Supplementary Material - CRUST: Software for the implementation of Regional Chronology Standardisation: Part 1, Signal-Free RCS : Authors: Thomas M Melvin and Keith R.Briffa

Figure SM01 There is a natural step increase in growth in the Finnish trees at about 1920 (Melvin 2004) and for the testing here we need to generate chronologies with a step-increase, zero step, and a step-decrease. Chronologies were produced using one curve RCS (a) without using the signal-free method and (b) using the signal-free method with varying size steps to establish suitable values. In (a) and (b) chronologies were smoothed with a 50-year low-pass spline for display. The steps were created by multiplying the measured values after 1920 by a factor between 0.4 and 1.0. From (a) and (b) it can be seen that the chronology with a step of 0.7 shows the least change in the decades before and after 1920 and can be considered as having an approximately "zero step" in growth. The chronologies with steps of 0.4 and 1.0 (a step of 1.0 represents no change to the original measurements) are used to represent chronologies with a step decrease and a step increase respectively. The ratio of the step chronologies to the zero-step (0.7) chronology are shown for without-signal-free (c) and with signal-free (d) chronologies. There are step size differences in chronologies at 1920. There are slope and mean differences in the simple RCS chronologies whereas there are only mean differences in the signal-free chronologies. The steps after 1920 tend to influence the older (later RCS years) rings and because tree ages vary considerably the change is distributed across ring ages in the RCS curve, thus RCS without the signal-free method converts the step change into a slope change in the RCS curve and resulting chronology. A situation where the with- and without-signal-free chronologies are similar indicates that there is no slope bias in the RCS curve, implying that there is no overall chronology slope (here we exclude consideration of "modern sample bias").

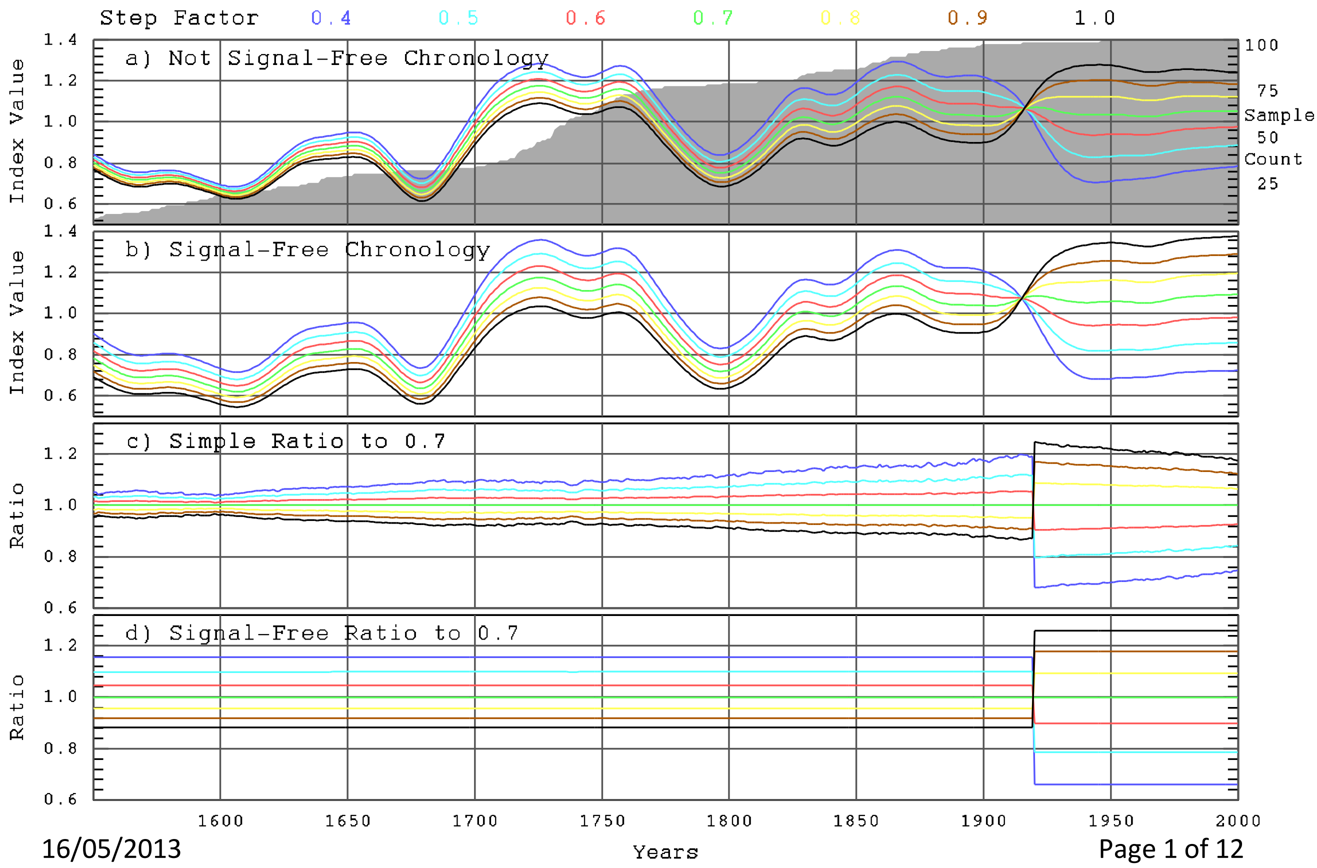


Figure SM02 unsmoothed RCS curves associated with the chronologies in Figure 5 of the main paper. The *Finnish TRW* measurements (black) were used to generate alternative data sets: one with the overall chronology slope reduced by -0.001 (blue) and one with the chronology slope increased by +0.001 (red), where each measurement was multiplied by the appropriate value (of a sloping straight line with a mean of 1.0) for that year to rotate the chronology about the centre year. Unsmoothed RCS curves for one-curve RCS without using the signal-free method are shown in (a) and alternatively, using the signal-free method (b). To highlight the differences in the generated RCS curves, we show the ratios of firstly the +0.001 slope-increase RCS curve divided by the original-slope RCS curve (red) and secondly the -0.001 slope-decrease RCS curve divided by the original-slope RCS curve (blue) for the non- signal-free chronologies (c) and for the signal-free chronologies (d). The positive and negative slope changes to the chronology appear in the RCS curves for simple RCS and do not appear in the single-free RCS curves.

