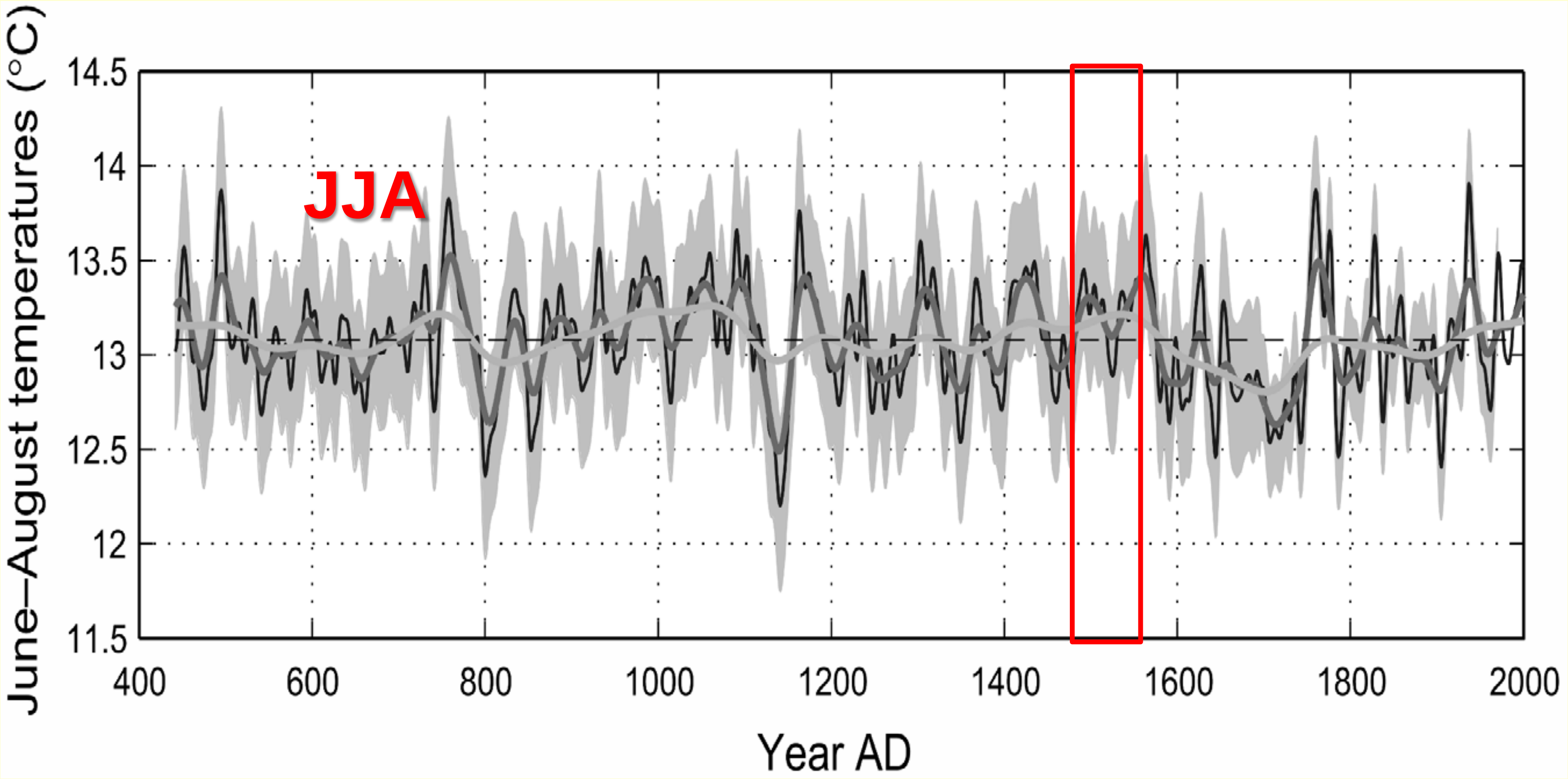
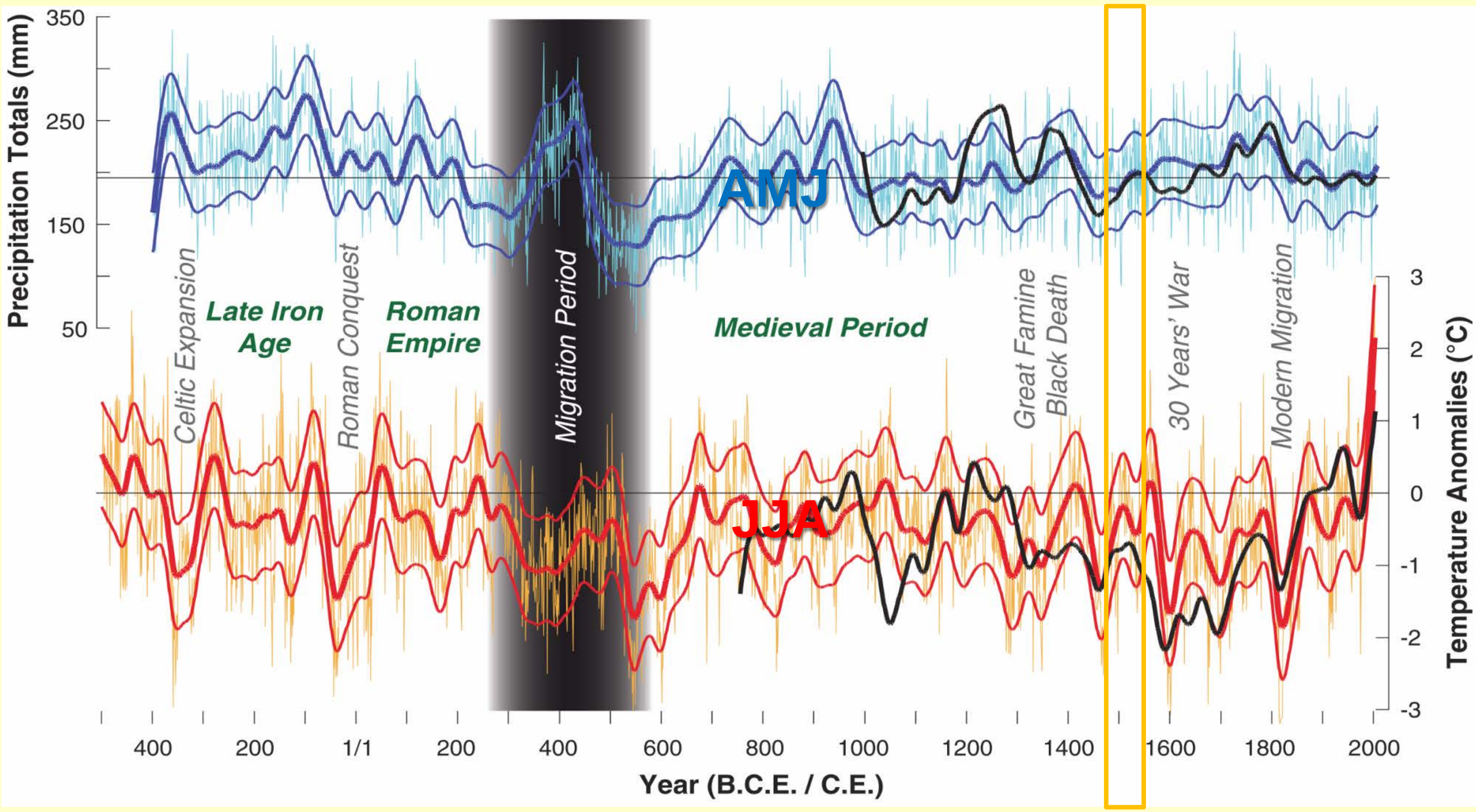
Fennoscandian regional-average summer (June–August) temperatures AD 442–1970 created by merging the seven reconstructions based on the seven networks (Gouirand et al. 2008, Fig.10. p. 17). The series is extended up to the year 2000 with instrumental data. Data are shown as smoothed (Gaussian filtered) temperatures (°C), highlighting variability on timescales longer than 10 years (thin black), 30 years (grey), and 100 years (thick light dark grey). The dashed horizontal line is the average for the entire period. The uncertainty in reconstructed temperatures (based on the calibration period statistics) is illustrated by ±2 standard errors with grey shading (for the 10-year smoothing only)



