

**(1) comments from Referees, (2) author's response, (3) author's changes in manuscript**

**Point- by – Point response Ed Cook**

**Comment 1:**

5 (1) The authors note that there are 415 “temperature-sensitive” tree-ring chronologies in the  
global PAGES 2k database and proceed to use them to illustrate the lack of a pre- industrial  
cooling trend in tree-ring series relative to the other temperature proxies (Fig. 2). The 50-year  
binned composite tree-ring series do have a very slight negative trend, but it is not statistically  
10 significant compared to the much larger negative trends found in the other proxies. While this  
initial comparison sets the stage for the investigations carried out in the rest of the paper, it is  
somewhat strange because by my calculation (using the 402 NH chronologies noted in Fig. 1a)  
there are  $415-402=13$  SH tree-ring series in the 415-chronology total that could have orbitally-  
driven positive temperature trends in them. Thus, including the 13 SH chronologies in the  
15 binned composite (Fig. 2b) likely weakens the chance of finding a statistically significant  
negative trend in the 402 NH chronologies. Figure 2b should therefore be redone using only  
the 402 NH chronologies for the binned evaluation of the temperature trend. I do not  
necessarily expect a change of outcome, but it should be done to be consistent with the  
argument. On line 60, the reference to “average global tree-ring record” should consequently  
20 be changed to “average Northern Hemisphere tree-ring record” as well. Later in the paper it is  
finally mentioned that the SH tree-ring data were excluded from further analysis (lines 128-  
129). This should have been mentioned in the beginning, and the SH chronologies immediately  
excluded, as suggested above.

(2) We acknowledge the point that there might arise a trend distortion.

(3) Changed, but not only for tree-ring records. Fig. 2a and Fig. 4 were changed accordingly.

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**Comment 2:**

(1) At the hypothesis testing stage (pg. 5) the original 415 global chronologies were winnowed to  
a subset of 70 NH tree-ring collections, each at least 800 years long (line 143). It would be  
useful to have a table in the paper (as an appendix?) that lists these data sets by location,  
30 species, length, and modeled climate sensitivity (e.g., maximum correlation with monthly  
summer temperature), so that others can download the same tree-ring data and repeat the  
same evaluations on their own.

(2) Due to additional consideration of Signal Free (see below), the number of records had to be reduced to 67 NH records, because the program failed to detrend 3 of the datasets.

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(3) Metadata table (selection of information provided by PAGES) was added to the appendix.

### Comment 3:

(1) Regardless, selecting only the longer series for further evaluation is quite sensible because the preservation and detection of a negative pre-industrial temperature trend (if there) will be far easier to accomplish with  $\geq 800$  year-long series due to issues related to the 'segment length curse'. This being the case, I cannot fathom why experiments with (i) 100-year spline detrending (SPL) were carried out. The result is totally predictable with respect to the preservation of multi-centennial to millennial-long trends; they are all removed. Therefore, no negative pre-industrial temperature trend can ever be expected to be detected. Thus, SPL detrending has no relevance to testing the effects of detrending on the presence or absence of the expected negative temperature trend.

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(2) The 100-year spline detrending was added to show how close the results are compared to a method removing multi-centennial variability. Anyway, we understand that true insiders find the result predictable.

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(3) The 100-year spline detrending was removed (and Signal Free added. See below.).

### Comment 4:

(1) This leaves (iii) regional curve standardization (RCS) as the only detrending option that may preserve the negative pre-industrial temperature trend from ring widths being sought. Thus, the authors are right in stating that that this method is the best of the three. Unfortunately, they are also right in stating the tree-ring measurements in the PAGES 2k database are for the most part inadequate for the application of RCS detrending. Besides the datasets not being nearly large enough in general, there are other reasons detailed in Briffa and Melvin (2011) on why use of RCS on inappropriate data sets can lead to the creation of utterly spurious long-term trends. This is because it is rarely appropriate to use RCS on datasets based only on living trees from the same site. Yet, I suspect that this is the case for most of the datasets in the PAGES 2k database. Applying RCS to such datasets can introduce what Briffa and Melvin (2011) call 'modern sample bias' in the form of an artificial positive slope to the final RCS chronology, which is exactly the opposite to what is expected here based on orbital forcing. This being said, the 50-year binned RCS composite may still be useful to evaluate because any 'modern sample bias' in individual chronologies may be attenuated in the large-scale multi-site composite. This is still not optimal, however. On a positive note, I actually find the

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results shown in Fig. 5 to be encouraging. The 2/3 of the tree-ring chronologies (based on RCS? unclear in the text.) have negative trends up to 1800 CE.

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(2) Sure not all datasets are fully appropriate for applying RCS.

(3) As an additional test, we performed Signal Free Regional Curve Standardization that should cope with some of the biased in the TRW chronologies.

#### Comment 5:

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(1) Although most are declared not statistically significant, it would be useful to test for the probability that the combined outcome is in fact statistically significant in favor of a cooling trend being there more than by chance alone in 2/3 of the series. This can be easily done using Fisher's combined probability test ([https://en.wikipedia.org/wiki/Fisher%27s\\_method](https://en.wikipedia.org/wiki/Fisher%27s_method)) assuming (quite reasonably here) independence between the individual test outcomes.

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(2) We have chosen another option in line with a comment of reviewer 3. The reviewer claimed that we do not account for a latitudinal sampling bias. This was addressed by adding uncertainty estimates retrieved from MonteCarlo based tests.

(3) Figure S.4 was added.

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#### Comment 6:

(1) However, again there appears to be a mismatch in the number of series longer than 800 years declared for use (70) (line 143) and the number indicated in the left-hand bar chart in Fig. 5 (89). The same problem is apparent in the total chronology count (89) shown in Fig. 7b. This inconsistency must be corrected.

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(2) We are simply not able to access all 89 raw datasets, a circumstance we have to accept (and point to in our paper).

(3) Further information was added to explain the varying numbers.

#### Comment 7:

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(1) The results of the other two tested hypotheses – climate sensitivity and spatial distribution – appear reasonable to me, although it is unclear which version of the chronologies is being used; SPL, NEG, or RCS. This ambiguity must be corrected.

(3) Information was added.

00 **Comment 8:**

05 (1) I would, however, caution about using chronologies with “mixed climate sensitivity”, i.e. a combination of temperature and moisture sensitivity in the ring widths. Published work by Matt Salzer and Andy Bunn show that even at the highest, most temperature limited, elevations in the White Mountains of California it is easy to find bristlecone pine trees that have mixed precipitation/temperature signals in their ring widths. When this occurs, the correlation with summer temperature can be negative, leading to the suggestion here to invert those chronologies to rectify the correlation with temperature (lines 125-126). I am not sure this is a good idea. This form of negative temperature sensitivity is completely different from that for trees with positive temperature sensitivity because the negative correlation with temperature most likely reflects an evapotranspiration demand signal associated with a positive response to soil moisture content and precipitation amount. It is not clear that one should expect this relationship to have the same trend (in inverted form) as that due to the direct effect of summer temperatures on radial growth because this mixed-signal climate response is likely to include the direct effect of changing precipitation amount, which behaves more like a ‘white noise’ process compared to temperature. At the very least, one might expect the temperature trend expressed in the inverted tree-ring series to be reduced by the effects of a precipitation signal on ring width.

(2) [The inversion of records affected only some non-tree ring records.](#)

(3) [Explanation about the records that were inverted was added to the methods section.](#)

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**Point- by – Point response Lea Schneider**

**Comment 1:**

25 (1) Although the different tests applied by Klippel et al. are meaningful and reasonable, I would like to suggest one other experiment that might explain some of the offset in trends. The data preparation in this study follows the steps outlined in the PAGES2k network study. However, the last step described in the PAGES study, a scaling to temperature, is not applied (for some unknown reason, data were also not scaled in the corresponding PAGES figure). For the significance of long term trends, the scale is irrelevant and I’m not suggesting a scaling to temperature.

30 (2) [We did not scale the data to temperature, to produce Figure 2 \(this publication\) because in Figure 8 of the original publication \(Pages 2k 2017\) the data were also not scaled to temperature. See the original caption: “Figure 8. 50-year binned composites stratified by archive type, for all types comprising 5 or more series. Composites with fewer than 10](#)

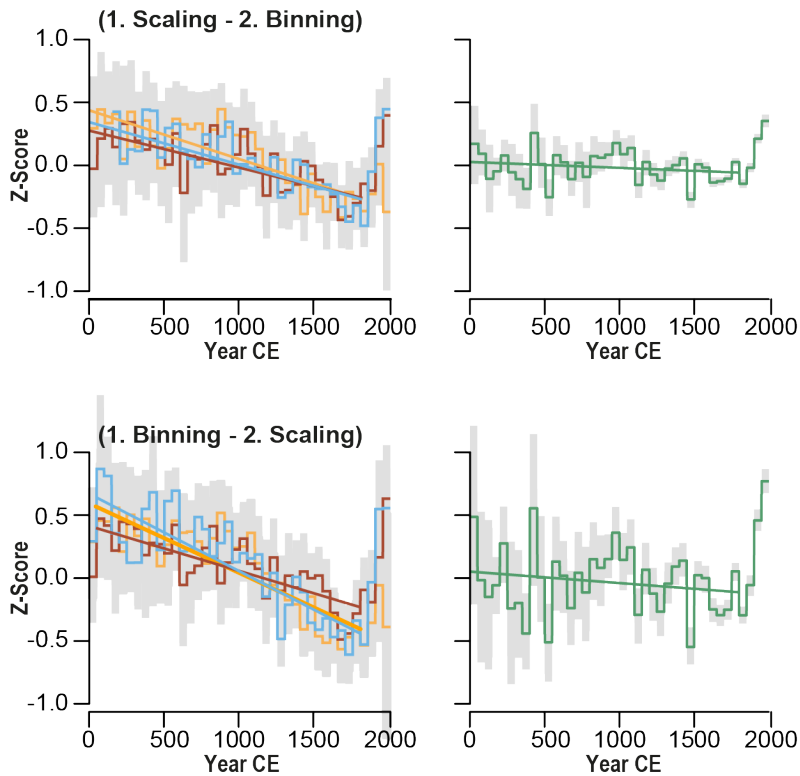
35 available series are shown by a dotted curve, while solid lines indicate more than 10 series. Shading indicates 95% bootstrap confidence intervals with 500 replicates. Gray bars indicate the number of records per bin. The composites are expressed in standard deviation units, not scaled to temperature”.

(3) No changes made.

40 **Comment 2:**

(1) More importantly, I want to point out that binning (or any other sort of low-pass filtering) needs to be followed by a scaling to either standard normal deviates or temperature, if the frequency spectra of the original data are very different. The latter is to be expected according to the title of this manuscript. The signal of low resolution records will be inflated compared to the low frequency tree-ring signal if scaling precedes binning. I expect the weak negative trend in the tree-ring compilation over the 1 1800CE period to become less weak compared to trends in other archives (Fig. 2) if scaling to a common target follows binning (or low-pass filtering). This is a common procedure in multiproxy studies (e.g. Ljungqvist et al. 2016). These considerations should not alter the significance of trends. However, even binned tree-ring records might still have a less negative slope in the frequency space compared to records with an originally low temporal resolution.