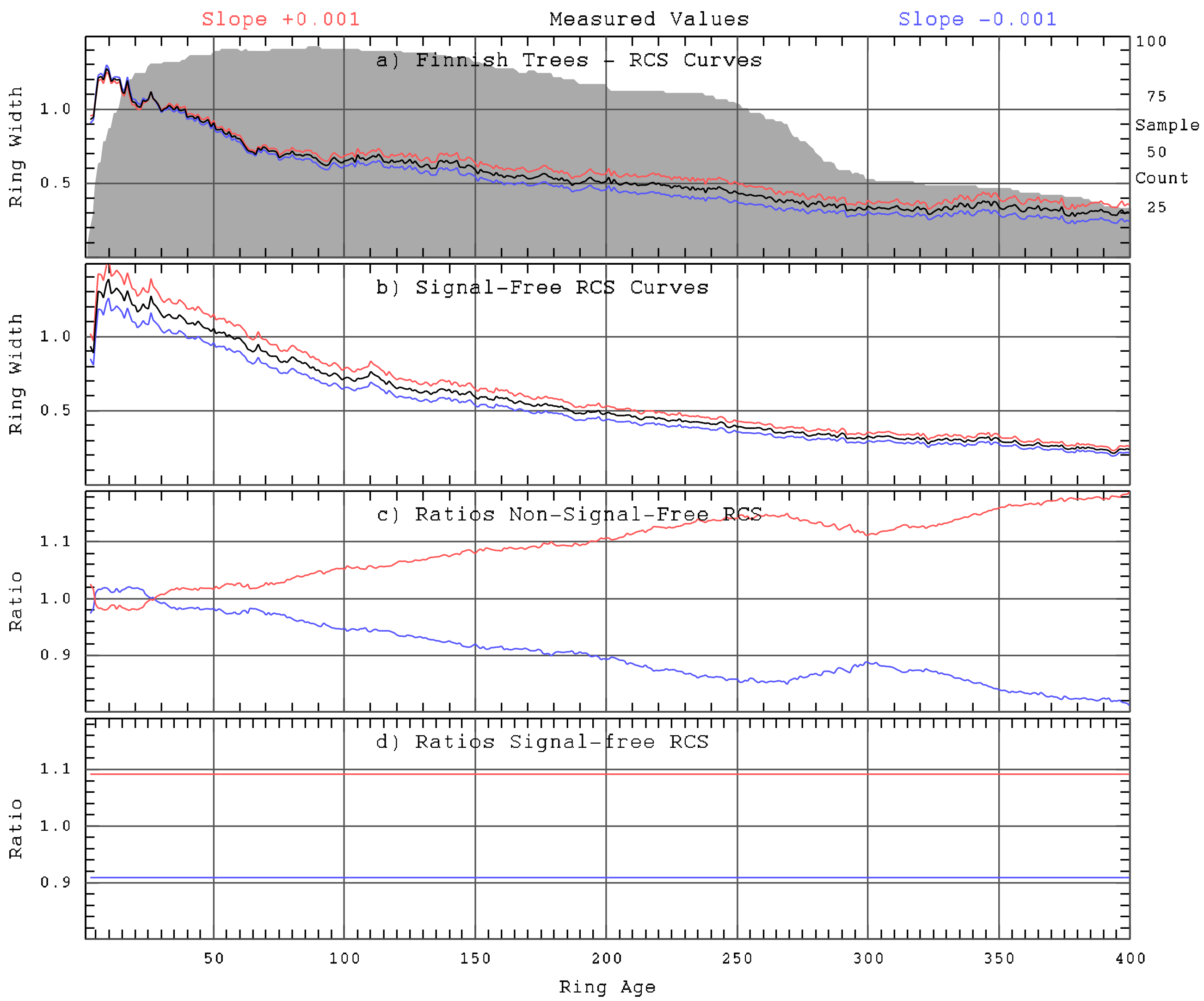


Figure SM03 The *Finnish TRW* measurements (black) were used to generate alternative data sets: one with the slopes of each tree reduced by -0.001 (blue) and one with the slopes of each tree increased by +0.001 (red), where each measurement was multiplied by the appropriate value (of a sloping straight line with a mean of 1.0) for that year to rotate the measurements series about the centre year of that tree, thus the means of each tree were not changed. Unsmoothed RCS curves for one-curve RCS without using the signal-free method are shown in (a) and alternatively those using the signal-free method are shown in (b). To highlight the differences in the generated RCS curves, we show the ratios of firstly, the +0.001 slope-increase RCS curve divided by the original-slope RCS curve (red) and secondly, the -0.001 slope-decrease RCS curve divided by the original-slope RCS curve (blue) for the non-signal-free chronologies (d) and for the signal-free chronologies (c). As expected, the positive and negative slope changes to the chronology appear in the RCS curves when using simple RCS. The slope changes also appear in the signal-free RCS curves. This occurs because the slopes in these individual trees are not consistent with the slopes in the chronology (created by the changing mean value of tree) and the signal-free method cannot remove that part of the slope not in the chronology.