Reconstructed AMJ precipitation totals (top) and JJA temperature anomalies (bottom) with respect to the 1901–2000 period. Error bars are ±1 RMSE of the calibration periods. Black lines show independent precipitation and temperature reconstructions from Germany (Büntgen et al. 2010) and Switzerland (Büntgen et al. 2006). Bold lines are 60-year low-pass filters. Periods of demographic expansion, economic prosperity, and societal stability are noted, as are periods of political turmoil, cultural change, and population instability (Büntgen et al. 2011b, Fig. 4, p. 581)



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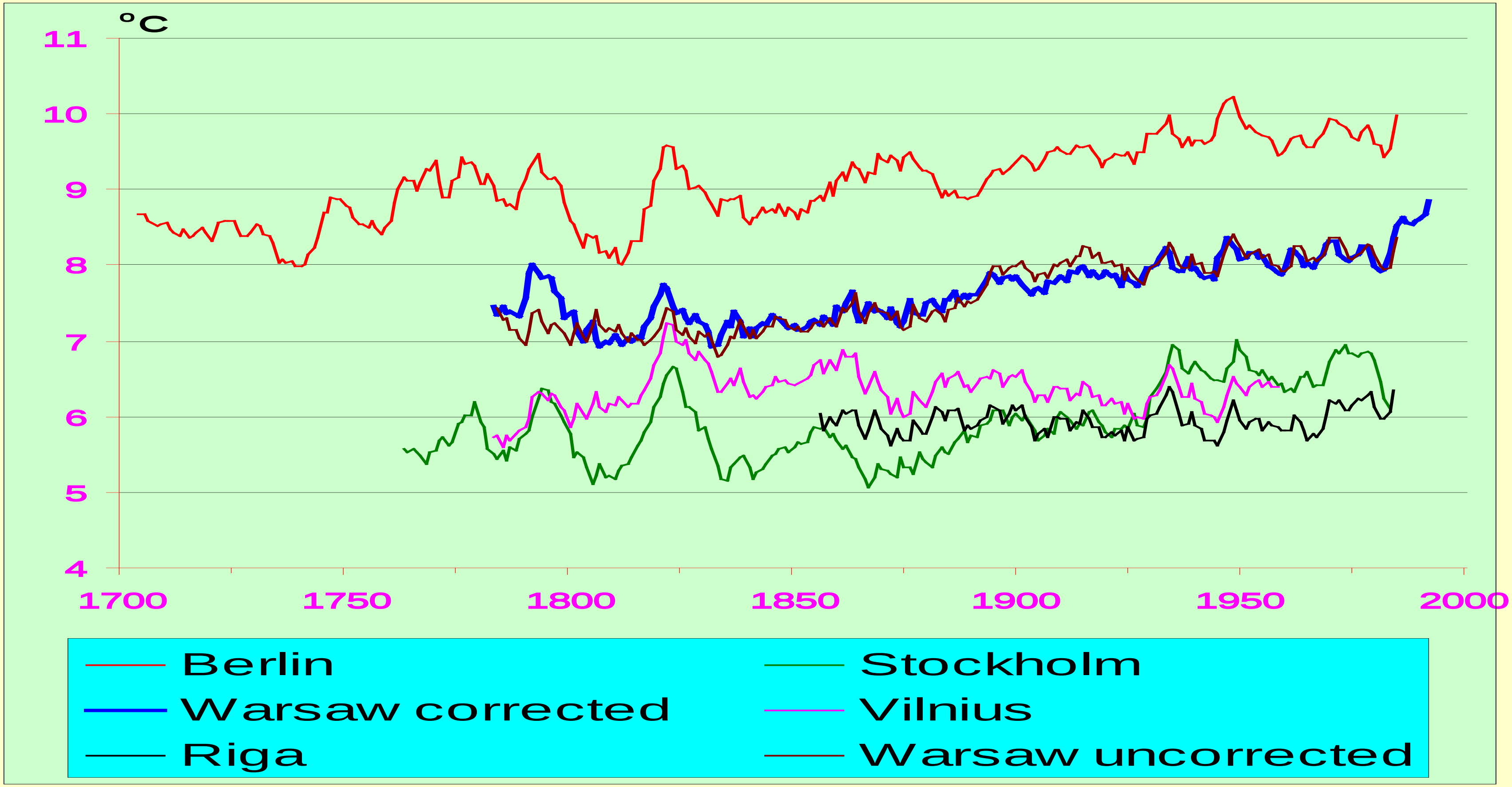
Mean annual 11-year running air temperatures for chosen Central European stations



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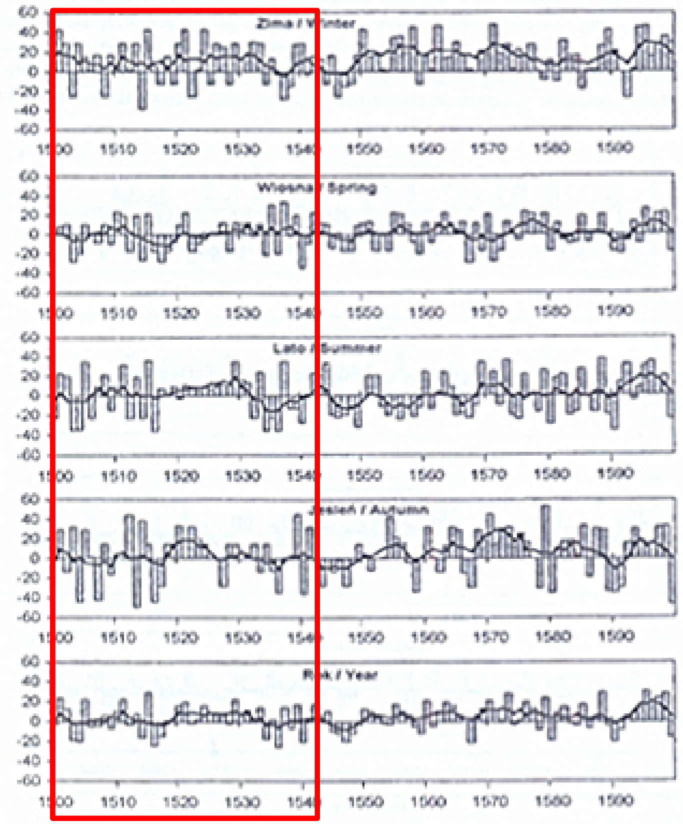
Atmospheric precipitation