(2) This was tested by switching the procedure: First binning, the scaling (blue = glacier ice, orange = marine sediment, red = lake sediment, green = tree-ring records). Here we show both a reproduction of Figure 2 (upper panel) and the result of the suggested, reversed processes of binning followed by scaling (lower panel).



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Reversing the binning/scaling procedure increases multi-decadal to centennial scale variability. However, this is the case for all proxies, i.e. not only for the tree-ring data. The reduced pre-industrial cooling in the tree-ring data remains the same.

(3) No changes added to the manuscript.

**Comment 3:**

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(1) Marine sediment records with 200 year time steps, which fulfil the PAGES selection criteria, should have no (non-random) loading at frequencies around 50 years and therefore a steeper negative slope. Having a higher proportion of variability at multidecadal scale (compared to millennial scale) might penalize tree-ring records when assessing the significance of linear trends over almost 2 millennia. Whether this effect is relevant or not, could be tested, e.g., by binning with 200 years intervals. This might decrease the difference between tree-rings and other archives in Fig. 5.

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(2) The test slightly changes the differences, however, the major discrepancies remain the same (see below).

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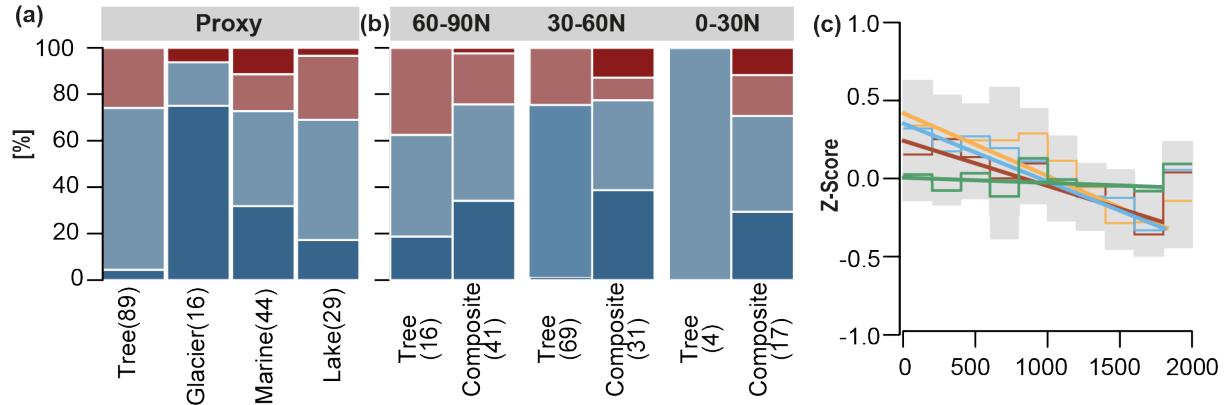


Fig. 5 after using 200-year bins.

(3) No changes added to the manuscript.

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#### Comment 4:

(1) The significance of trends might be even more affected by the variable length of tree-ring records. Is there a relationship between the length of the records and the significance of trends? It is reported that trends were calculated over the 1-1800CE period, but it is not clear how the authors dealt with records terminating before 1CE. Even if only records of >800 years are selected, the vast majority of them will not cover the entire 1-1800CE period. I assume the trends were then calculated over the remaining period, e.g. from 1000-1800CE. The authors need to specify in which way they considered that a shorter record (i.e. less degrees of freedom) likely reveals less significant millennial scale trends.

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(2) We are aware of the problem, thus analysis was constraint to records longer than 800 years.

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(3) Further information and explanation was added to the manuscript (Fig. S.3).

#### Comment 5:

(1) The authors are a bit ambiguous in their terminology when it comes to the appropriateness of detrending methods. Although they acknowledge that RCS detrending is best applied to datasets with certain characteristics (L52-54), they term individual detrending methods as inappropriate (L64+102). I agree that individual detrending methods are often inappropriate to

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00 preserve low frequency trends. However, depending on the age structure and the replication of the dataset, RCS can be likewise inappropriate. Some authors of tree-ring based climate reconstructions consider such shortcomings by stating that their record cannot capture millennial scale trends, an information that is usually ignored when incorporating data in larger scale compilations. Multiproxy data collectors are not necessarily dendrochronologists. Thus, it is vital to be more specific when discussing these aspects to keep dendroclimatology credible.

05 (3) This is very correct, we adopted the text accordingly and by including Signal Free Regional Curve Standardization.

### Minor comments

#### Comment 6:

10 (1) P3 L61-65 Differences between TRW and MXD data are not discussed in this manuscript. Without testing the hypothesis that MXD is better able to preserve millennial scale trends, I suggest to remove these sentences in order to prevent wrong expectations among readers.

(2) Even though it is not tested in the publication, we consider this a very important finding which needs to be considered in the introduction.

(3) No Changes.

#### Comment 7:

15 (1) P3 L74 Inhomogeneous spatial distributions and mixed climate signals are not only problems for the tree-ring component! In fact, I would guess that the average climate signal is much stronger among tree-ring records compared to other archives.

20 (2) Yes this is likely true. However, we have no expertise in assessing the limitations and strength of other archives. Thus we focus only on tree-ring records to perform this analysis.

(3) No changes made.

#### Comment 8:

25 (1) P7 L14 Please define Arctic.

(3) Explanation was added.



**Comment 9:**

- 30 (1) P8 L41-42 But the trend is not only significant in the global (or NH) mean. Fig. 5 shows that about half of the records exhibit a significant trend at local scale.
- (3) Changed to “multiple” tree-ring datasets.

**Comment 10:**

- 35 (1) P9 L70-72 Instead of presenting the number of overlapping tree-ring chronologies it would be more helpful to report a percentage (although this might be more difficult under a constantly changing number of records).
- (2) “Although this might be more difficult under a constantly changing number of records”. We agree and therefore we don’t consider to report a percentage to be a useful information here.
- (3) No change.

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**Point- by – Point response Anonymous**

**Comment 1:**

- 45 (1) With regard to 1, the authors appropriately discuss the latitudinal gradient in the orbitally forced trends in temperature. They nevertheless do little to describe and investigate the latitudinal sampling biases in the two populations that they explore, namely the dendro and composite proxy populations. This sampling bias is obvious in Figure 1 and in the sample sizes listed in Figure 5. And yet figures like Figure 2 are presented with little caveat. Such a figure is misleading, given that the composite records are biased toward the high latitudes and the dendro records are biased toward the midlatitudes and the lower midlatitudes in particular (incidentally, it is not mentioned anywhere whether these means are themselves weighted by  $\cos(\text{lat})$ , as they should be). How should we interpret these time series given that the explored effect intensifies at the higher latitudes? Splitting Figure 2 into time series representing different latitude bands would help (30 degree boxes may be too large for this), as would a scatter plot of trends vs. latitude for each of the two populations. While not definitive, it would be helpful for understanding how spatial sampling of a spatially-dependent temperature trend may be biasing the mean trends estimated from the two populations. I suspect that the authors will bring up Figure 5 as a rebuttal to what I am pointing out, but please see my
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- 55 comments on my second principle concern below.

- 60 (2) Figure 2 is merely a reproduction of a figure shown in the Pages publication (and in response  
with suggestions of reviewer 1, only the NH is shown). The figure is not part of our analysis,  
but demonstrates that we can reproduce the Pages trends. The latitudinal sampling bias is  
indeed tested Figure 5, but we added another splitting as suggested.
- 65 (3) Supplement figure added showing composite chronologies after splitting by latitude.

### Comment 2:

- 70 (1) Before I get to that, however, I would add that another overlooked bias is that of the proxies  
comprising the composite records. They all sample different seasonal windows, some reflect  
marine temperature changes as opposed to continental changes, and many have their own  
biases tied to representation of low-frequencies. The authors take the composite proxies at  
face value, presumably because they fit their assumptions about latitudinal trends (in most  
cases), but it is insufficient to do so.
- 75 (2) This is obviously a critique on the data composition and/or papers using this by combining  
proxies, which is exactly what we try to make readers aware of. Here we point to systematic  
differences among proxies, and even include a splitting by season.
- (3) No changes made.

### Comment 3

80 There may be biases in these other records that promote spurious trend estimates that the authors do  
nothing to highlight. One observation that may point to such biases is the increase in the percentage  
of significant mid-latitude trends in the composite records relative to the high latitude records, which  
is of course counter to the expected spatial dependence. These factors are not sufficiently discussed.  
Regarding concern 2, the authors present Figure 5 as a measure of the latitudinal differences in the  
significance testing of trends in the dendro and composite records. The percentage of each  
85 population with significant and insignificant trends is nevertheless hard to interpret. Some additional  
significance testing would go a long way toward helping to interpret this figure and the results. The  
first question that should be addressed is: given the expected magnitude of trends estimated a priori  
from the orbitally-forced changes in insolation (signal), time series with the level of variance  
representative of the proxy series (noise), and the size of the sample populations, how many times  
90 would one achieve significant positive/negative trends and insignificant positive/negative trends for  
different realizations of noise? For instance, it may be the case that for 16 time series and the level of  
variance that is estimated in each, the trend percentages in the dendro high-latitude bin is actually  
what you would expect for a modestly detectable trend. Moreover, how should we interpret the  
comparison between the percentages associated with the dendro and composite series in a band like  
95 the high latitudes in Figure 5? It may be that the PDF of the percentage distributions spans the

00 differences shown in Figure 5 and the results are fully consistent with each other. Put differently, for multiple noise realizations, how robust is the separation between the trend percentages in the dendro and composite records? It is impossible to answer these questions from what the authors have done and they should better characterize the statistical likelihood that the differences they describe are more than just noise. All of the above is fundamental for two reasons. The first is that the difference in the number of statistically significant trends is the primary metric by which the authors argue there are differences in the representations of trends between the two populations. If the physical expression of those trends is latitudinally dependent and their spatial sampling is heterogenous and biased in the two populations, it must be controlled for. Secondly, the robustness of the differences must also be statistically constrained so that real differences (statistically speaking) can be separated from differences that can arise simply by chance.

10 (3) We added a test and (supplementary) figure addressing the problem of latitudinal sample biases. We randomly (1000 times) drew 10 series from all tree ring series, and the composite (glacier, marine and lake records), at the latitudinal bands 0-90°N, 30-60°N and 60-90°N (below 30°N sample replication is too low), and calculated the percent of records showing insignificant/significant cooling and insignificant/significant warming trends.

#### Minor comments:

##### 15 Comment 4:

(1) Pg. 1, Ln. 13: It should be noted here that the 692 proxies are the temperature sensitive records in the database (the full database is closer to 3000).

20 (2) No, the database includes exactly 692 records. We refer to PAGES 2k Consortium: A global multiproxy database for temperature reconstructions of the Common Era, Nat. Sci. Dat., 4, 1-33, 2017.

(3) No changes.

##### Comment 5:

25 (1) Pg. 1, Ln. 24: There are a lot more reviews that speak to this issue than Frank et al. Consider adding Jones et al. (2009), North et al. (2006), Mann (2007), Smerdon and Pollack (2016), and Christiansen and Ljungqvist (2017).

(3) Further references added.

##### Comment 6:

30 (1) Pg. 2, Ln 28: The list of multiproxy reconstructions does not include the data assimilation work (e.g. Hakim et al. (2016) and Steiger et al. (2018)) nor does it include the PAGES products from 2013 and 2018. This should be corrected.