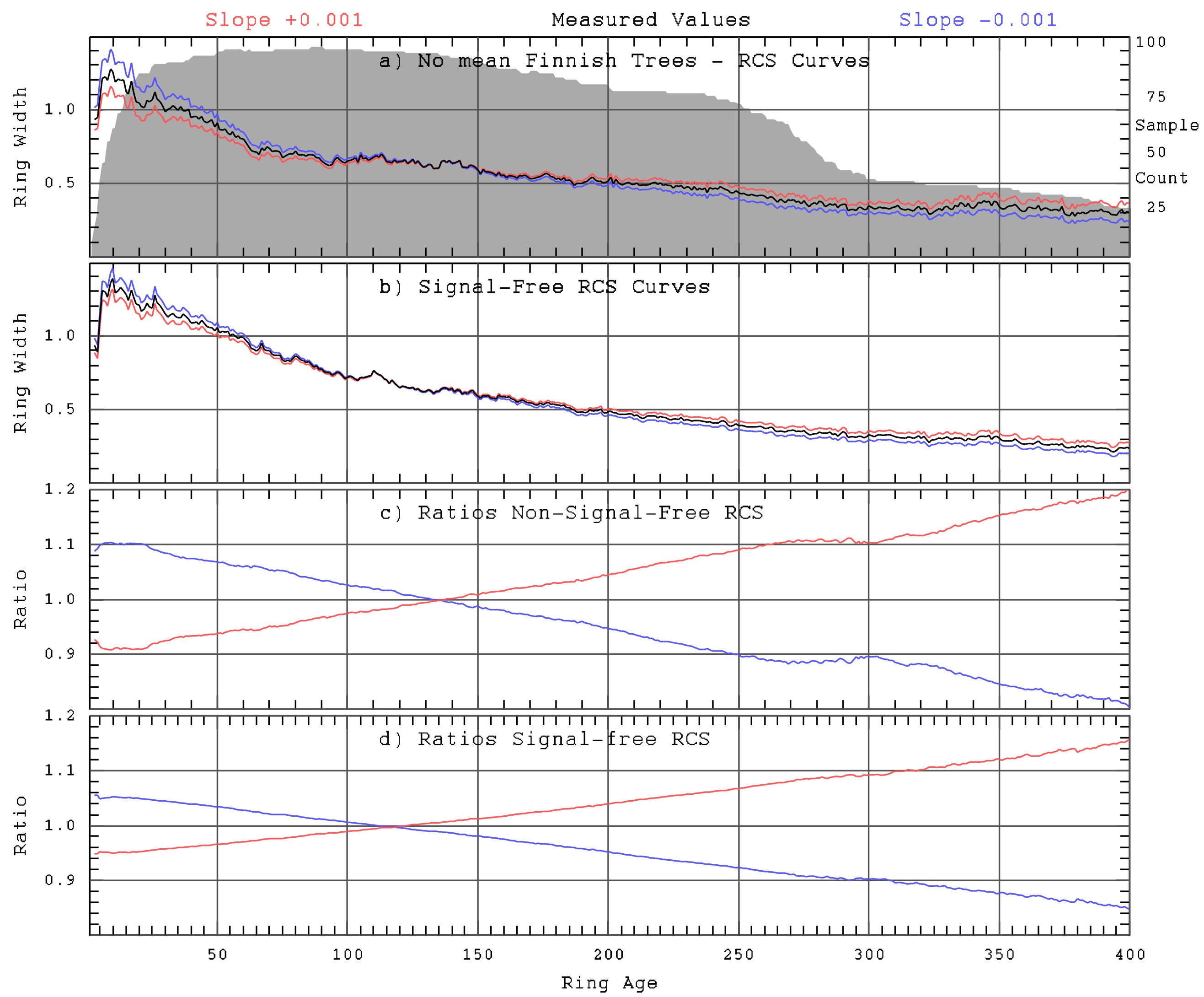


Figure SM04 The *Finnish TRW* measurements (black) were used to generate alternative data sets: one with the slopes of each tree reduced by -0.001 (blue) and one with the slopes of each tree increased by +0.001 (red), where each measurement was multiplied by the appropriate value (of a sloping straight line with a mean of 1.0) for that year to rotate the measurements series about the centre year of that tree, thus the means of each tree were not changed. Sample counts and the mean of raw measurement series are shown in (a). Chronologies were generated from the three data sets standardised with one-curve RCS without using the signal-free method (b) and alternatively using the signal-free method (c). To highlight the differences in the generated chronologies, we show the ratios of firstly, the increased-slope chronology divided by the original-slope chronology (red) and secondly, the decreased-slope chronology divided by the original-slope chronology (blue) for the non-signal-free chronologies (d) and for the signal-free chronologies (e). The ratios for the expected trend (i.e that produced if both the slope and means of measurements had been correctly amended) is shown as cyan lines in (d) and (e). Because the chronology slope in each tree is inconsistent with the chronology slope created by the changing mean values of each tree, the signal-free method cannot recover the slope over the length of the trees.

