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A tree-ring chronology and paleoclimate record for the Younger Dryas – Early Holocene transition from northeastern North America

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Complete List of Authors:	Griggs, Carol; Cornell University, Cornell Tree Ring Lab Peteet, Dorothy; NASA / GISS; Lamont-Doherty Earth Observatory Kromer, Bernd; University of Heidelberg, Heidelberg Academy of Sciences Grote, Todd; Indiana University Southeast, Geoscience Program Southon, John; University of California Irvine, W.M. Keck Carbon Cycle AMS Laboratory
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Running Title: Younger Dryas – Early Holocene tree rings in NE North America

Authors:

Carol Griggs, Cornell Tree Ring Laboratory, Cornell University, Ithaca, NY, 14853; cbg4@cornell.edu

Dorothy Peteet, NASA/GISS, 2880 Broadway, NY, NY 10025 and Lamont-Doherty Earth Observatory, Palisades, NY; peteet@ldeo.columbia.edu

Bernd Kromer, University of Heidelberg, Heidelberg, Germany, bernd.kromer@iup.uni-heidelberg.de

Todd Grote, Indiana University Southeast, New Albany, IN; tdgrote@ius.edu

John Southon, W.M. Keck Carbon Cycle AMS Laboratory, University of California at Irvine, Irvine, CA; jsouthon@uci.edu

Contact: Carol Griggs, cbg4@cornell.edu

Abstract

Spruce and tamarack logs dating from the Younger Dryas and Early Holocene (YD-EH; ~12.9-11.3k cal a BP) were found at Bell Creek in the Lake Ontario lowlands of the Great Lakes region, North America. A 211-year tree-ring chronology dates to ~11,755-11,545 cal a BP, across the YD-EH transition. A 23-year period of higher year-to-year ring-width variability dates to around 11,650 cal a BP, infers strong regional climatic perturbations, and may represent the end of the YD.

Tamarack and spruce were dominant species throughout the YD-EH interval at the site, indicating that boreal conditions persisted into the EH, in contrast to geographic regions immediately south and east of the lowlands, but consistent with the Great Lakes interior lowlands. This infers that Bell Creek was at the eastern boundary of a boreal ecotone, perhaps a result of its lower elevation and the non-analog dynamics of the Laurentide Ice Sheet. This finding suggests that the ecotone boundary extended farther east during the YD-EH transition than previously thought.

Key words: Younger Dryas-Early Holocene transition, spruce, tamarack, dendroclimatology, Northeastern North America

Introduction

Terrestrial proxy records of major climatic transitions are limited for the late glacial into Early Holocene interval, especially high-resolution records for the extreme climatic changes of the Younger Dryas (YD). These data are necessary for acquiring rates of change and understanding the associated mechanisms, causes, and consequences. Annual tree-ring data is ideal for obtaining the high-resolution temporal data, but late glacial wood suitable for dendrochronological analysis is sparse (e.g. Guyette *et al*., 2006; Panyushkina *et al*., 2008; Hua *et al*., 2009; Kaiser *et al*., 2012; Hogg *et al*., 2013). In northeastern North America (NENA), recovered late glacial wood has been exclusively pre-YD or in such small quantity for the YD that high-resolution climatic extraction is minimal (Griggs and Kromer, 2008; Miller and Griggs, 2012).

Terrestrial proxy records for the YD transition into Early Holocene (YD-EH) in NENA include extensive pollen and macrofossil data. In the Eastern Coastal and Appalachian Mountain regions the records show an abrupt reduction in spruce at the transition, inferring a rapid warming from boreal to temperate conditions (e.g. Peteet *et al*., 1990; 1993; Maenza-Gmelch, 1997; Peteet, 2000; Menking *et al.*, 2012). In contrast, the pollen and macrofossil records of the Great Lakes lowlands indicate a more gradual transition with spruce persisting into the Early Holocene, inferring that the lowlands remained a boreal ecotone after the transition (Shane and Anderson, 1993; Yu, 2000; Anderson and Lewis, 2012; Schaetzl *et al*., 2013). Today, climatic conditions are temperate from the lower Great Lakes east to the coast except at higher elevations (e.g. Peel *et al*., 2007). For the YD-EH, the spatial relationship between the two ecotones indicate a steeper temperature gradient from the eastern Great Lakes to the east coast, influenced by the changing Laurentide Ice Sheet, meltwater discharge, and isostatic adjustment on the dynamics of late glacial atmospheric and oceanic circulation and other teleconnections (e.g. Kirby *et al*., 2002; Wunsch, 2006; Cronin *et al*., 2008; Broecker *et al*., 2010; Anderson and Lewis, 2012, Hladyniuk and Longstaffe, 2016). The limited high-resolution proxy records from the Lake Ontario lowlands to the east coast, especially immediately southeast of the lowlands, make it difficult to fine-tune either temporal or spatial transitions.