(3) Corrected.

35 **Comment 7:**

(1) Pg. 2, Ln 32: The list of review articles that discuss this should be expanded as above.

(3) Expanded.

40 **Comment 8:**

(1) Pg. 2, Ln 34: This is once again a limited list of papers that compare reconstructions and models. The authors should at least include the PAGES efforts from PAGES2k- PMIP Group (2015) and PAGES Hydro2K Consortium (2017), if not include some of the additional references that are discussed in those studies.

45 (3) 3 references added.

**Comment 9:**

(1) Pg. 4, Ln 6: Consider discriminating instead of critical

(3) Changed, accordingly.

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**Comment 10:**

(1) Pg. 5, Ln 46: It seems strange to use cubic smoothing splines for standardization in the context of this investigation, given that they will explicitly remove the long-term trends. The effect is clearly visible in Figure 6 where even the 20th century trends have been removed. Incidentally, I find the bracket and description in Figure 6b a bit clumsy and hard to follow. The bracket in particular looks like it was drawn in by hand!

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(3) Spline detrending was removed and replaced by Signal Free detrending in line with suggestions made by reviewer 1. Bracket replaced with an arrow.

60 **Comment 11:**

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- (1) Pg. 6, Ln. 84-86: Doesn't this contradict a central premise of the paper? This seems a lot more concerning than the attention it is given in the manuscript.
  - (2) No, this is "just" related to removing cambial/biological age-trends inherent to tree-ring width and density data.
  - (3) No changes.

**Comment 12:**

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- (1) Pg. 7, Ln 90: The subset is described as 70 but there are multiple places where this number appears to be different. Figure 5, for instance, discusses 89 dendro series. Are these typos or am I missing something?
  - (3) [Further explanation added.](#)

**Comment 13:**

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- (1) Pg. 7, Ln. 5: How does -0.32 compare to -0.03?!
  - (3) [Removed.](#)

**Comment 14:**

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- (1) Pg. 7, Ln. 9: Consider preserving instead of conserving
  - (3) [Changed.](#)

**Comment 15:**

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- (1) Pg. 8, Ln. 37: I find the discussion starting here and extending to the end of the paragraph very confusing. It seems to be saying that the authors have demonstrated differences between proxies, but that there are no differences between proxies. With regard to the last sentence, I do not think the authors have demonstrated the lack of spatial sampling bias, based on the principle arguments I have provided above.
  - (2) [See above, response to comment #3.](#)
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**Point- by – Point response Freddy Ljungqvist (not for Clim. Past) – No official Review / Private suggestions.**

95 **Comment 1:**

(1) Page 2, Line 24: Would also, besides Frank et al., cite: <https://doi.org/10.1002/wcc.418>  
Inserted.

**Comment 2:**

00 (1) Page 2, Lines 28–29: Would also add: <https://doi.org/10.1126/science.1177303> And replace Christiansen and Ljungqvist (2011) with: <https://doi.org/10.5194/cp-8-765-2012>  
Done.

**Comment 3:**

05 (1) Page 2, Line 34: Add <https://doi.org/10.1175/JCLI-D-18-0525.1>  
Done.

**Comment 4:**

10 (1) Page 3, Lines 67–69: I'm not sure if it a good idea to just cite a list with references to different reconstructions with different amplitude of low-frequency temperature variability. In my opinion, it would be better to cite articles that discusses the mechanisms/reasons for these differences.  
Not Done.

15 **Comment 5:**

20 (1) Page 3, about lines 76–79 and page 5, lines 32–35 (and other places): I do not agree that summer-temperature sensitive proxies necessary would capture orbital cooling trends the best. The forcing change is during summer but the climatic effect may be as strong in other seasons due to feedback mechanisms. See, for example, <https://doi.org/10.5194/cp-6-609-2010> Actually, I would remove the discussions about seasonality altogether from the article as it would make a very complicated discussion about feedback mechanisms necessary to include it. Honestly, I think the expectation that orbital-induced cooling would be strongest in summer (only because the change in forcing occurred during these season) may be flawed – at least it is controversial. It exists conflicting evidence for which season that the orbitally

25 forced mid-Holocene Thermal Maximum made the warmest. Some lines of evidence suggests  
it was winter or annual mean temperature and not in summer for the high-latitudes in the NH  
(although much pollen data and model simulations mostly indicate it was summer). This said,  
orbital cooling still ought to be found in summer too of course.

30 **Comment 6:**

(1) Page 4, Line 97: I would insert “e.g.” before Seim et al. (2012) as it is an example only.  
[Done.](#)

**Comment 7:**

35 (1) Page 4, Line 102: I rather think a mixed temperature and hydroclimate sensitivity is a problem  
here. To this problem you may cite:

Babst F et al 2013 Site- and species-specific responses of forest growth to climate across the  
European continent. *Global Ecol. Biogeogr.* 22 706–17

40 Babst F et al 2019 Twentieth century redistribution in climatic drivers of global tree growth. *Sci. Adv.* 5  
eaat4313

Galván JD, Camarero JJ, Ginzler C, Büntgen U 2014 Spatial diversity of recent trends in  
Mediterranean tree growth. *Environ. Res. Lett.* 9 084001

Klesse S et al 2018 A combined tree ring and vegetation model assessment of European forest  
growth sensitivity to interannual climate variability. *Global Biogeochem. Cy.* 32 1226–40

45 [Done.](#)

**Comment 8:**

(1) Page 7, line 14: At some place – but not here – I would recommend to make an even larger  
issue of the low r-values for Asia. The correlations are barely significant on average!

50 [At some place – but not here... ?](#)

**Comment 9:**

(1) Page 8, line 18: I would expand this discussion of different sample strategies. Happy to talk to  
you about it.

55 [Not done.](#)

**Comment 10:**

(1) Page 8, line 33: Add citation: <https://doi.org/10.1038/s41586-019-1060-3>  
[Added.](#)

60 **Comment 11:**

(1) Page 8, section 4.1. This section needs revision. The data–model mismatch could be due to a lack of certain feedback mechanisms in the models. Actually, the same “mismatch” problem exists for many regions outside the North Atlantic region (see, for example, <https://doi.org/10.5194/cp-2018-145>). Moreover, borehole data supports an even  
65 larger annual mean temperature increase during the mid-Holocene globally (1–1.5°C relative to pre-industrial). The borehole estimates are totally independent from other proxies and their noise sources. See: <https://doi.org/10.1029/2008GL034187>  
[?](#)

**Comment 12:**

70 (1) Page 9, line 54: Guess it should be late twentieth century and early twenty-first century temperatures.  
[Added.](#)

**Comment 13:**

75 (1) Page 9, line 66: Mann et al. (1999) is NOT discussing this issue. Improper reference here  
[Removed.](#)

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# Differing pre-industrial cooling trends between tree-rings and lower-resolution temperature proxies

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**Abstract.** The 692 proxy records of the new PAGES2k [global](#) compilation [of temperature-sensitive proxies](#) offer an unprecedented opportunity to study regional to global trends associated with orbitally-driven changes in solar irradiance over the past two millennia. Here, we analyse the significance of long-term trends from 1-1800 CE in the PAGES2k compilation's tree-ring, ice core, marine and lake sediment records and find, unlike ice-cores, glacier dynamics, marine and lake sediments, no suggestion of a pre-industrial cooling trend in the tree-ring records. To understand why tree-ring proxies lack [any evidence of a](#) significant pre-industrial cooling, we divide [those](#) data by location (high NH latitudes vs. mid latitudes), seasonal response (annual vs. summer), detrending method, and temperature sensitivity (high vs. low). We conclude [that](#) the ability [of tree-ring proxies](#) to detect any pre-industrial, millennial-long cooling [is not affected by](#) latitude, seasonal sensitivity, or detrending method. Consequently, caution is advised when using multi-proxy approaches to reconstruct long-term temperature changes [over the entire Common Era](#).

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## 1 Introduction

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Apart from documentary archives (Pfister et al., 1999), our perception of climate variability prior to the systematic collection of instrumental measurements in the mid nineteenth century relies on climate-sensitive proxy data ([Christiansen and Ljungqvist et al., 2017](#); Frank et al., [2010](#); Jones et al., [2009](#); Smerdon and Pollack, [2016](#)). Paleotemperature information can

be extracted from natural archives such as ice cores (Steig et al., 2013), speleothems (Martín-Chivelet et al., 2011), tree-rings (Esper et al., 2014), lake and marine sediments (Nieto-Moreno et al., 2013), and glacier fluctuations (Solomina et al., 2016), among others (Jones et al., 2009; Wanner et al., 2008). Today there are a number of multiproxy (Christiansen and Ljungqvist, 2012; Hegerl et al., 2007; Jones et al., 1998; Ljungqvist et al., 2012; Mann et al., 2008; Mann et al., 2009; Shi et al., 2013), and solely tree-ring based reconstructions (Briffa, 2000; D'Arrigo et al., 2006; Esper et al., 2002; Schneider et al., 2015; Stoffel et al., 2015; Wilson et al., 2016) of Northern Hemisphere (NH) and global temperatures. These reconstructions offer defensible characterizations of pre-instrumental, naturally forced climate variability at annual resolution and millennial timescales (Christiansen and Ljungqvist, 2017; Wanner et al. 2008; Wanner et al., 2015), which is essential for placing Anthropogenic warming in a long-term context. Proxy data themselves provide valuable climate information needed to test and verify paleoclimate model simulations (Braconnot et al., 2012; Fernández-Donado et al., 2013; Hartl-Meier et al., 2017; Ljungqvist et al., 2019, PAGES Hydro 2k Consortium, 2017; PAGES 2k- PMIP3 group, 2015).

The PAGES2k database represents a unique community effort organized by PAGES (<http://pastglobalchanges.org>), to amass the world's largest collection of proxy records covering the Common Era (CE) (PAGES 2k Consortium, 2017). The PAGES2k database 2.0.0 contains 692 temperature-sensitive proxy records from trees (415), ice cores (49), lake (42) and marine sediments (58), corals (96), documentary evidence (15), sclerosponges (8), speleothems (4), boreholes (3), bivalves (1), and a hybrid tree/borehole (1), from 648 locations distributed across all continents and major oceans (Fig. 1 and Fig. S1).