Fluctuation of seasonal and annual total precipitation anomalies in Central Europe (reference period 1901-1960) in the 16th century smoothed by 10-year Gaussian filter (after Pfister and Brazdil 1999)



Ryc. 7.13. Sezonowe i roczne fluktuacje anomalii PACE (%, okres porównawczy 1901-1960), wygładzone za pomocą 10-letniego filtra Gaussa, dla XVI w. (wg Pfistera i Brázdila 1999)
Fig. 7.13. Fluctuations of seasonal and annual PACE anomalies (%, reference period 1901-1960) smoothed by a 10-year Gaussian filter in the 16th century (after Pfister and Brázdil 1999)

DJF

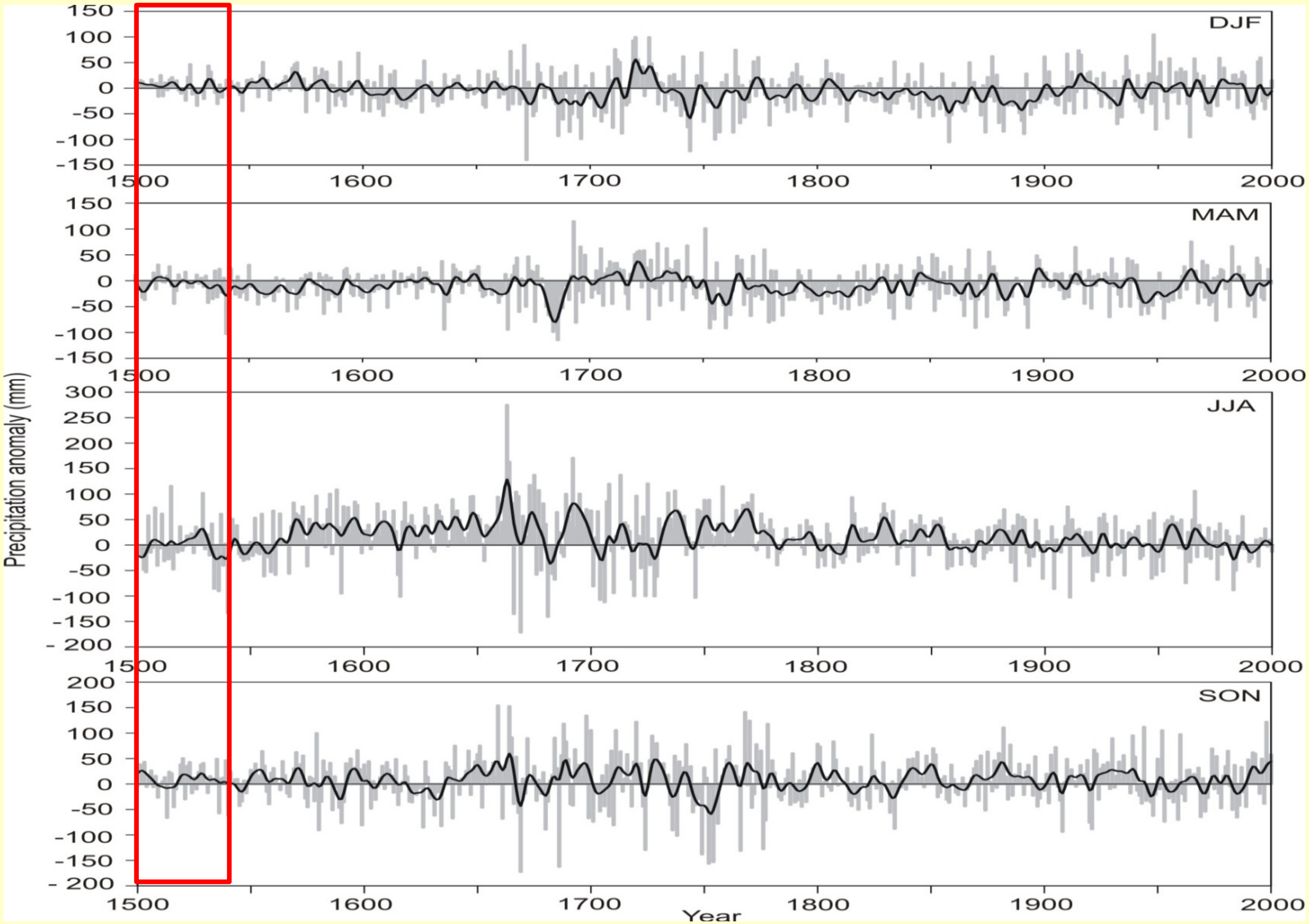
MAM

JJA

SON

Year

Fluctuations of anomalies (reference period 1961-1990) of seasonal precipitation totals averaged for Central Europe (using data from grids every 0,5º, 45-53ºN and 5-18ºE) in period 1500-2000 (thick line – 10-year Gaussian filter) (Pauling et al. 2006)