Logs of spruce and tamarack dating from the YD-EH, ~12.8 to 11.2k cal a BP have been found in Bell Creek within the Lake Ontario lowlands of the Great Lakes region, North America

(Figures 1, 2). The late YD into EH, ca. 11.9-11.3k cal a BP, is the best-represented interval in the collection. A tree-ring chronology of 211 years in length was assembled from 12 logs, and 14C-dates at ~11,755-11,545 cal a BP. A 23-year interval of higher year-to-year growth variability may represent the YD-EH transition, but the tree-ring widths contain no record of sustained climatic change. The dominance of spruce and tamarack throughout the represented period indicates a persistence of boreal conditions in the southeastern Lake Ontario lowlands across the transition.

Material and methods

The Bell Creek site

Bell Creek is located within a drumlin field on the lowlands south of eastern Lake Ontario in central New York (Figure 1). The lowlands were submerged beneath proglacial lakes until the onset of the YD when proglacial Lake Iroquois drained with the opening of the St. Lawrence River Valley (Cadwell *et al.,* 2003; Anderson and Lewis, 2012). Subsequent lower lakes drained to the closed basin of Early Lake Ontario by ca 12.9k cal a BP (Anderson and Lewis, 2012). The study site is located ~22km southeast of Oswego, NY, at 43°16.8′N, 76°21.0′W, 116m asl, and ~41m above the water level of modern Lake Ontario (Figure 1).

Field collection

Samples were collected from logs in the lower banks and bed of the creek channel and in 23 2 x 3m trenches excavated to ascertain the spatial extent of the YD-EH log-bearing zone. A 15-25cm segment of each log was wrapped in gauze and cut off, leaving the remainder *in situ*. Samples from smaller fragments were collected for species ID. All samples were wrapped in plastic, bagged, labelled, and refrigerated. Stratigraphy, sediment type, and geomorphological features were recorded and sediment samples taken for further analyses.

Laboratory methods

Wood samples were cleaned, noting any retained sediments, and tree species were identified from macro and minute features on the transverse, radial, and tangential surfaces using speciation keys in Panshin and de Zeeuw (1970) and Hoadley (1990). Several radii on the transverse surface of each sample were prepared with razor blades, rings counted, and ring-widths measured on samples with more than 40 rings. For ^{14}C analysis, samples from key stratigraphic locations were chosen, and segments of 2-20 rings from each sample were sent for radiometric dating.

Ring-width sequences were detrended to remove individual growth trends, and growth patterns between samples were compared and relatively dated, or "crossdated" (Cook and Kairiukstis, 1990). All crossdates of samples were validated by visual inspection and statistical tests, including the Student's *t* –test and the percentage of year-to-year increase or decrease in ring widths of both samples in their overlap, a "trend coefficient" (=*Gleichläufigkeit*; Eckstein and Bauch, 1969). The samples' on-site locations and relationships to ^{14}C-dated samples were also considered. A minimal 75-year overlap was required for the establishment of a chronology. Shorter-lived samples were used to confirm the crossdates of the longer sequences and add to sample depth. Crossdated sequences were combined into a multi-sample chronology and further validated by the intercorrelation of the samples and the expressed population signal (EPS). The EPS indicates how close a chronology is to a hypothetical chronology of the total population; a value of >0.85 is considered significant (Cook and Kairiukstis, 1990).

To place a relatively-dated chronology in absolute time, a data set of the ^{14}C ages of the dated segments in the chronology was constructed when available. A multiple-segment ^{14}C data set results in calibrated dates with a smaller error value than does a single ^{14}C age (e.g. Kromer, 2009). The multiple ^{14}C ages are placed in a time series using the relative year of the middle ring of each segment, separated by the number of years between the middle rings (Table 1, Figure 2). The data set thus consists of multiple ^{14}C ages at fixed relative positions on a timeline. The series is then fitted, or "wiggle-matched," to a radiocarbon calibration curve using the "D-sequence" in OxCal software (Figure 2; Bronk Ramsey *et al*., 2009) to absolutely date the chronology.