Unlike previously published multiproxy compilations (Mann et al., 2008; PAGES2k Consortium, 2013), the PAGES2k database includes substantially more evidence from sources other than tree-rings, and many more records that cover the first millennium, thereby expanding the spatial and temporal coverage over oceanic and polar regions (PAGES2k Consortium, 2017). The number, spatial distribution, and diversity of the PAGES2k dataset provides an unprecedented opportunity to analyse regional to large-scale temperature patterns over the Common Era. The PAGES2k Consortium (2017) produced a collection of global mean composites from each of the major proxy types in its dataset (PAGES2k 2017). Here we present a similar visualization using only the PAGES2k NH records. The average NH composites of all proxies sensitive to summer temperature including marine sediments, lake sediments, and glacial ice cores (Fig. 2a) exhibit strong negative trends that are consistent with the gradual pre-1800 cooling reported previously by other major syntheses of Holocene proxies (cited previously). By contrast, the NH composite derived from just the tree-ring records (Fig. 2b) shows the rapid post-1800 increase was preceded by an essentially flat trend from 1-1800 CE. A pre-industrial cooling can be attributed to gradual changes in orbital forcing, shown to be an important driver of Holocene long-term climate oscillations (Milanković, 1941; Wanner et al., 2015). Changes in solar insolation (Huybers and Curry, 2006) are caused by variations in the Earth's tilt (obliquity), orbit (eccentricity) and rotation axis (precession). Over the Common Era, precession triggers a shift of the Perihelion (the closest point between sun and Earth) from December to January (Berger, 1978; Berger and Loutre, 1991). The collective effects of eccentricity, precession and obliquity reduces NH warm season (June-August) incoming solar radiation by  $\sim 9 \text{ W/m}^2$  at  $90^\circ\text{N}$ ,  $5.5 \text{ W/m}^2$  at  $60^\circ\text{N}$ , and  $3.4 \text{ W/m}^2$  at  $30^\circ\text{N}$ , and increases Southern Hemisphere warm season

(December-February) radiation by  $\sim 3.8$  W/m<sup>2</sup> at 90°S, 4.1 W/m<sup>2</sup> at 60°S, and 5 W/m<sup>2</sup> at 30°S (Laskar et al., 2004) (Fig. 3). These long-term changes in orbital forcing should, theoretically, affect regional temperatures differentially (Masson-Delmotte et al., 2013).

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The lack of a long-term negative trend in the average global tree-ring record stands in stark contrast to the cooling detected in the well-replicated maximum latewood density (MXD) record from northern Scandinavia (Esper et al., 2012). Esper et al. (2012) argues that, unlike long MXD records, tree-ring width (TRW) records are incapable of capturing orbital trends. If this is the case, then including TRW records in past global temperature assessments might result in an underestimate of pre-instrumental warmth, e.g. during Medieval and Roman Times (Esper et al., 2004; Frank et al., 2010; Wang et al., 2014). Combining proxies that systematically vary in their low-frequency trends seemingly contributes to the development of temperature reconstructions of differing temperature amplitudes over the pre-industrial era (Christiansen and Ljungqvist, 2012; Christiansen and Ljungqvist, 2011; D'Arrigo et al., 2006; [Hakim et al., 2016](#); Jones et al., 1998; Juckes et al., 2007; Ljungqvist et al., 2012; Mann et al., 1999; Mann et al., 2008; [PAGES 2k Consortium, 2013](#); Schneider et al., 2015; [Steiger et al., 2018](#); Wilson et al., 2016). Here, we analyse the PAGES 2k collection of temperature-sensitive proxy records to understand why the mean tree-ring record lacks a pre-industrial millennial-scale cooling trend that is otherwise preserved in ice core, lake and marine sediment data. We hypothesize that the absence of this long-term negative trend in tree-ring chronologies may be a consequence of the climate sensitivity of the trees used, their detrending, and spatial distribution of the datasets. To test these potential explanations we explore the effect of three significant attributes of just the tree-ring component that may have bearing on the long-term temperature trend reported in the PAGES 2k initiative.

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(1) Based on the spatial and seasonally varying effect of orbital forcing over the Common Era, we expect a millennial-scale cooling trend prior to the industrial period, particularly in summer-sensitive, high northern latitude proxies, compared to annually-sensitive proxies (Esper et al., 2012; Kaufman et al., 2009). Therefore, the absence of a distinct pre-industrial cooling in the PAGES 2k tree-ring network could be a by-product of the spatial distribution of tree-ring proxies in the network. If the network were not biased by northern, mid-latitude tree-ring sites it should capture the millennial-length cooling trend in summer, as we expect proxy records from high northern latitudes to contain a stronger summer cooling trend than their mid-latitude counterparts.

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(2) All tree-ring parameters, with the possible exception of  $\delta^{18}\text{O}$  (Esper et al., 2015; Helama et al., 2015; Young et al., 2011), include age-related, non-climatic signals that need to be removed prior to chronology development and reconstruction (Bräker, 1981; Cook, 1990; Douglass, 1919; Fritts, 1976). The selection of a suitable tree-ring detrending method is one of the fundamental challenges in the field of dendroclimatology (Briffa et al., 1992; Cook et al., 1995; Esper et al., 2004; Melvin et al., 2013). However, tree-ring detrending methods vary in their approach to model tree growth and if applied indiscriminately can remove long-term cooling trends related to orbital forcing, either intentionally or inadvertently,

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75 interpreted as biological noise (Cook et al., 1995; Esper et al., 2004). Given that the PAGES 2k database contains no  
information regarding the detrending method used to produce the tree-ring chronologies in its collection, we assume all were  
produced using different detrending methods, and that those methods are applied to differently structured tree-ring datasets  
(i.e. the temporal distributions of short and long tree-ring measurements series, indicative of young and old trees, over the  
80 past 2k years are not the same). If this is the case, such disparities will affect the database chronologies' low frequency  
variance, causing the tree-ring mean to lack millennial scale trends (Briffa et al., 2013; Büntgen et al., 2017; Linderholm et  
al., 2014).

(3) The inclusion of chronologies having a mixed climate sensitivity ([e.g. Seim et al., 2012](#)) and their potential introduction  
of non-temperature related noise (Baltensweiler et al., 2008) might weaken a reconstruction. The establishment of large-  
scale (continental or hemispheric) temperature reconstructions relies on the assumption that all proxy records used to  
85 produce the reconstruction have a substantial temperature signal, and that the signal is temporally stable over the entire  
record length (Esper et al., 2016). We assume the inclusion of tree-ring chronologies with a mixed sensitivity, including  
other climate parameters besides temperature ([Babst et al., 2019](#); [Babst et al., 2013](#); [Galván et al., 2014](#); [Klesse et al., 2018](#)),  
weakens a reconstruction, and that reconstructions composed of weakly calibrating chronologies contain less or no orbitally  
forced trends.

90 [We begin by describing](#) the varying ability of the proxies used in the PAGES2k network to preserve orbitally forced,  
millennial-scale, temperature trends. Then we evaluate and discuss how a more [discriminating](#) proxy selection could  
improve our understanding of past climate variability over the Common Era.

## 2 Data and methods

### 95 2.1 Data preparation

The PAGES 2k database (Fig. 1) was accessed via the website of the NCEI-Paleo/World Data Service for Paleoclimatology  
(<https://www.ncdc.noaa.gov/paleo/study/21171>). The Southern Hemisphere was excluded from [our](#) analysis due to having  
too few samples (111 records in total, with [only 13](#) tree-ring records) and the suggestion of ambiguous links between the  
hemispheres on orbital timescales (Kawamura et al., 2007; Laepple et al., 2011; Petit et al., 1999). [All NH](#) records were  
00 normalized over their individual record lengths by subtracting the time series mean ( $\mu$ ) from each single proxy value, then  
dividing the difference by the series' standard deviation ( $\sigma$ ). Normalization is a necessary step to eliminate differences in  
measuring scale, as the database includes a variety of measured parameters, including  $\delta^{18}\text{O}$  (Horiuchi et al., 2008), TRW  
(Luckman and Wilson, 2005), MXD (Klippel et al., 2018), blue intensity (Björklund et al., 2014), varve thickness (Moore et  
al., 2001) or Sr/Ca (Rosenheim, 2005). We [appreciate](#) that the choice of normalization period, from which we calculate  $\mu$   
05 and  $\sigma$ , has an influence on the expression of low-frequency trends as seen in the tree-ring data (Fig. 4). Using  $\mu$  and  $\sigma$  of all

the tree-ring chronologies' common period (1758-1972) leads to a slightly different millennial-scale trend compared to the PAGES 2k procedure of using the individual records' total lengths. Large trend discrepancies arise from using  $\mu$  and  $\sigma$  of even shorter periods (e.g., 1800-50, 1850-1900 and 1900-50; Fig. 4). A  $\mu_{\text{sub period}}$  and  $\sigma_{\text{sub period}}$  smaller, or a  $\mu_{\text{sub period}}$  and  $\sigma_{\text{sub period}}$  larger, than the entire time series  $\mu$  and  $\sigma$  produces records with increased or decreased temperature levels and trends, respectively (Fig. S2). By normalizing all the proxies in the same manner, we minimize the influence of the normalization method on the preservation of low-frequency trends in tree-rings.

All proxy records having a negative correlation with instrumental temperature were inverted (multiplied by -1) to ensure that high proxy values represent warm temperatures and low proxy value cold temperatures. This procedure was applied to one marine sediment and four lake sediment records. To account for the varying temporal resolution among the proxies, from sub-annual to multi-decadal, all normalized records are averaged and set to the same resolution consisting of 50-year bins (e.g. 1901-1950; 1951-2000; Fig. 4).

## 2.2 Hypothesis testing

To test the influence of (i) orbital forcing, (ii) tree-ring detrending and (iii) temperature sensitivity, we extracted a subset of proxy records from the PAGES 2k database, restricted to only those records longer than 800 years. This 800-year threshold is based on the reasonable assumption that longer records are more likely to express stronger millennial-scale trends. The subset includes 89 tree-ring, 16 glacier ice, 44 marine and 29 lake sediment records.

(1) Based on the Milankovitch cycles (Milanković, 1941) we expect latitudinally and seasonally varying temperature trends, with the strongest cooling to be found in summer-sensitive proxies from high-latitude, and the least cooling to be found in the annual temperature sensitive proxies from lower latitudes (Berger and Loutre, 1991; Laskar et al., 2004). To assess the long-term trends preserved in an individual tree-ring record from the PAGES2k compilation (which does not report the specific detrending method used for each entry), the statistical significance of the slope of least-squares linear regressions through each proxy record (at 50-year resolution) was evaluated, and the fraction of records that exhibit a significant or insignificant cooling trend over the pre-industrial period (1-1800 CE), and a warming trend over the industrial (post 1800 CE) period were recorded. For those tree-ring records that do not span the entire pre-industrial period, this slope calculation was performed over their entire length. Those records with significant warming and cooling trends were further analysed with respect to proxy type (archive), latitude, and temperature sensitive seasonality. To account for the bias due to an inhomogeneous distribution of sites along a latitudinal gradient, we randomly selected 1000 times ten records from latitudinal bands 0-90°N, 30-60°N and 60-90°N to determine the number of records showing an (in-) significant cooling/cooling over the pre-industrial period. In addition, we produced 50-year binned records (tree composite versus glacier ice,

marine sediment and lake sediment composite) for each latitudinal band, to illustrate chronology trend changes along the gradient. Additionally, we explored the influence of the absolute record length on the strength of the pre-industrial cooling.