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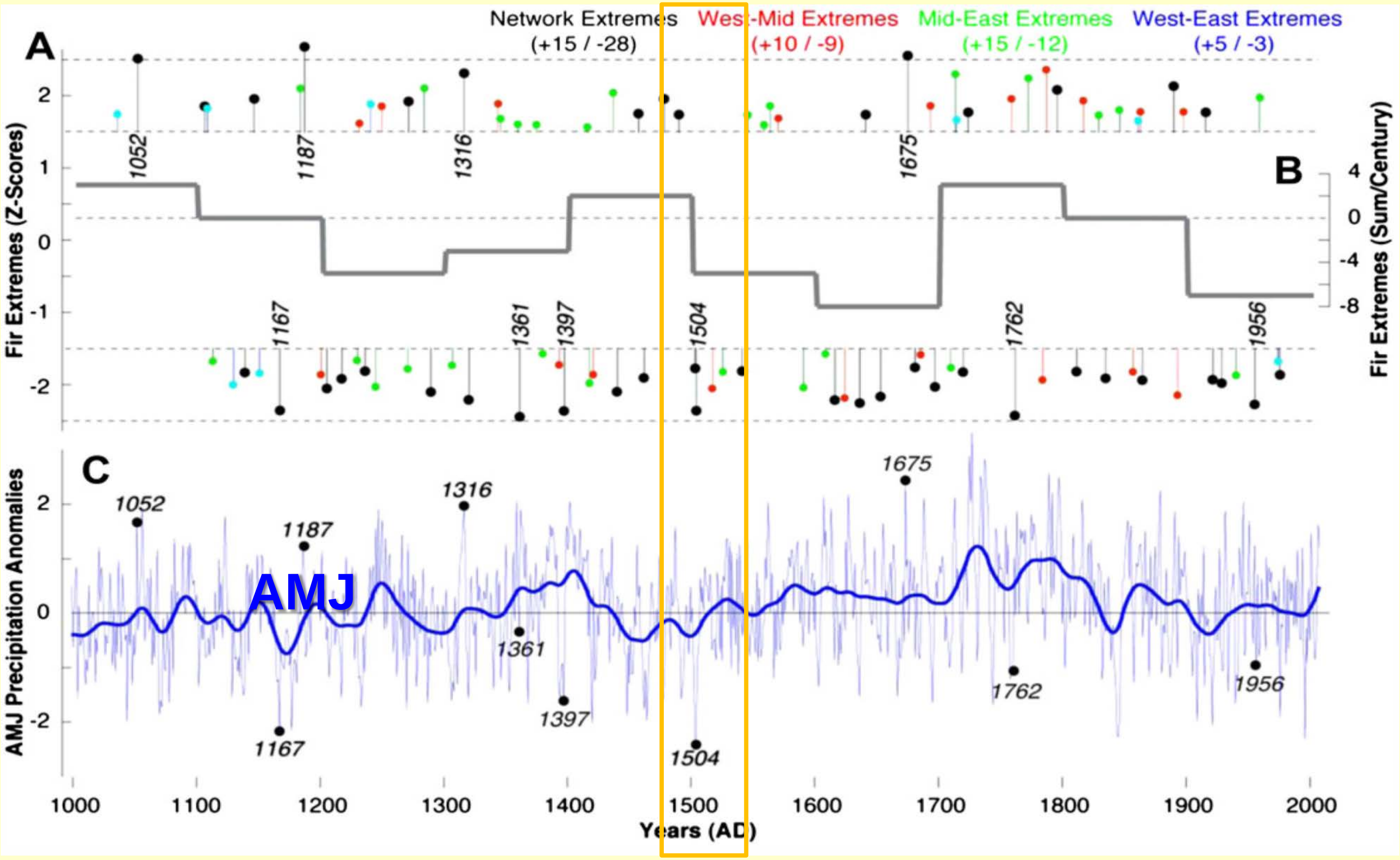
(A) Central European and regional fir TRW extremes, and (B) their centennial changes over the past millennium (network extremes were double weighted), compared to (C) annual-resolve and 40-year low-passed Central European April-June precipitation variability (Büntgen et al. 2011c, Fig. 5, p. 3951)