Results

Stratigraphy and sediments

The log-bearing zone, 1.5-3 meters below the surface of the modern floodplain, is contained within two stratigraphic units: an organic muck and a gravelly sand and silt below the muck.

The general stratigraphy of the floodplain consists of vertical accretion deposits from the surface down to ~1m depth, overlying a well-developed organic muck deposit extending to ~2 m depth. The contact between the muck and the overlying alluvium is typically abrupt, but not erosive, suggesting minimal erosion, re-working, or disturbance. Below the muck lies a 0.5-1 m gravelly sand and silt bed which unconformably overlies a suspected lacustrine or re-worked glacial deposit. The gradational contact between the muck and gravelly sand and silt bed likely represents an aggrading point bar sequence within a poorly drained valley landscape. The log-bearing strata were deposited between ~12.8 and 11.2k cal a BP, but the majority of the samples, dating from 11.9-11.3k cal a BP (Table 1), were embedded in the lower muck deposit.

Samples

Fifty logs were recovered from the muck with 41 of spruce species or tamarack (*Picea* spp., *Larix laricina*, respectively). Of the 41, 16 are spruce, 20 are tamarack, and 5 are spruce or tamarack. Their radii are between 5 and 14cm and ring counts of 31 to 153. The other 9 logs include 5 balsam fir, 3 poplar, and 1 pine (*Abies balsamea*, *Populus* spp., and *Pinus* spp., respectively).

Speciation between spruce and tamarack wood is difficult due to the similarity of species traits (Hoadley, 1990; Schweingruber, 1990), the decomposition of particular elements of subfossil wood, and the character of the reaction cells grown to retain a vertical position. For transcontinental spruce, speciation is not definitive from wood alone (Panshin and de Zeeuw, 1970). White and black spruce are the most represented spruce species in deglaciated NENA, but black spruce was established after the white spruce in central New York (Lindbladh *et al.*, 2007; Miller and Griggs, 2012).

Dendrochronology

For dendrochronological analysis, 22 of the 41 spruce and tamarack samples have over 60 rings, with 11 above 90 rings. Using samples of the same species is optimal for tree-ring analysis, but a comparison of tamarack and white and black spruce chronologies indicated that their growth responses are satisfactorily similar for crossdating (e.g. Lieffers and Macdonald, 1990; Mamet and Kershaw, 2015).

Of the 22 samples, the growth patterns of 12 samples crossdated and were combined into a 211-year chronology (Figure 3A,B) of 6 spruce, 4 tamarack, and 2 samples most likely spruce. Seven sequences are over 90 years in length, and the average overlap between them is 76 years. The chronology is supported by average *t* –scores and trend coefficients of 4.95 and 66.5% ($p < 0.01$). Sample intercorrelation is 0.534 ($p < 0.01$) and the EPS equals 0.928.

The ^{14}C ages of 4 segments in the chronology (Table 1), separated by the numbers of rings between segments created a 4-point, 130-year-long, time series (Figures 2, 3C). Wiggle-matching the series places the chronology at ~11,755 - 11,545 cal a BP +20/-95 (1σ; Figure 2), an interval that covers the range of possible YD-EH transition dates based on different proxy records (Steffensen *et al.*, 1998; Friedrich *et al.,* 1999; Hughen *et al.*, 2000; Denton *et al.*, 2005; Broecker *et al.*, 2010, Menking *et al.*, 2012).

Paleoclimate

The continuing dominance of spruce and tamarack after the YD-EH transition (Table 1, Figure 2) indicates a more gradual reduction of boreal conditions at Bell Creek over time. Their persistence suggests temperatures were below a minimum threshold for the establishment of many temperate species (Kramer and Kozlowski, 1979), similar to climatic conditions west and north of the site (Mott and Farley-Gill, 1978; Anderson, 1988; Yu, 2000; Dyke, 2005; Anderson and Lewis, 2012; Schaetzl *et al.*, 2013).