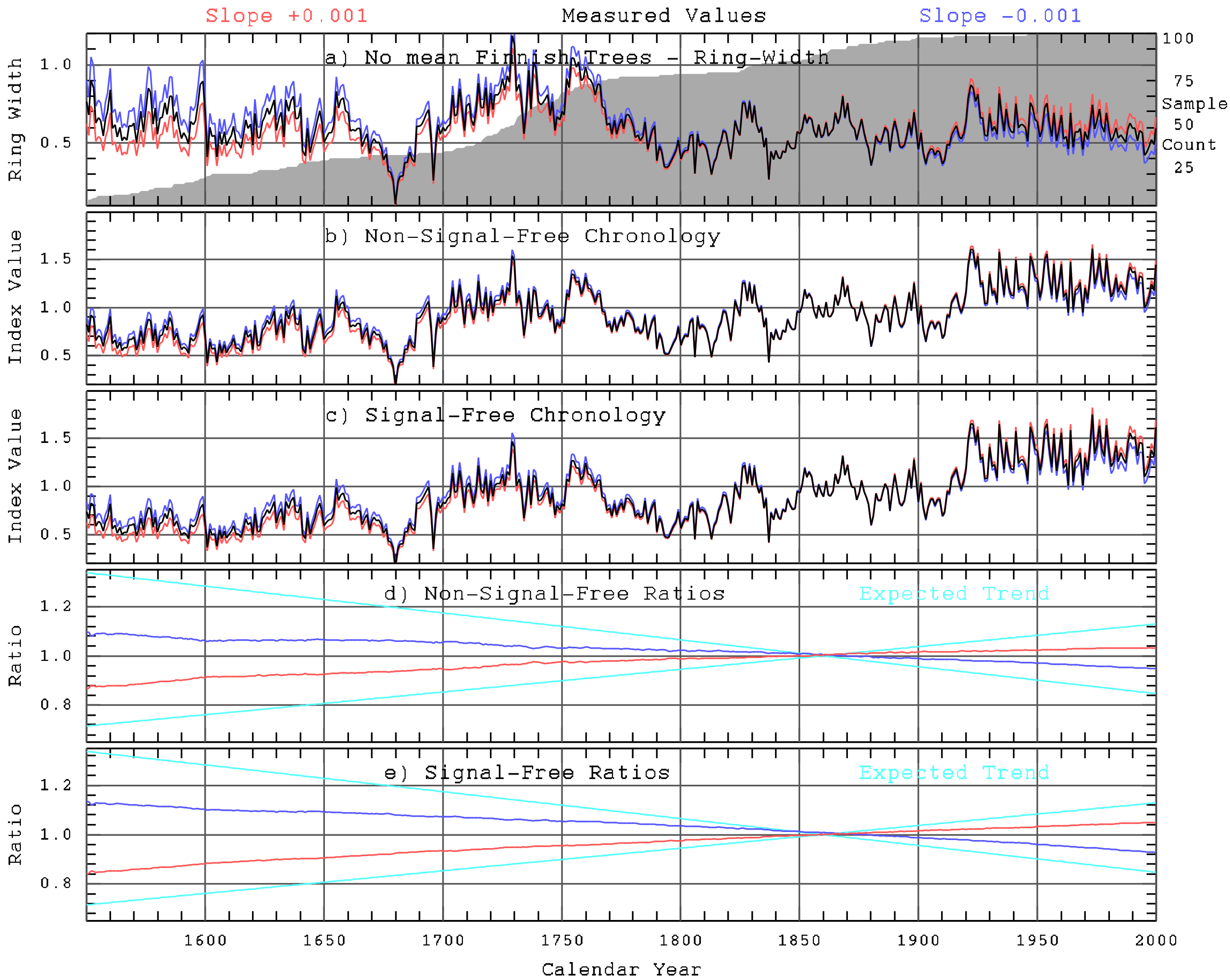


Figure SM05 The *Finnish TRW* measurements (black) were used to generate alternative data sets: one with the mean of each tree adjusted by the change of mean that would have occurred with a chronology slope change of -0.001 (blue) and with a chronology slope change of +0.001 (red). Each measurement series was scaled by the appropriate factor to produce a change of mean but the slopes of measurements of each tree were not changed. Unsmoothed RCS curves for one-curve RCS without using the signal-free method are shown in (a) and alternatively those using the signal-free method are shown in (b). To highlight the differences in the generated RCS curves, the ratios of firstly the +0.001 slope-increase RCS curve divided by the original-slope RCS curve is shown in (red) and secondly the -0.001 slope-decrease RCS curve divided by the original-slope RCS curve is shown in (blue) for the without using signal-free chronologies (d) and for the using signal-free chronologies (c). The oldest trees have zero change to their mean while the changes to mean up have larger effect for younger trees. The use of signal-free methods (b) accentuates the change relative to those not using signal free (a). The changes to mean values of trees create changes to the slopes of the RCS curves. The slope of the RCS curve is not caused solely by the reduction of TRW with ring age but also reflects any dependence of mean growth rates of trees with final tree age.

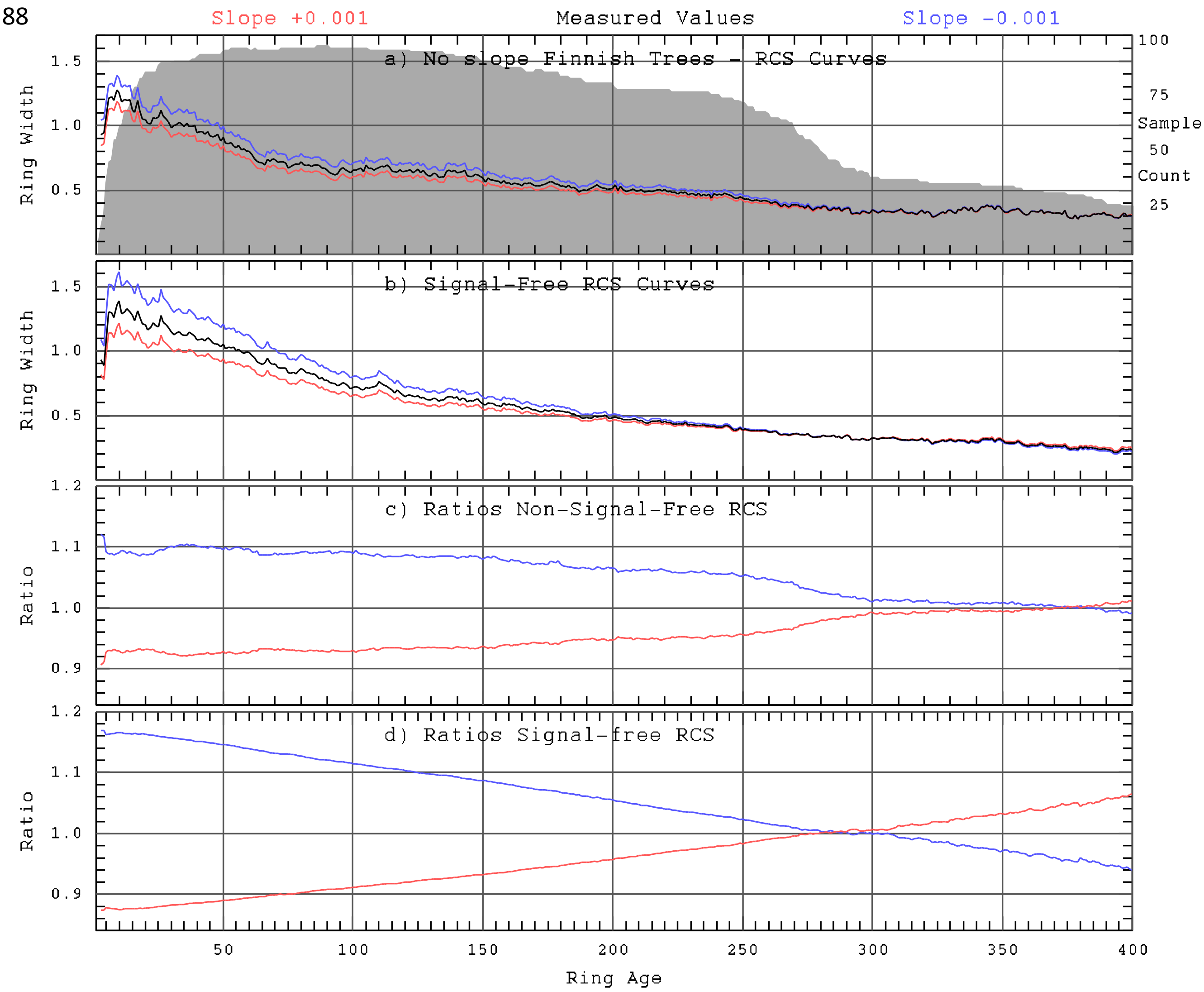
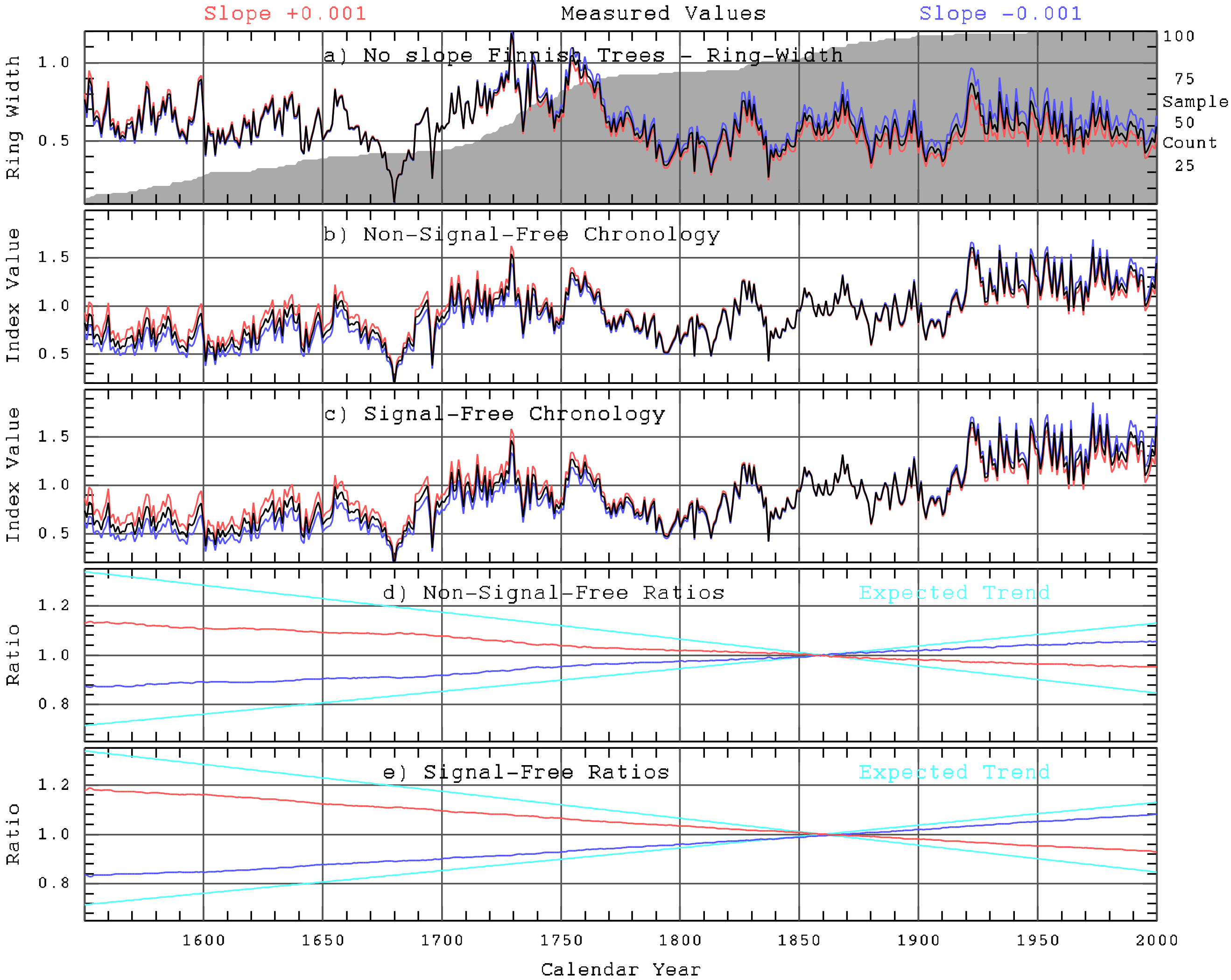