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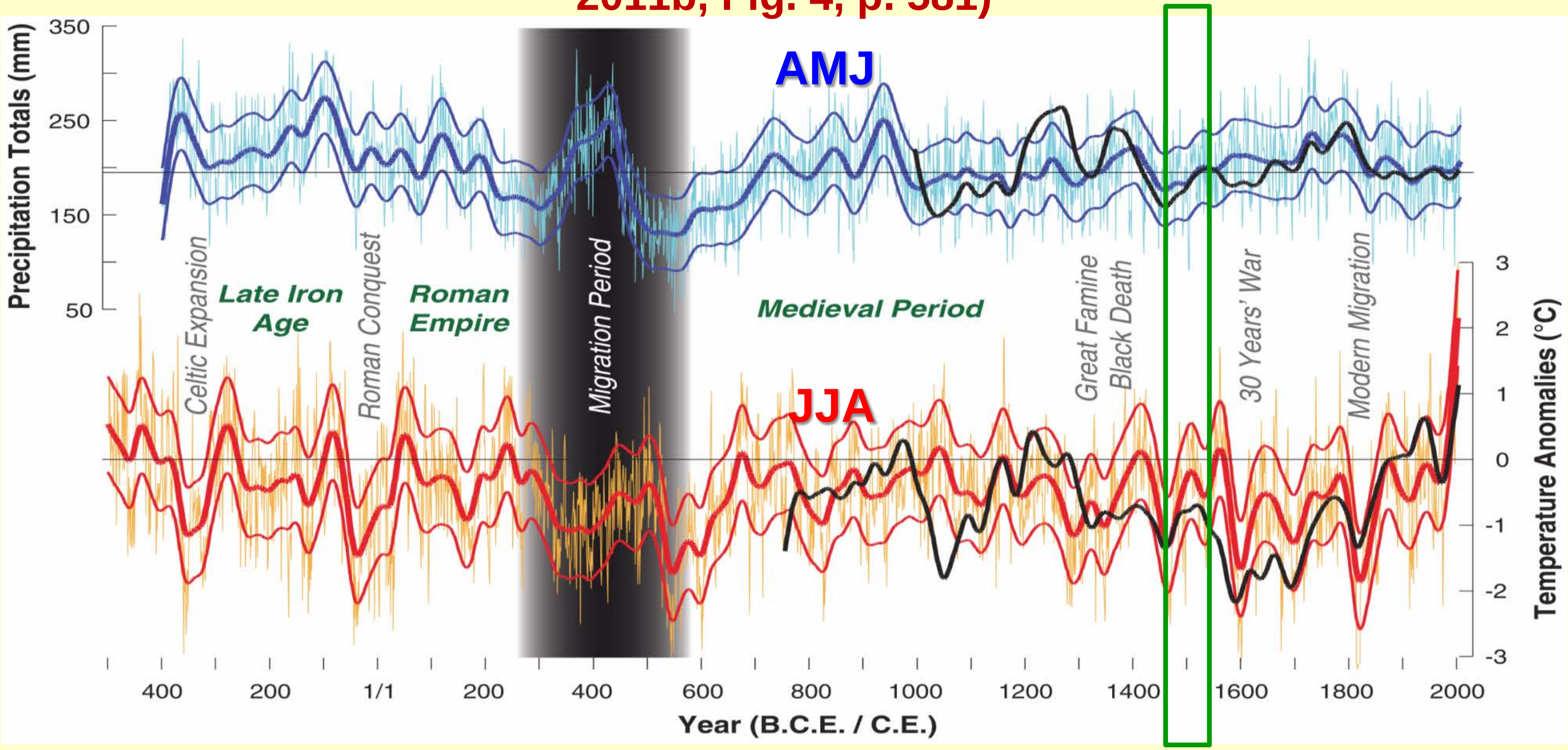
Reconstructed AMJ precipitation totals (top) and JJA temperature anomalies (bottom) with respect to the 1901–2000 period. Error bars are ±*1* RMSE of the calibration periods. Black lines show independent precipitation and temperature reconstructions from Germany (Büntgen et al. 2010) and Switzerland (Büntgen et al. 2006). Bold lines are 60-year low-pass filters. Periods of demographic expansion, economic prosperity, and societal stability are noted, as are periods of political turmoil, cultural change, and population instability (Büntgen et al. 2011b, Fig. 4, p. 581)