The Bell Creek chronology does not contain clear evidence of significant change in any primary growth-limiting factor (e.g. Barber *et al.*, 2000) during the represented 211 years. However, in RY 1108-1130, there was higher variability and more frequent fluctuations in ring growth (Figure 3A,B,C) and an increase in intercorrelation to 0.744 and an EPS of 0.95 infers that growth response was more uniform between trees. No significant mortality or recruitment occurred, and average ring growth remained the same. Together, the characteristics suggest extreme regional climatic perturbations overrode the influence of micro-scale conditions on ring growth (e.g. Guyette *et al.*, 2006), ca. 11,600 ±90 cal a BP, but with no sustained effect on tree-ring growth.

Conclusions

The logs recovered from Bell Creek have produced a 211-year tree-ring chronology spanning the late YD and its transition into the EH, ca. 11,755-11,545 cal a BP +20/-95. This is the first high-resolution proxy record for that interval in NENA.

The persistence of both tamarack and spruce species and the lack of evidence of change in the tree-ring proxy record indicate a gradual rather than abrupt warming through the YD-EH transition at the easternmost of the Great Lakes lowlands. The 23-year interval of higher variability in all trees plus the overall lack of climate change suggests stronger regional climatic perturbations for ~23 years, but with a return to the same climatic conditions after that period. The ^{14}C 1σ-range of absolute dates for the perturbation, ~11650 to 11535 cal a BP, does include most dates previously assigned to the YD-EH transition. The total range of all the ^{14}C dates of samples from the muck deposit confirms the timing of the persistence in the Great Lakes region, and the site location extends the spatial range of the boreal ecotone established by other YD-EH proxy records. This infers a greater spatial impact of the non-analog Laurentide Ice Sheet and all associated dynamics during the YD-EH interval.

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Table 1. Radiocarbon ages of segments from 13 tamarack or spruce logs in the muck deposit, grouped by chronological order of their ^{14}C ages, with possible calibration dates indicated in Figure 2. Segments in the YD-EH Transition Chronology, their relative years and ^{14}C ages are in bold (Figures 2, 3). *Hd: Heidelberg Radiocarbon Laboratory, UCIAMS: Wm Keck Carbon Cycle AMS Laboratory, WW: US Geological Survey.

Sample	Relative Years	^{14}C Age	^{14}C Error	^{14}C Lab* and Analysis Number
OBF-227		9640	25	UCIAMS-162636
OBF-188		9830	20	UCIAMS-178821
OBF-64, outer		9918	37	Hd-28655
OBF-135		9980	25	UCIAMS-161894
OBF-68		9995	30	WW-8906
OBF-212		9995	25	UCIAMS-162634
OBF-64, inner		10011	44	Hd-30270
OBF-215	**1153-1157**	**10035**	**25**	**UCIAMS-162635**
OBF-65, outer	**1120-1142**	**10046**	**33**	**Hd-30268**
OBF-69	**1036-1045**	**10125**	**38**	**Hd-28656**
OBF-65, inner	**1023-1028**	**10082**	**38**	**Hd-28653**
OBF-66, middle		10080	25	UCIAMS-163493
OBF-66, inner		10204	34	Hd-30271
OBF-48		10098	36	Hd-30269
OBF-79		10112	40	Hd-30278
OBF-63		10152	34	Hd-30253