40 (2) As noted previously, the PAGES2k compilation does not include mention of the detrending method used to produce each tree-ring chronology. To address this omission, we attempted re-standardized all 89 tree-ring records, to test how the choice of detrending method used affects the resulting chronologies' millennial scale trend. Of the 89 chronologies selected, the raw data 22 were unobtainable from either the International Tree-ring Databank (ITRDB), or after reaching out to the their authors. Consequently, this aspect of our analysis will focuses on a less than desirable subset of 67 chronologies. The tree-  
45 ring detrending methods applied are the calculation of residuals from individually fit (i) negative exponential functions (NEG), and (ii) from regional growth curves (RCS; Briffa et al., 1992; Esper et al., 2003). The individual series detrending method (i) emphasizes annual to centennial trends in the resulting index chronology (Cook and Peters, 1981) by removing long-term trends that exceed the lengths of sampled trees. By contrast, RCS (ii) attempts to preserve low-frequency climate variability through its address of the so called "segment length curse" (Briffa and Melvin, 2011; Cook et al., 1995).  
50 However, traditional RCS is best applied to large datasets with a homogenous age-structure through time to optimise the ideal representation of the population growth curve used to detrend the data (Esper et al., 2003), and most tree-ring measurements in the 2k database do not satisfy this criterion. To address this trend distortion due to increasing tree-age over time, we applied a third detrending method (iii) Signal-Free Regional Curve Standardization was performed (RCS-SIG; Melvin et al., 2014). Prior to detrending, a data adaptive power transformation was applied to all measurements to mitigate  
55 the heteroscedastic nature of the tree-ring series (Cook and Peters, 1997), and chronologies calculated using the bi-weight robust means of tree-ring indices in each calendar year. In addition, the average correlation coefficient among the individual series ( $\bar{R}$ ; Wigley et al., 1984) was used to stabilize the variance of the chronologies (Frank et al., 2007). The resulting chronologies from each of the three methodologies i, ii, and iii were then z-transformed and averaged over 50-year bins to produce three unique composite chronologies. The 50-year binned composites were compared with the PAGES 2k subset  
60 composite that includes the same 67 records to investigate the influence of tree-ring standardization on millennial scale temperature trends.

(3) The nature of the climate signal encoded in each tree-ring record was assessed by Pearson correlation coefficients between all 402 NH z-transformed tree-ring chronologies, the subset of 89 NH tree-ring chronologies, and both the 1° and 5°  
65 gridded CRU TS 4.01 (Harris et al., 2014) monthly June-September temperatures from 1950-1980. The relatively short interval of 31 years was selected for computing correlations in response to the sparse station data availability, especially in Asia, and the decline in the quality of interpolated observational temperature data prior to 1950 (Cook et al., 2012, Krusic et al., 2015). For each re-standardized and z-transformed chronology, the highest monthly maximum correlation coefficient was extracted and plotted with respect to the trees' location as provided in the metadata table (PAGES 2k Consortium,  
70 2017). The use of extended calibration periods (prior to 1950 and post 1980), and annual temperatures, yielded no

75 meaningful differences in the calibration results. The stability of the growth-climate relationship was assessed by first smoothing the tree-ring and corresponding CRU temperatures using 10-year splines then using the splines to high-pass filter the data and accentuate inter-annual variances. The tree-ring records were ranked according to the strength of their maximum monthly temperature response between June and September, and averaged into 50-year binned composites to evaluate the importance of changing signal strength of any preserved millennial-scale trend.

### 3 Results

#### 3.1 Latitude and season

80 In total, 66.3% of the tree-ring, 93.8% of the glacier ice, 75.0% of the marine and 79.3% of the lake sediment records, longer than 800 years, reveal a millennial-scale cooling over the period 1-1800 CE (Fig. 5a). There exists no relationship between the strength of this trend and the absolute length of the records (Fig. S3). Substantial proxy differences appear when comparing the fraction of records with a significant overall cooling trend ( $p < 0.05$ ): 68.8% of the glacier ice, 54.5% of the marine and 37.9% of the lake sediment records, but only 11.2% of the tree-ring records. Sorting the data by latitude reveals that the fraction of significantly cooling tree-ring records decreases from 25.0% at 60-90°N to 8.7% at 30-60°N, which, though the percentages are fairly small, supports the theory that the signature of orbital forcing in tree-rings has a meridionally declining spatial signature. In contrast, the cooling trends in glacier ice, marine and lake sediment records reach their maximum in the mid-latitudes, from 30-60°N, which contradicts this explanation. This finding remains stable even after repeating our analysis by 1000 times, each time randomly drawing 10 unique combinations of tree-rings records or composites of glacier ice, marine and lake sediments. Pre-industrial cooling remains significantly stronger in glacier ice, marine and lake sediment records compared to tree-ring records at different latitudinal bands. This result indicates clearly that differing pre-industrial cooling trends are not by-product of the spatially varying distribution along a latitudinal gradient (Fig. S4). Organizing the chronologies with respect to latitude confirms that glacier ice, marine and lake sediment records from the mid-latitudes (30-60°N) show an enhanced cooling compared to their high-latitude counterparts (60-90°N), whereas the NH tree-ring composites lack any significant cooling (Fig. S5.). The overall number of summer temperature sensitive proxy records showing long-term cooling is similar to the number of annual temperature sensitive proxies showing long-term cooling, suggesting that the orbitally forced reduction in summer insolation over the past 2k years has no substantial effect on the expression of long-term trends. Over the industrial period, 1800-2000 CE, glacier ice, marine and lake sediments, and tree-ring records particularly, consistently show a temperature increase (Fig. 5b).

#### 3.2 Tree-ring detrending

00 We applied three different detrending methods with varying ability to preserve low-frequency information on a subset of 67 of the 415 datasets in the PAGES 2k database. The single best replicated collection is the Torneträsk (Sweden) TRW dataset

containing 650 measurement series. The least replicated is a dataset from southern China containing just 10 measurement series. This huge range of underlying data points to potential weaknesses in our application of RCS, which ideally requires high sample replication (Briffa et al., 1992, Esper et al., 2003). Comparisons between our NEG, RCS, RCS-SIG composite and the PAGES 2k subset composites, reveals how there is substantially more low-frequency variability present in the RCS and RCS-SIG chronologies (Fig. 6). Extended cool periods are from 500-750 CE, 1450-1500 CE and 1600-1800 CE, and prolonged warm periods between 850-1200 CE and 1800-2000 CE. Cooling is more pronounced in the RCS chronology compared to the RCS-SIG chronology, whereas the latter has an increased industrial-era warming. In the NEG and PAGES 2k subset composite, pre-industrial temperature variations are restricted to multi-decadal scales, indicating cool conditions from 250-300 CE and 1450-1500 CE, warm conditions from 550-600 CE, and a more persistent warming from 1850 CE to present. Comparison of the RCS and RCS-SIG detrended composites against the PAGES 2k tree-ring composite reveals substantial differences in long-term trends in the first millennium. This demonstrable difference is a consequence of the pronounced cooling from 500-750 CE, a feature lacking in the both the PAGES 2k subset (Fig. 6) as well as entire PAGES 2k tree-ring composite (Fig. 2), but conserved in the RCS and RCS-SIG mean chronologies. Good agreement exists in the second millennium, as the magnitude, timing and strength of warm and cool intervals largely overlap. The best fit over the entire Common Era exists among the NEG and PAGES 2k subset composites, suggesting the PAGES 2k database includes a sizable amount of NEG detrended records. However, even with the application of RCS, arguably the best current method for preserving low-frequency trends in tree-rings when suitably applied, the pre-industrial cooling trend in the PAGES 2k tree-ring dataset differs significantly from those found in glacier ice, marine and lake sediment records (Fig. 2 and Fig. 6).

### 3.3 Climate signal strength

Pearson correlation analyses between the tree-ring proxy records and their respective local temperature grids reveals considerable inter-continental differences in the proxy's response to maximum monthly June-September temperature (Fig. 7a). The median correlation coefficients differ substantially by region, reaching  $r = 0.6$  in the Arctic (contributed by the PAGES2k Arctic regional),  $r = 0.21$  in Asia,  $r = 0.54$  in Europe and  $r = 0.38$  in North America. In the Arctic 87.5%, Asia 21.1%, Europe 75.0% and North America 61.33% of the maximum monthly June-September correlation coefficients are significant ( $p < 0.05$ ), indicating a more stable growth-climate relationships in the Arctic and Europe, compared to Asia and North America. However, these differences might be an artefact of different sampling strategies. In the first case (Arctic and Europe), only 16 and 8 highly temperature sensitive records are considered, but Asia and North America have 228 and 150 records respectively. The differences among the continents, as demonstrated by the distributions of their June-September correlation coefficients, remains fairly stable in the different frequency domains, as well as for records longer than 800 years (Fig. 7b). To account for seasonal responses beyond June-September, and potential influences of the calibration period, the analysis was repeated for all months, varying warm season means, and extended the calibration periods (1950 to the end dates of the individual chronologies). Consequently, no substantial changes were recorded (not shown). Despite significant



differences in high-to-low-frequency temperature signals, we find that none of the composites, integrating the good, medium and poorly calibrating records, contain a significant millennial-scale cooling (Fig. 7c-d). This result suggests climate signal strength is not related to the low-frequency trends present in tree-ring chronologies.

## 4 Discussion

### 4.1 Orbital signatures in regional and large-scale records

The signature of orbital forcing has been described in regional studies from the Arctic and Antarctica (Esper et al., 2012; Kaufman et al., 2009; Kawamura et al., 2007), as well as in one Holocene climate reconstruction based on a multiproxy collection from the northern high- and mid-latitudes; the latter attributing a distinct value to the orbital cooling effect of 0.5°C since the Holocene Thermal Maximum (Marcott et al., 2013; Routson et al., 2019). However, in the case of Marcott et al. (2013), it has been shown that NH cooling is only apparent in high-latitude North Atlantic proxies, and that the trend would not exist without them (Marsicek et al., 2018). Previous studies have also reported that it is difficult to reconcile the negative orbital forcing trends preserved in proxy data with simulated temperatures which show a strong warming of about 0.5°C over the Holocene (Liu et al., 2014; Laepple et al., 2011). Our results demonstrate that millennial-scale trends in NH proxy records are inconsistent between proxies. From a theoretical perspective, independent of the proxy type, we would expect a stronger cooling trend in summer temperature proxies and an increase in the strength of the trend from the mid to the high-latitudes (e.g., Esper et al. 2012; Kaufman et al. 2009). The absence of a clear meridional and seasonal pattern demonstrates the importance of internal climate variability (Deser et al., 2010; Schneider and Kinter, 1994) and other external forcing factors (Sigl et al., 2015; Vieira et al., 2011) on proxy records. We conclude that although multiple tree-ring datasets are systematically limited in their low-frequency amplitude, they deviate from forcing expectations in the same way as all other proxies. We conclude that the reduced low-frequency variability in tree-ring data cannot be explained by an overrepresentation of the mid-latitudes in the global mean composite.

Despite the insignificant pre-industrial temperature changes in 86.5% of the tree-ring records, compared to other proxies, the post 1800 CE warming trend in tree-rings is significant (25.8% versus 11.9%). Consequently, large scale multiproxy climate reconstructions that include long tree-ring records (> 800 years), or solely tree-ring based reconstructions developed from the PAGES 2k database, will likely show a stronger post-1800 warming than multiproxy reconstructions that deliberately exclude (long) tree-ring records (Fig. 2 and Fig. 6). The selection of the proxy type has major implications on the reconstructed warmest interval over the Common Era. Using marine data, the warmest period is 151-200 CE and the pre-industrial Era is dominated by a strong cooling trend, suggesting the magnitude of the current warming is not outstanding. By contrast, in lake sediments, ice cores, and tree-ring data, the most recent period is exceptionally warm (Fig. 2). This finding highlights the importance of tree-ring data in any effort to determine whether, over the past two millennia, the

twentieth-century and early twenty-first century temperatures are unprecedented in both their magnitude and rate of warming (Büntgen et al., 2011; Foley et al., 2013).