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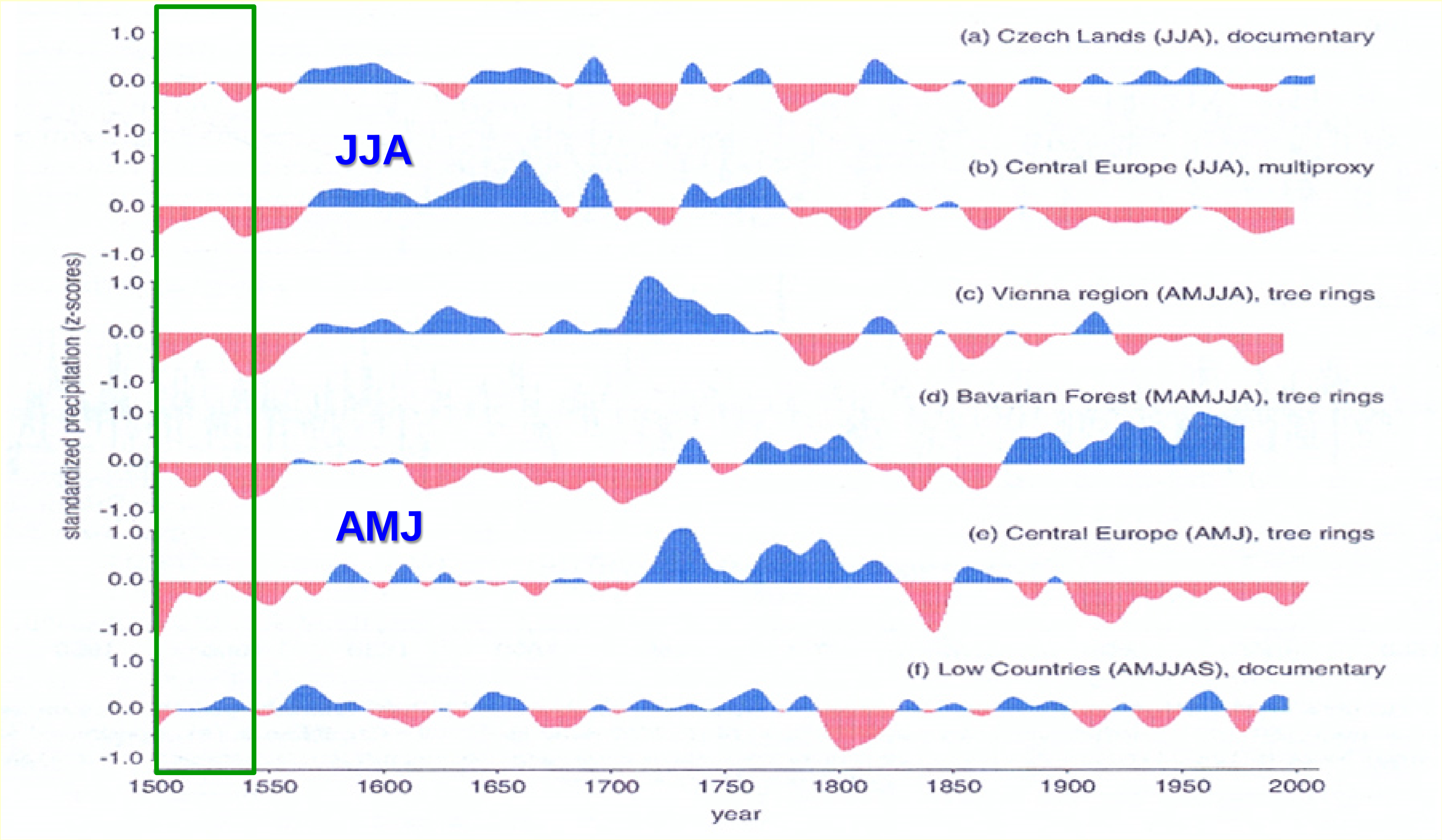
Fluctuations of precipitation in Europe according to 6 different reconstructions, 1500-2010. Data were smoothed by 30-year Gaussian filter (after Dobrovolny et al. 2014)