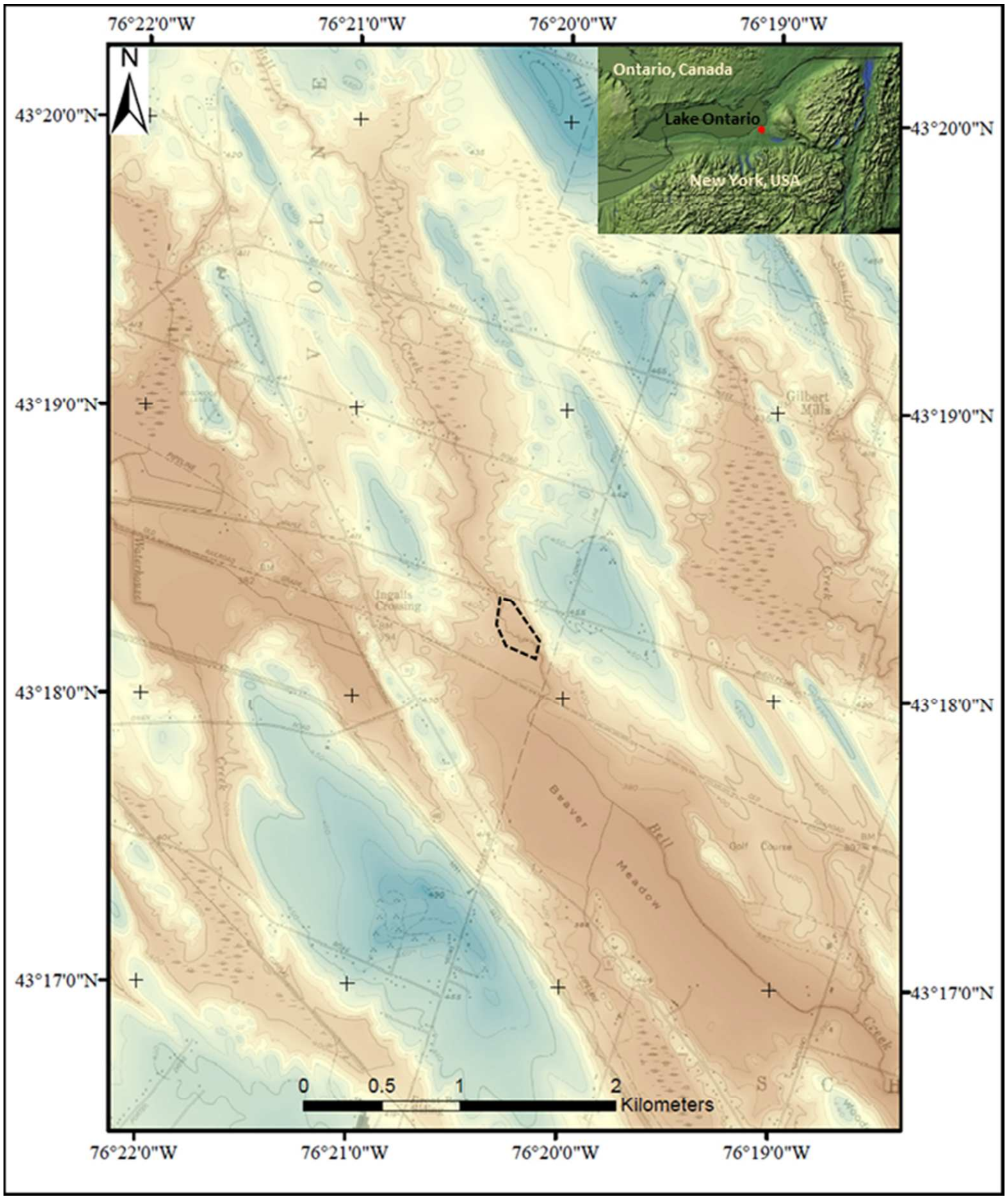

Figure 1. The Bell Creek Valley and site location (dashed polygon) within a drumlin field on the Lake Ontario lowlands, upstate New York, USA. Blue colors are higher elevations up to ~450 ft (~140m), brown colors at lower elevations down to ~380ft (~115m), with contour lines at every 10ft (~3m). Inset shows site location relative to Lake Ontario and the surrounding geographic regions.

101x121mm (200 x 200 DPI)