Figure SM06 The *Finnish TRW* measurements (black) were used to generate alternative data sets: one with the mean of each tree adjusted by the change of mean that would have occurred with a chronology slope change of -0.001 (blue) and with a chronology slope change of +0.001 (red). Each measurement series was scaled by the same factor to produce a change of mean but the slopes of measurements of each tree were not changed. Sample counts and the mean of raw measurement series are shown in (a). Chronologies were generated from the three data sets standardised with one-curve RCS without using the signal-free method (b) and alternatively using the signal-free method (c). To highlight the differences in the generated chronologies, the ratios of firstly, the increased-slope chronology divided by the original-slope chronology (red) and secondly, the decreased-slope chronology divided by the original-slope chronology (blue) for the non-signal-free chronologies (d) and for the signal-free chronologies (e). The ratio of the expected trend, had both the slope and means of measurements been amended, is shown as cyan lines in (d) and (e). Because the changing mean values of each tree are inconsistent with chronology slope in each tree the chronology slope created by the signal-free method cannot recover the slope over the length of the trees.



Figures SM07-SM11 The *Finnish TRW* measurements (red) were used to generate alternative data sets: one with measured values after 1920 reduced by 30% (black) and one with measured values after 1920 reduced by 60% (blue). Various subsets of these living-tree data all sampled in 2001, distinguished by the temporal distribution of measurement series start dates (here equivalent to changing tree age), are used to test the ability of the non-signal-free and signal-free methods to recover the artificial adjustments made to the common signal. In all cases the non-signal-free method performs poorly. The signal-free implementation performs well, provided there is sufficient range of temporal representation of samples in different parts of the RCS curve. The signal-free chronologies degrade as the range of tree ages in the chronology is reduced.

Figure SM07 Using data from the 66 series starting between 1704 and 1946. The signal-free method recovers the artificial signals without distortion.