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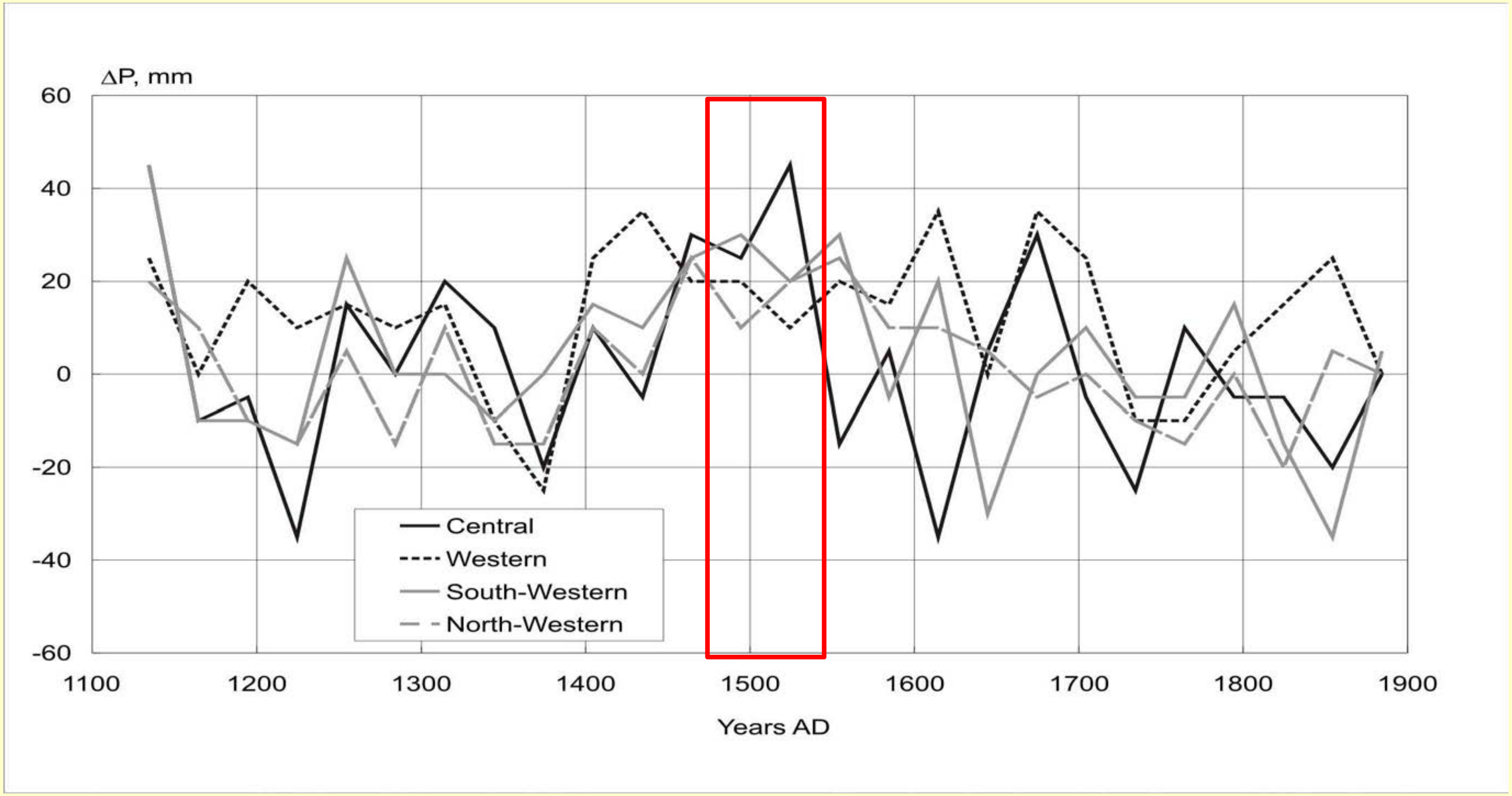
Mean anomalies of annual totals of precipitation (mm) in Eastern European Plain (reference period 1890-1950) reconstructed based on documentary evidence (Klige et al. 1993)



CONCLUSIONS

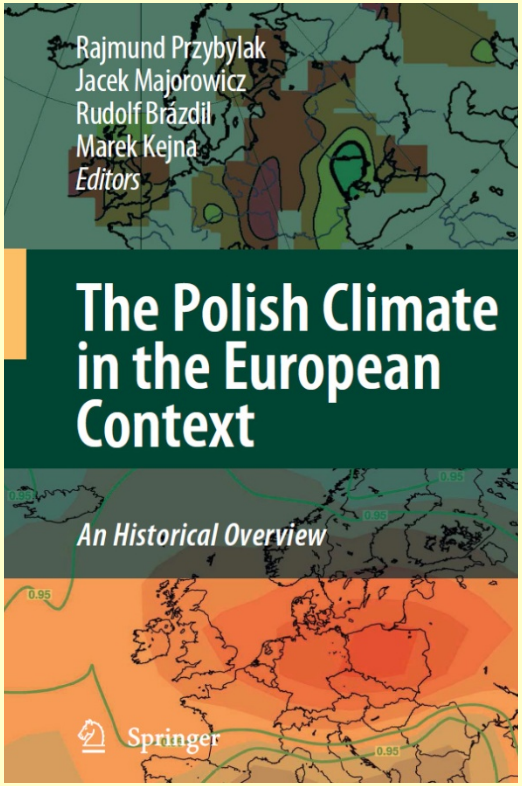
1. The climate of Nicolaus Copernicus's lifetime can be considered to be transitional between the Medieval Warm Period, which probably ended in Poland at the beginning of the 15th century, and the Little Ice Age, which began in the middle of the 16th century.

2. Extreme situations (including both air temperature and precipitation) were most frequent and most changeable in winter (temperature) and summer (precipitation).

CONCLUSIONS (2)

3. The climate in Copernicus's time was more continental than it is today, mainly due to the very severe winters occurring in the later stages of his life (1-3^{o}C colder in reference to the mean for 1901-1960). The summers he experienced were slightly warmer and wetter than today, while mean annual air temperatures and surface-ground temperatures were lower, on average, by ca. 1.0-1.5^{o}C than contemporary values.

For more details about Poland's and European Climate in the last millennium see monograph edited by R. Przybylak et al. (2010)



Thank you