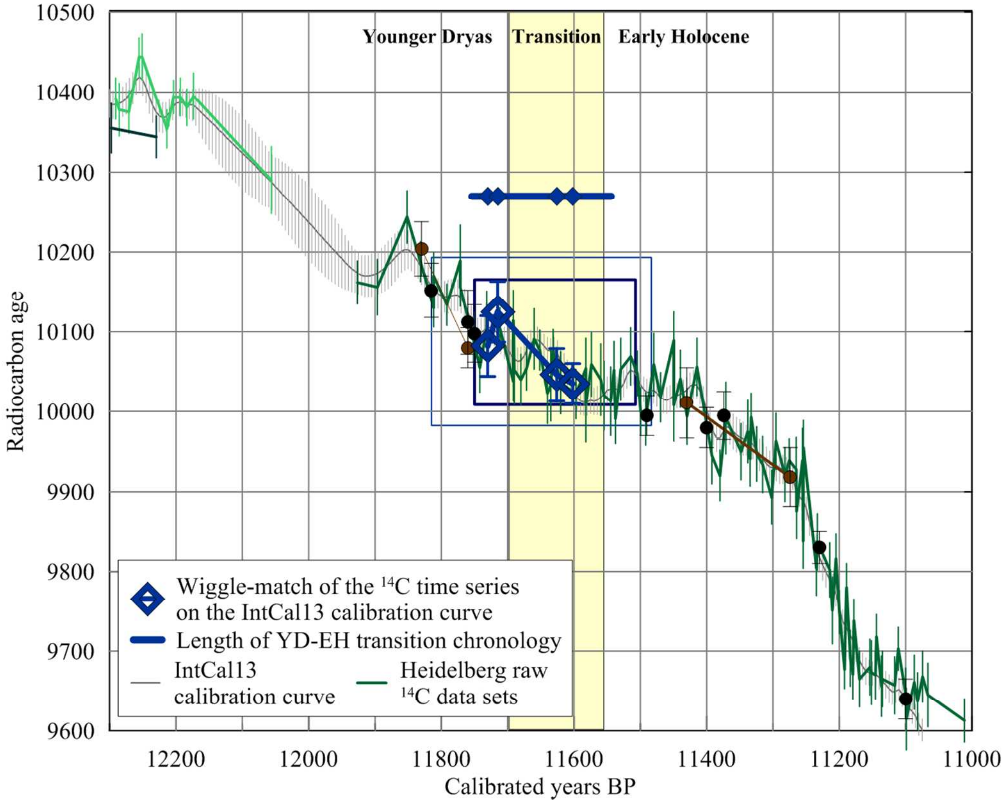

Figure 2. The ^{14}C time series of the chronology is placed at 11,755 - 11,545 cal a BP +20/-95, represented by the blue diamonds and connecting lines and are placed at one possible position on the IntCal13 calibration curve (OxCal version 4.2; Reimer et al., 2013) and a tree-ring ^{14}C data (Kromer et al., 2004, Kaiser et al., 2012) that is part of the data used in IntCal13. The 1σ range is within the dark blue box, and the outer box is the 2σ error range. The relatively wide error range despite wiggle-matching is due to the plateau in the calibration curve, a result of changes in atmospheric ^{14}C content during the YD (e.g. Muscheler et al. 2008, Kromer, 2009). The black and brown circles are the other ^{14}C dates from samples in the muck, placed at possible calibrated years. The width of the yellow bar covers the established YD-EH transition dates (see text).

176x141mm (200 x 200 DPI)

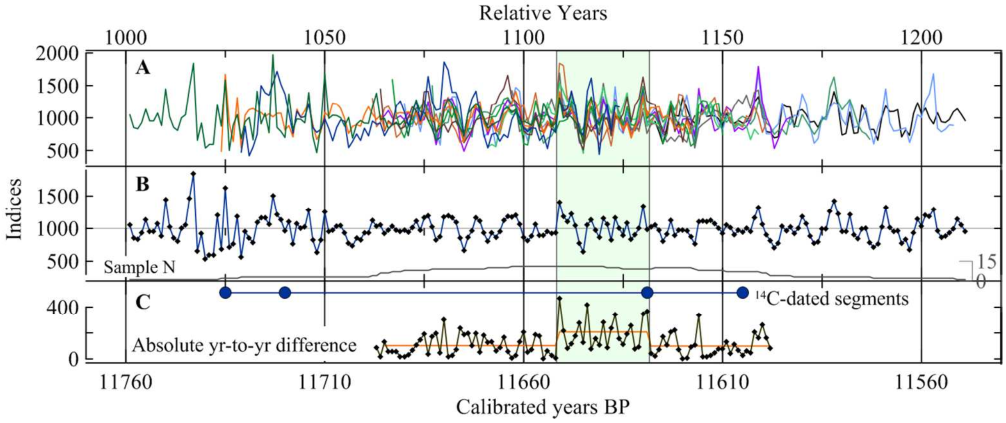

Figure 3. Panel A. The detrended sequences of 12 samples in the Bell Creek YD-EH chronology. Panel B. The YD-EH chronology, with sample number at bottom. Panel C. The time line of the four ^{14}C segments at top; at bottom is the year-to-year change in ring growth when sample count is 4 and over. Its Y-axis scale is twice that of panels A and B. In all panels, the 23-year interval, where variability and correlation are greater than in other years, is shown in the green box. This interval possibly represents the YD-EH transition. The top X-axis represents the relative years of the chronology; the bottom X-axis represents the calibrated dates shown in Figure 2. The Y-axes on the left are non-dimensional; on the right in panel B is the sample count.

194x81mm (200 x 200 DPI)