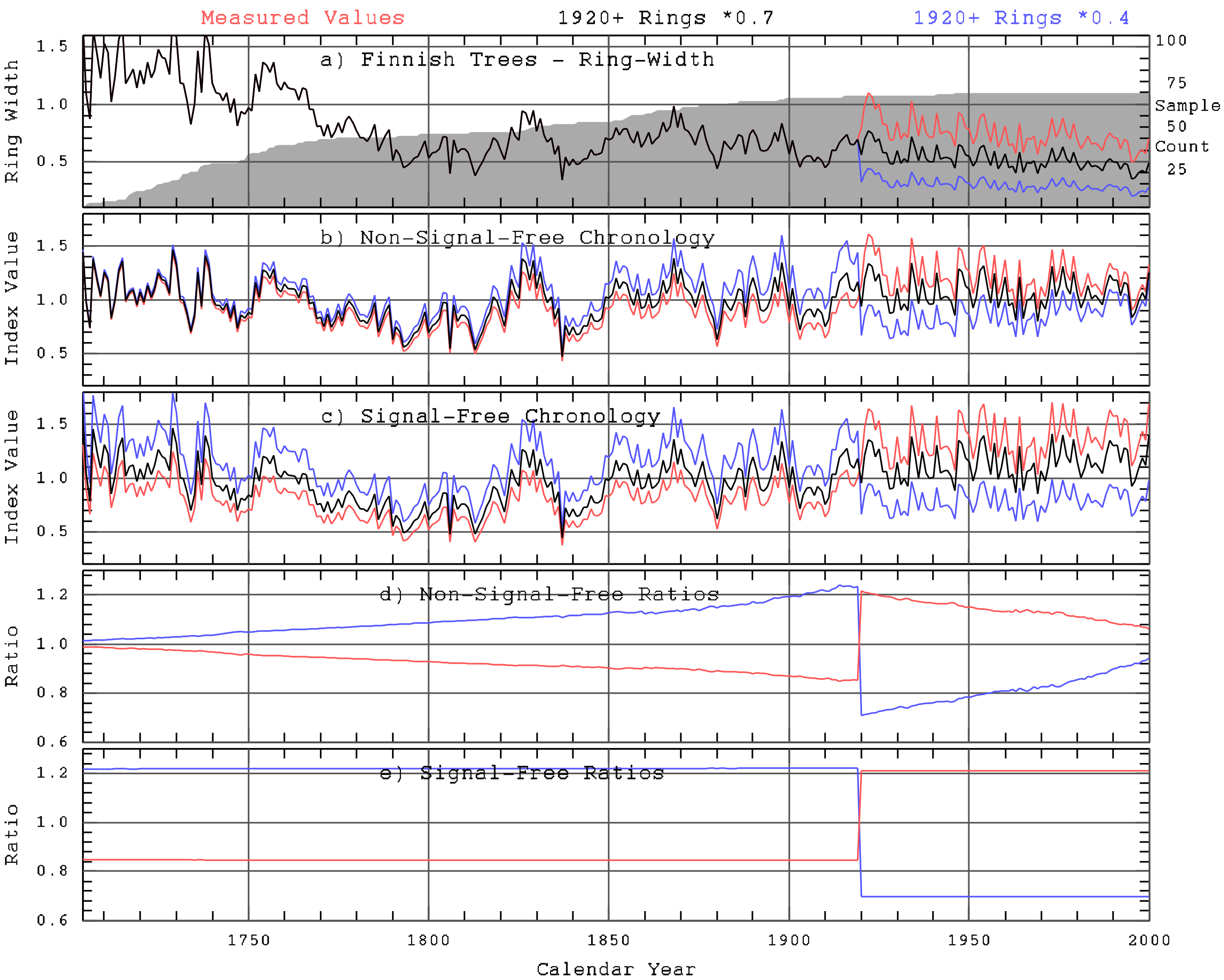


Figure SM08 Using the 55 series starting between 1704 and 1886, the signal-free method recovers the artificial signals with only slight distortion which can be seen in none-zero slopes of the red and blue lines in (e).

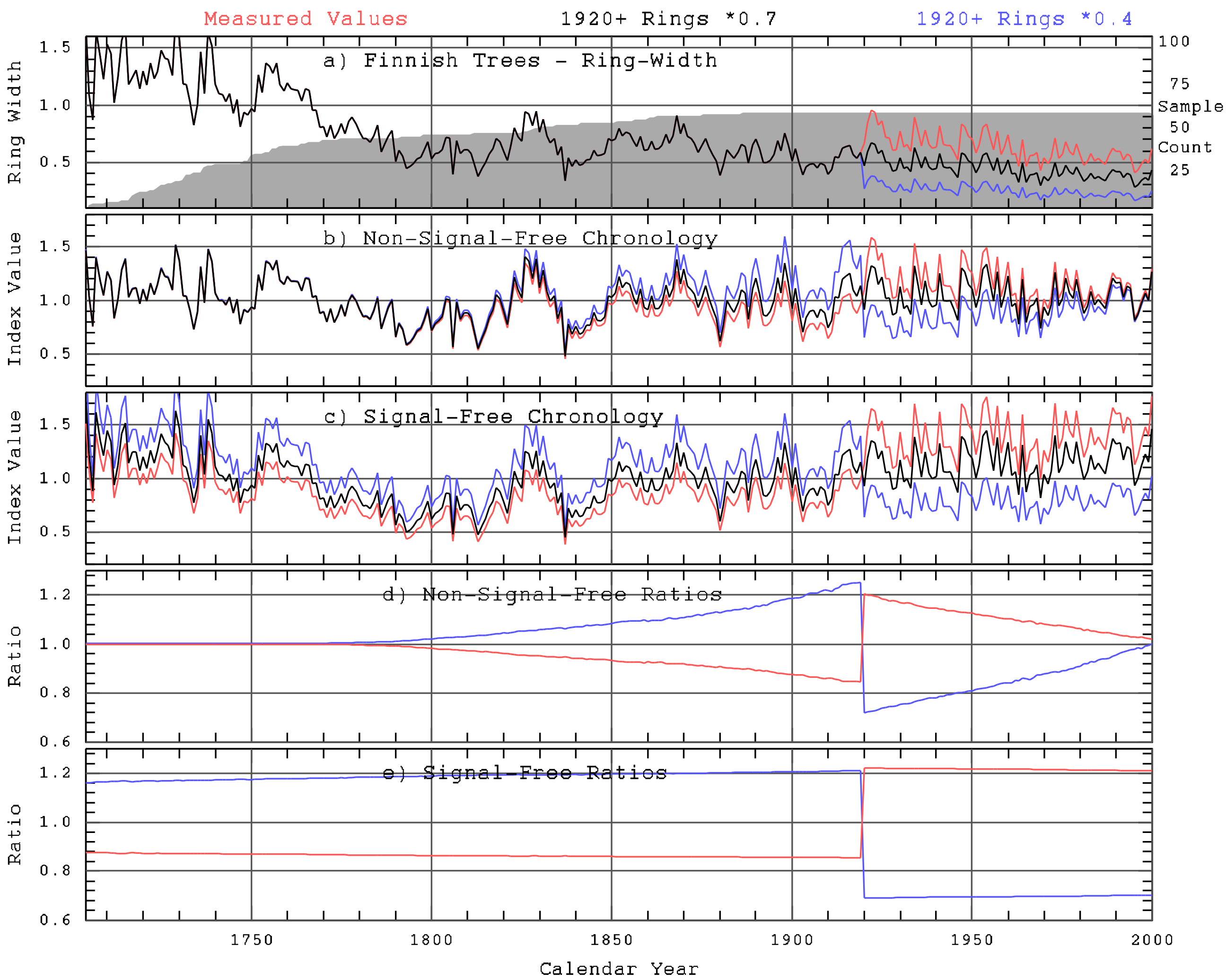


Figure SM09 Using the 40 series starting between 1704 and 1774, the signal-free method does not recover the artificial signals. Severe distortion can be seen in the slopes of the red and blue lines in (e) which should be horizontal.