## 65 4.2 The impact of detrending on temperature trends

The degree of similarity between the NEG tree-ring chronology produced here and the corresponding PAGES 2k version suggests that the current PAGES2k tree-ring collection is not the most ideal for studying millennial scale trends. This is in large part due to the limitations of individual series detrending (Cook et al., 1995). Even with the application of RCS and RCS-SIG (Briffa et al., 1992; Esper et al., 2003, Melvin et al., 2014), the detection of a millennial-scale cooling trend is still  
70 elusive. These findings clearly demonstrate that the limited low-frequency variance in tree-ring chronologies is not solely an artefact of inappropriate detrending, previously identified as main explanation for the observed lack of long-term oscillations in large scale temperature reconstructions (Esper et al., 2002). Our reassessment of tree-ring chronologies also highlights the importance of the detrending methodology in reconstructing centennial scale temperature variability, as evidenced by the performance of the RCS and RCS-SIG chronologies. In both we can clearly identify the Late Antique Little Ice Age (LALIA) (Büntgen et al., 2016), a cool period from 300-750 CE that is absent in the PAGES 2k version, albeit with slightly greater uncertainty about the mean. The Büntgen et al. (2016) analysis and the dataset used in this study only share four tree-ring records in common, thus our analysis provides independent confirmation of the existence of LALIA and cooler conditions during the Migration period (Büntgen et al., 2011). In contrast, during LALIA the PAGES 2k tree-ring time series suggest a period of alternating warm and cool decades, but no persistent cooling on large spatial scales.

## 80 4.3 Temperature sensitivity and the link to long-term trends

Temperature sensitivity was a key criterion for the inclusion into the PAGES 2k database (PAGES 2k Consortium, 2017) and was assessed by the PAGES community through comparison with gridded HadCRUT 4.2 temperatures (Morice et al., 2012). Our analysis has shown the PAGES 2k database includes many tree-ring records that have a weak relationship with  
85 local temperature at high-to-low frequencies. The monthly maximum correlation coefficients between 1x1° CRU TS 4.01, June-September temperature data falls below 0.2 in 126 cases. The lowest correlation coefficient is -0.25 (unfiltered data). Such weak temperature sensitivities amongst the tree-rings is likely related to confounding non-climatic (Johnson et al., 2010; Konter et al., 2015) or hydroclimatic (Ljungqvist et al., 2016) growth controls, or to the circumstance that some records are by nature less sensitive to summer temperature than others (St. George, 2014). Further contributions to the extreme range of PAGES 2k tree-ring proxies?, climate signal strength is related to the fact that MXD chronologies more sensitive to temperature than TRW chronologies. (Büntgen et al., 2009). At the same time, some records might be more temperature sensitive than they appear due to their calibration against noisy or inappropriate temperature targets (Böhm et al., 2009; Cook et al., 2012). The re-calibration against instrumental temperatures showed that temperature sensitivity and

95 absolute climate signal strength are of limited importance for the preservation of millennium scale cooling trends in tree-ring records. Even the best calibrated records ( $r > 0.6$ ; 1950-1980) convey a different low-frequency signature compared to the glacier ice, marine, and lake sediment records. This observation is relevant to the current debate in paleoclimatology on optimal strategies for compiling proxy datasets to represent past natural temperature variability. Is it best to include (a) a large number of proxy records, including those possessing a relatively weak temperature signal, or (b) a small number of only the very best calibrated proxies (Christiansen and Ljungqvist, 2017)?

## 00 **5 Conclusion**

The community-sourced database of 692 different temperature-sensitive proxy records in the PAGES2k initiative provides unprecedented opportunities to study long-term temperature trends at regional to global scales. Combining glacier ice, marine and lake sediment records that span the Common Era reveals a persistent, millennial-scale cooling over the pre-industrial period that is missing in the tree-ring data. This analysis has shown that the observed discrepancies in long-term trends do not arise from the latitudinal and seasonally varying imprints of orbital forcing or the limited temperature sensitivity of tree-ring records. Despite application of the most suitable tree-ring detrending, one that can potentially support the preservation of low-frequency temperature trends at millennial time scales, substantial long-term trend differences between proxies remain. We conclude that some, possibly many of the tree-ring records in the PAGES 2k database are artificially limited in their low-frequency variance at centennial and longer time scales due to inappropriate detrending. This observation is supported by the fact that when a more low-frequency conserving tree-ring detrending method is applied to a large subset of suitable records, new corroborating evidence for the existence of the LALIA appears. Such nuances in the affect various tree-ring detrending methods have on low-frequency variance conservation needs to be considered when combining proxies in large scale temperature reconstructions to avoid the underrepresenting late Holocene cooling trends prior to post-industrial warming in hemispheric and global mean temperature reconstructions.

### 15 **Data availability.**

The PAGES 2k database was accessed via the website of NCEI-Paleo/World Data Service for Paleoclimatology (<https://www.ncdc.noaa.gov/paleo/study/21171>).

### 20 **Author contributions.**

JE and SSG were the leaders of the project. PK and UB contributed to the planning and structuring of the analysis and publication. LK performed the analysis and wrote the manuscript with contributions from all co-authors.

### **Competing interests.**

25 The authors declare that they have no conflict of interest.

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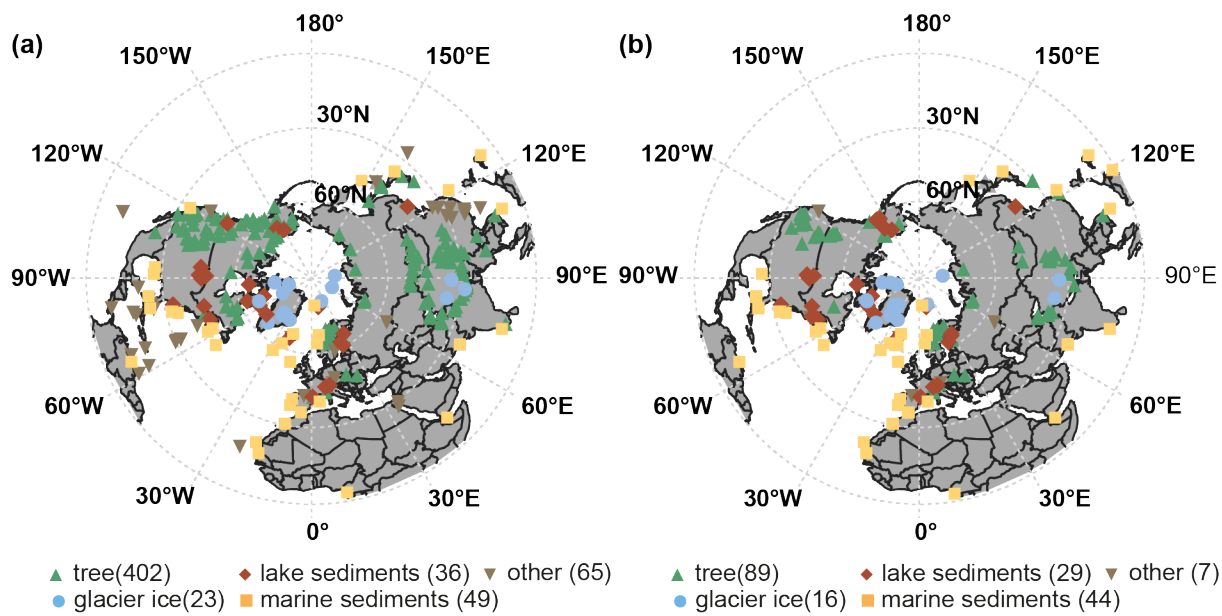
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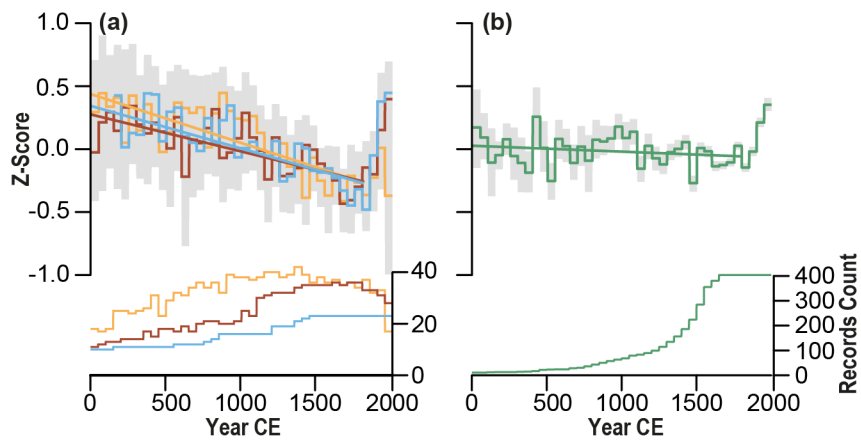
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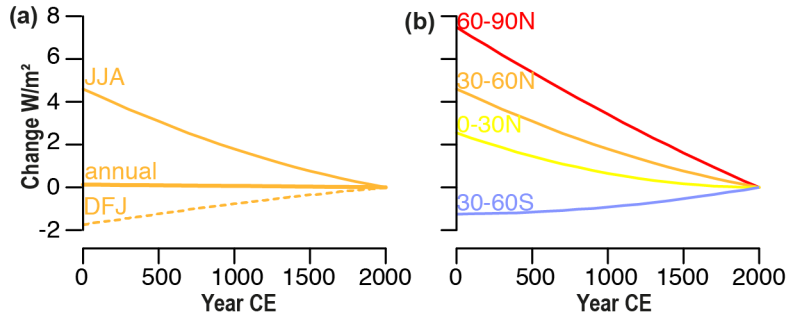
**Fig. 1.** (a) Map showing the spatial distribution of Northern Hemisphere proxy records from the PAGES 2k 2.0.0 database including primary tree-ring (green), glacier ice (blue), marine (orange) and lake (red) sediment records as well as a smaller number of records from bivalves, boreholes, corals, documents, hybrids, sclerosponges, and speleothems (brown). (b) same as (a) but showing only those records longer than 800 years.