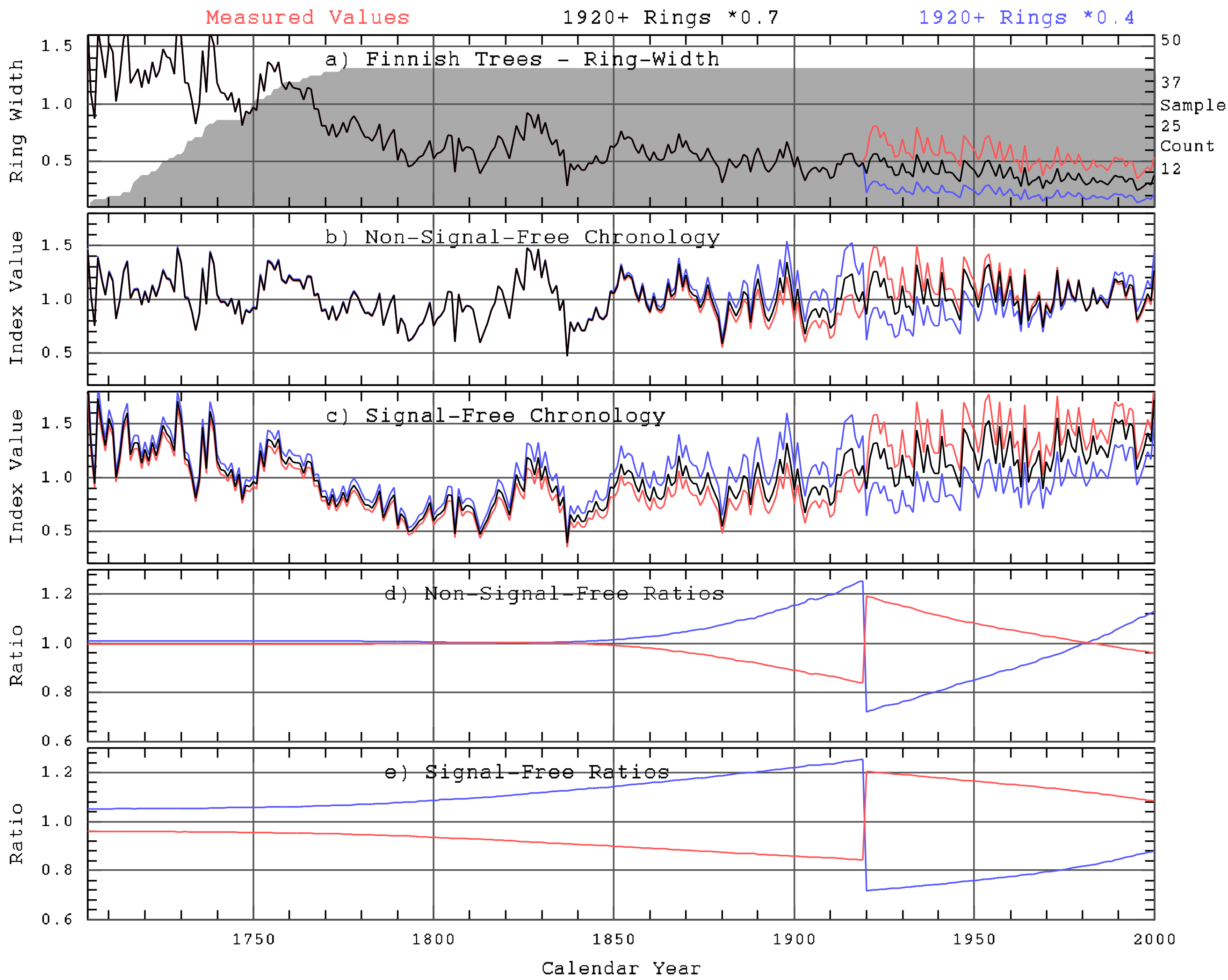
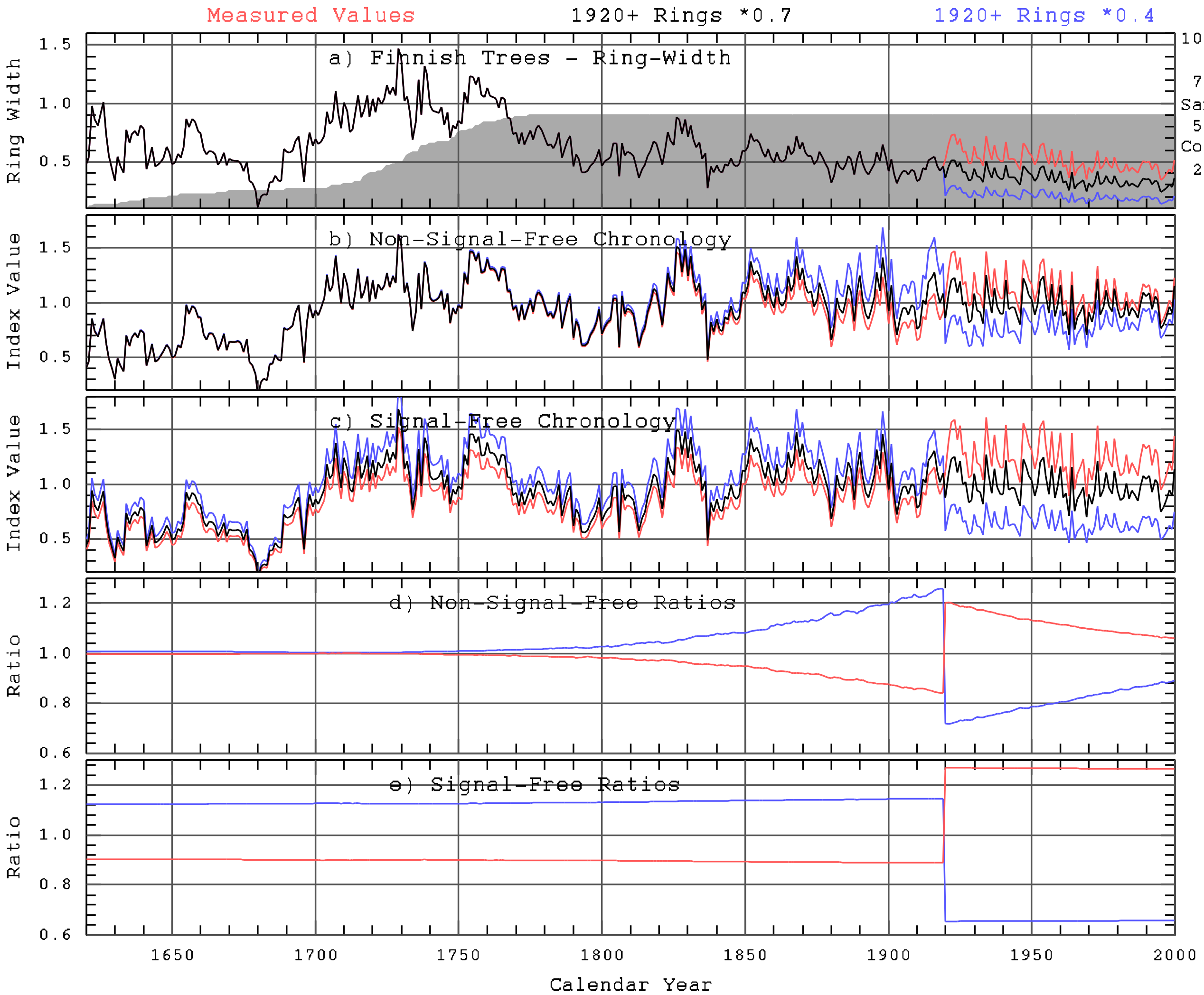


Figure SM10 Using the 53 series starting between 1620 and 1774, the signal-free method recovers the artificial signals with only slight distortion which can be seen in the none-zero slopes of the red and blue lines in (e).



126 **Figure SM11** Using the 74 series starting between 1550 and 1774, the signal-free method
127 recovers the artificial signals without distortion.

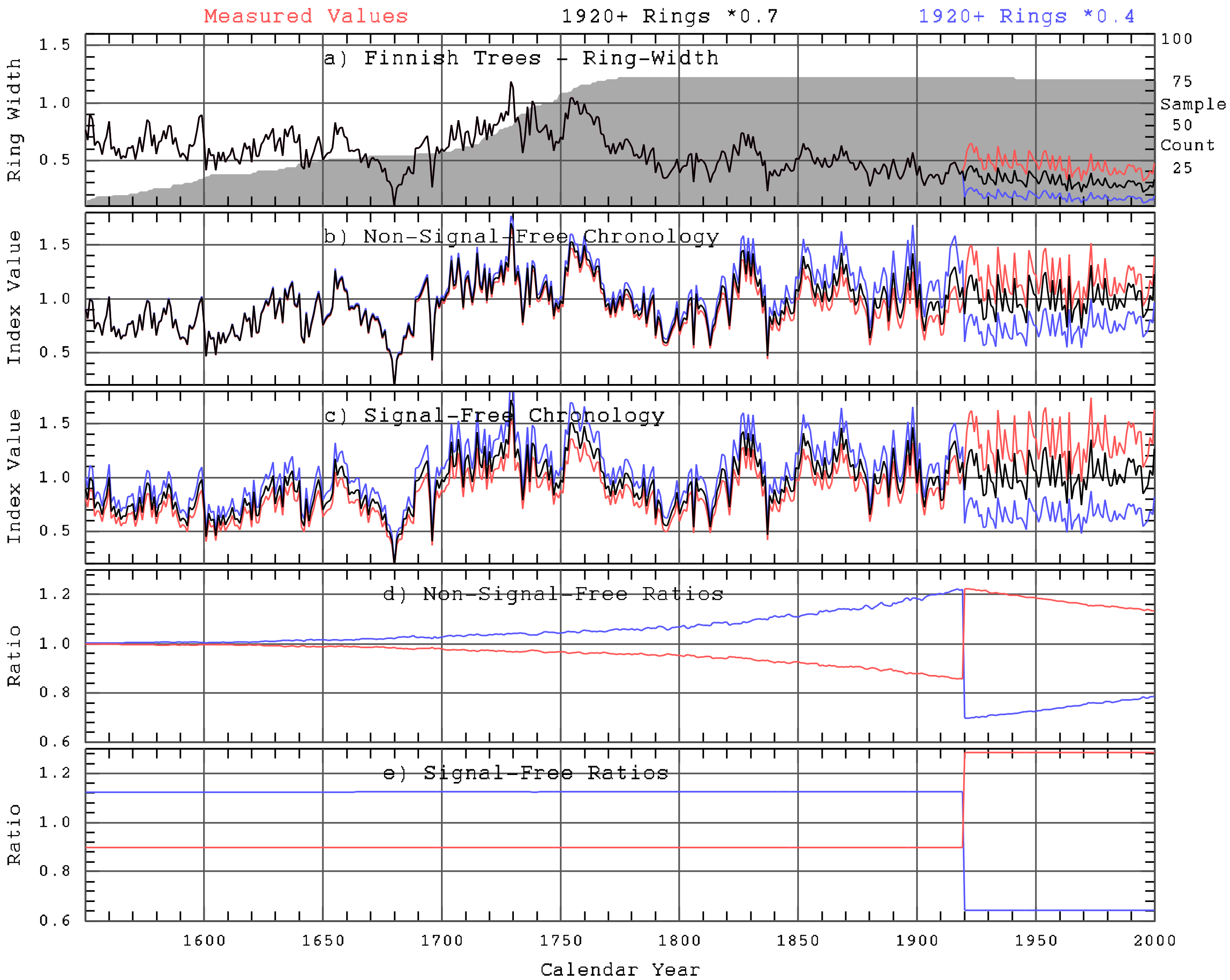


Figure SM12 The *Finnish TRW* measurements were used to generate alternative data sets: one with the chronology slope reduced (blue) and one with the chronology slope increased (red), where each measurement was multiplied by the appropriate factor for that year to rotate the chronology about the centre year with a change of 0.001 per year. Various subsets of these data, distinguished by the age distribution of trees, were standardised using one-curve, signal-free RCS. The ratio between the increased-slope and the original chronologies (red) and the ratio between the decreased-slope and the original chronologies (blue dashed line) are plotted for (a) the 66 series starting between 1704 and 1946, (b) the 55 series starting between 1704 and 1886, (c) the 40 series starting between 1704 and 1774, (d) the 53 series starting between 1620 and 1774, and (e) the 74 series starting between 1550 and 1724. Sample counts over time are shown by grey shading. The ratio of the expected slope change relative to the original series is shown as cyan. For (a) and (e) there in no distortion, for (b) and (d) there is slight distortion, but for (c) there is considerable distortion in the recovered signal. As the temporal range in series starting years is reduced below 200 years, distortion appears in the signal-free RCS. With a starting year range below 100 years the distortion is large. Without signal-free the slopes of RCS chronologies generated from living trees are indeterminate. Provided that there is a sufficiently wide distribution of tree starting dates (i.e. tree ages for a living chronology), the signal-free method can accurately recover the slope.