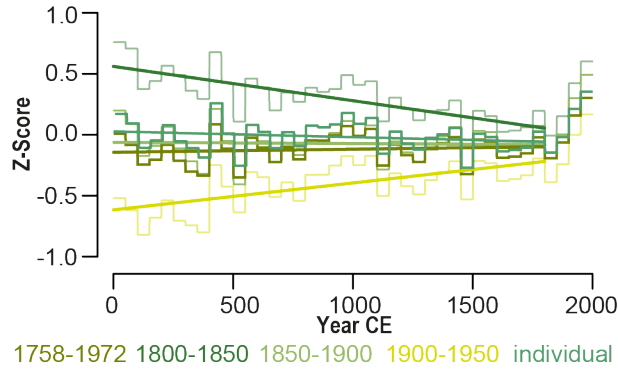
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**Fig. 2.** Compilation of NH temperature-sensitive proxy records from the PAGES2k initiative. (a) 50-year binned composites from 49 marine sediment (orange), 36 lake sediment (red) and 23 glacier ice (blue) records expressed in standard deviation units. Straight lines

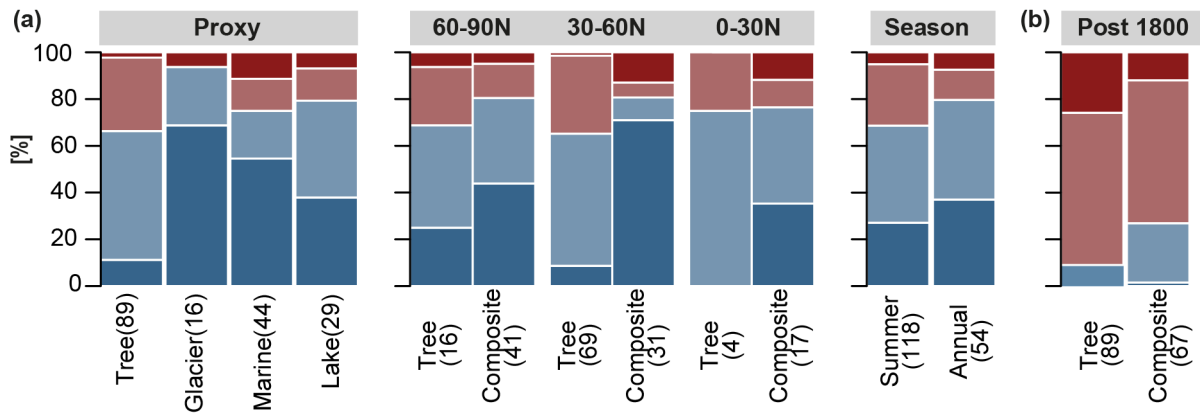
highlight the pre-industrial temperature trends (1-1800 CE) and lower panels show the corresponding temporal distribution of the records. Grey shadings indicate 95% bootstrap confidence intervals with 500 replicates. **(b)** same as in **(a)** for [402](#) tree-ring records.



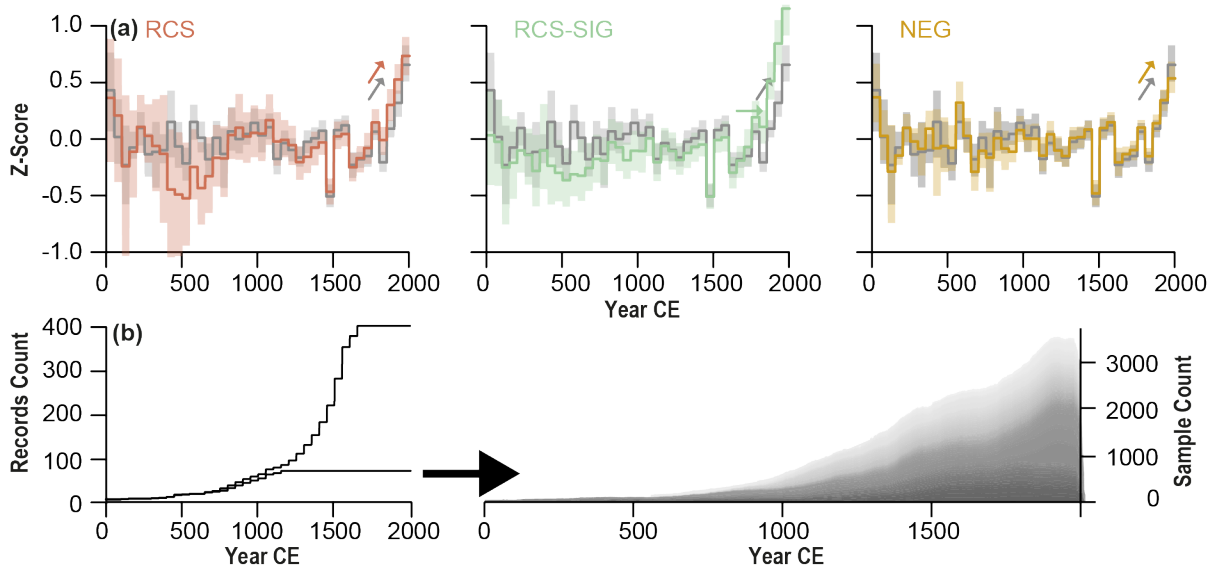
**Fig. 3.** **(a)** June-August, December-February, and annual insolation changes at 30-60°N relative to 2000 CE and **(b)** June-August insolation changes at different latitudinal bands (Laskar et al., 2004).



**Fig. 4.** Effect of tree-ring normalization on low-frequency temperature trends. **NH** composite tree-ring records from [402](#) records normalized using the means and standard deviations over different time spans.



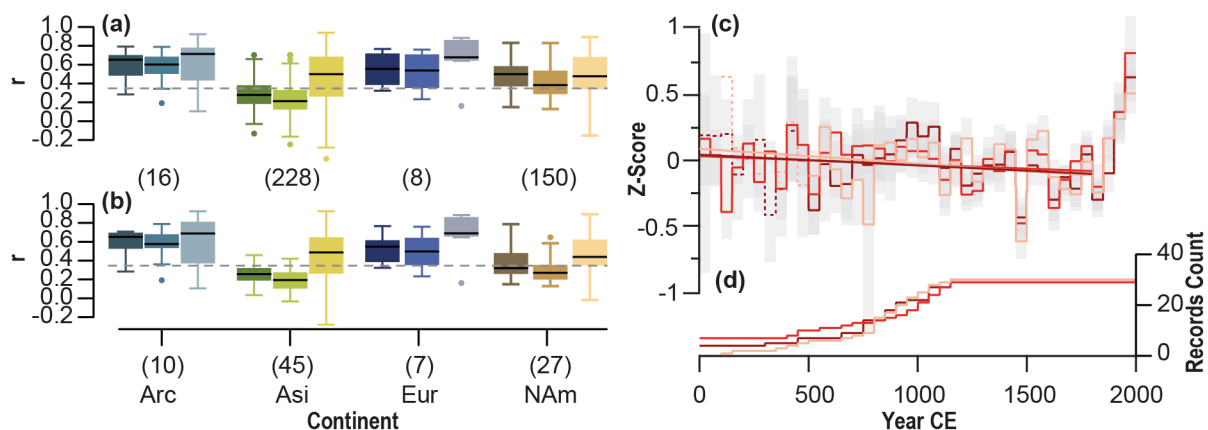
**Fig. 5.** Effects of orbital forcing on low-frequency trends. Summary of NH long-term trends from tree-ring, glacier ice, marine and lake sediment records longer than 800 years. The fraction of 50-year binned records that exhibit a significant negative (dark blue) and non-significant cooling (blueish) trend or significant (red) and non-significant (reddish) warming trend at  $p < 0.05$  over **(a)** the pre-industrial (1-1800 CE) and **(b)** industrial (post 1800 CE) period derived from the statistical significance of the slope of least-squares linear regressions through each individual 50-year binned proxy record. Pre-industrial summaries are split by proxy, latitude, and seasonality. The category composite includes glacier, marine and lake sediments, and brackets indicate the number of records per category.



**Fig. 6.** Effects of tree-ring detrending on low frequency trends. **(a)** 50-year binned composites from 67 RCS (red), RCS-SIG (green) and NEG (gold) standardized datasets. The PAGES 2k composite (dark grey) includes the corresponding chronology versions that are provided in the 2.0.0 database. Shadings indicate 95% bootstrap confidence intervals with 500 replicates, and the arrows indicate the direction of the

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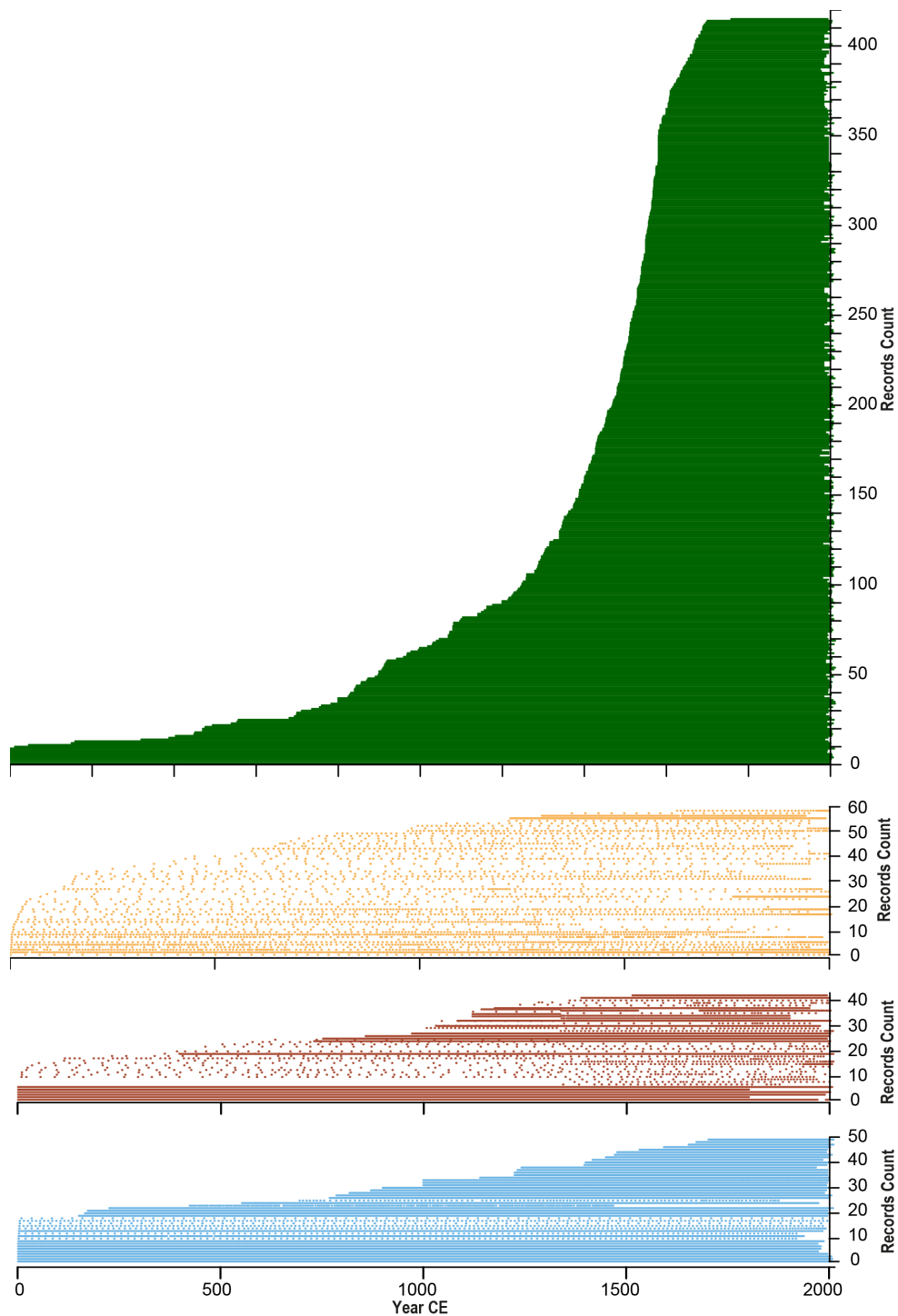
post-1800 trend. **(b)** Temporal distribution of [the NH tree-ring samples](#) (402) relative to the detrended subset (67) and distribution of individual samples from records included in the subset (grey shadings).



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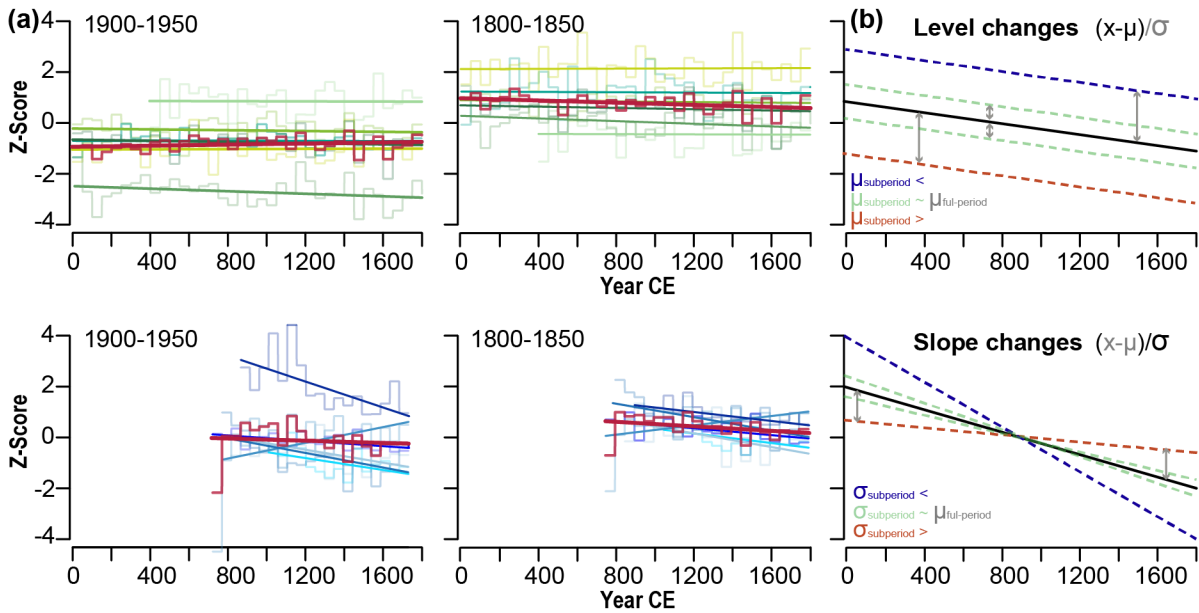
**Fig. 7.** Effects of tree-ring calibration on low-frequency temperature trends. **(a)** Maximum correlation coefficients between NH individual site-level tree-ring records [from the Arctic \(Arc\), Asia \(Asi\), Europe \(Eur\) and North America \(Nam\)](#) and  $1 \times 1^\circ$  CRU TS 4.01 June-September monthly temperature data over the period 1950-1980, divided by region, using 10-year high-pass filtered data (left box), original data (central box), 10-year smoothed data (right box). Dashed line indicates the  $p < 0.05$  threshold. **(b)** Same as (a) using only records longer than 800 years, and corresponding **(c)** 50-year binned composites divided by climate signal strength including records with the lowest ( $n=30$ ; rose), medium ( $n=31$ ; red) and highest ( $n=30$ ; dark red) climate sensitivity. Light grey shadings indicate 95% bootstrap confidence intervals with 500 replicates and **(d)** temporal distribution of the records.

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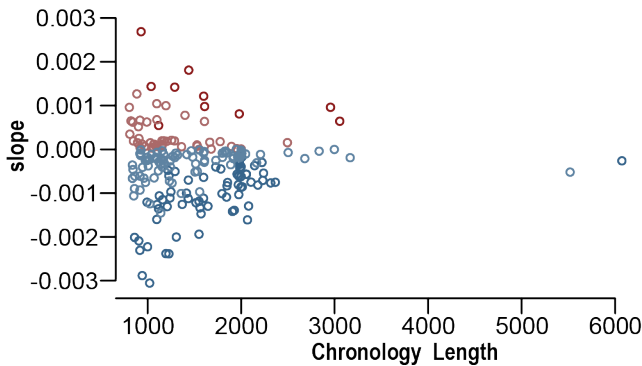


**Fig. S1.** Temporal distribution and resolution of the tree-ring (green), lake sediment (red), marine sediment (orange) and glacier ice (blue) proxy records from the PAGES 2k 2.0.0 database. (Dashed) lines indicate proxy resolution ranging between sub-annual and 145 years.



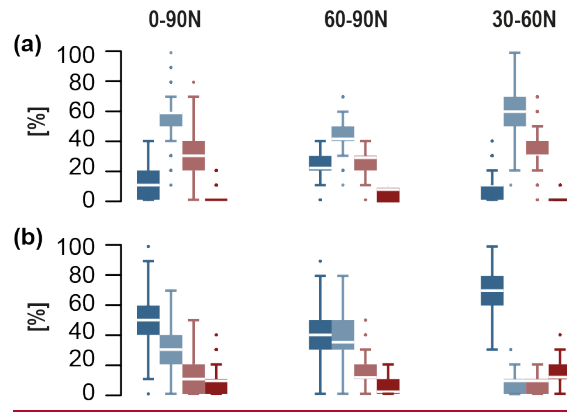


45 **Fig. S2.** (a) Differently normalized tree-ring records (green, blue), their chronology means (red) and corresponding pre-industrial temperature trends (1-1800 CE) and (b) explanation, why level and slope change dependent on the period chosen for tree-ring normalization.



50 **Fig. S3.** Relationship between the slope over the pre-industrial period (1-1800 CE) and the absolute length of the tree-ring, glacier ice, marine and lake sediment records from the Northern Hemisphere. Red refers to a significant warming, reddish to a non-significant warming, blueish to a non-significant cooling and blue to a significant cooling.

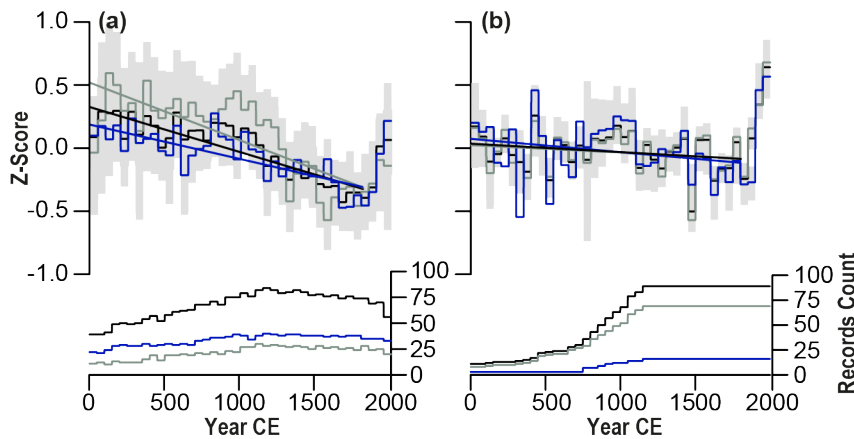
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**Fig. S.4.** Effects of orbital forcing on low-frequency temperature trends. Uncertainty estimates of a selection of plots displayed in Fig. 5. Randomly 1000 times, 10 (a) tree-ring and (b) marine, lake sediment and glacier ice records from the latitudinal bands 0-90N, 60-90N and 30-60N were selected. The fraction of 50-year binned records that exhibit a significant negative (dark blue) and non-significant cooling (blueish) trend or significant (red) and non-significant (reddish) warming trend at  $p < 0.05$  over the pre-industrial (1-1800 CE) and derived from the statistical significance of the slope of least-squares linear regressions through each individual 50-year binned proxy record was assessed.

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**Fig. S.5.** Compilation of NH and at least 800 year-long temperature-sensitive proxy records from the PAGES 2k initiative. 50-year binned composites from different latitudinal bands, 0-90°N (black), 30-60°N (green), and 60-90°N (blue) including (a) marine sediment, lake sediment and glacier ice records expressed in standard deviation units. Straight lines highlight the pre-industrial temperature trends (1-

1800 CE) and lower panels show the corresponding temporal distribution of the records. Grey shadings indicate 95% bootstrap confidence intervals with 500 replicates. **(b)** same as in for tree-rings.

**Table S.1.** Information about 67 tree-ring records used for the detrending test, listed in and retrieved from Pages 2k 2017 (Pages 2k Consortium, 2017) metadata base.

<u>Series</u>	<u>Lat</u>	<u>Lon</u>	<u>Country</u>	<u>Site Name</u>	<u>Proxv</u>	<u>First</u>	<u>Last</u>
<u>Arc 008</u>	<u>67.90</u>	<u>-140.70</u>	<u>Canada</u>	<u>Yukon</u>	<u>TRW</u>	<u>1177</u>	<u>2000</u>
<u>Arc 061</u>	<u>66.90</u>	<u>65.60</u>	<u>Russia</u>	<u>Polar Urals</u>	<u>MXD</u>	<u>891</u>	<u>2006</u>
<u>Arc 062</u>	<u>68.26</u>	<u>19.60</u>	<u>Sweden</u>	<u>Tornetrask</u>	<u>MXD</u>	<u>557</u>	<u>2008</u>
<u>Arc 065</u>	<u>66.30</u>	<u>18.20</u>	<u>Sweden</u>	<u>Arjeplog</u>	<u>ΔDensity</u>	<u>1200</u>	<u>2010</u>
<u>Arc 079</u>	<u>66.80</u>	<u>68.00</u>	<u>Russia</u>	<u>Yamalia</u>	<u>TRW</u>	<u>914</u>	<u>2003</u>
<u>Asi 048</u>	<u>36.30</u>	<u>98.08</u>	<u>China</u>	<u>CHIN006</u>	<u>TRW</u>	<u>159</u>	<u>1993</u>
<u>Asi 049</u>	<u>37.00</u>	<u>98.08</u>	<u>China</u>	<u>CHIN005</u>	<u>TRW</u>	<u>840</u>	<u>1993</u>
<u>Asi 051</u>	<u>35.07</u>	<u>100.35</u>	<u>China</u>	<u>MOAXJP</u>	<u>TRW</u>	<u>1082</u>	<u>2001</u>
<u>Asi 052</u>	<u>34.78</u>	<u>99.78</u>	<u>China</u>	<u>MOBXJP</u>	<u>TRW</u>	<u>470</u>	<u>2002</u>
<u>Asi 053</u>	<u>34.72</u>	<u>99.67</u>	<u>China</u>	<u>MOXJJP</u>	<u>TRW</u>	<u>1163</u>	<u>2001</u>
<u>Asi 077</u>	<u>38.70</u>	<u>99.68</u>	<u>China</u>	<u>HYGJUP</u>	<u>TRW</u>	<u>540</u>	<u>2006</u>
<u>Asi 084</u>	<u>37.47</u>	<u>97.23</u>	<u>China</u>	<u>CHIN050</u>	<u>TRW</u>	<u>843</u>	<u>2001</u>
<u>Asi 085</u>	<u>37.47</u>	<u>97.22</u>	<u>China</u>	<u>CHIN051</u>	<u>TRW</u>	<u>828</u>	<u>2001</u>
<u>Asi 086</u>	<u>37.45</u>	<u>97.53</u>	<u>China</u>	<u>CHIN052</u>	<u>TRW</u>	<u>404</u>	<u>2002</u>
<u>Asi 087</u>	<u>37.43</u>	<u>98.05</u>	<u>China</u>	<u>CHIN053</u>	<u>TRW</u>	<u>451</u>	<u>2002</u>
<u>Asi 088</u>	<u>37.45</u>	<u>97.78</u>	<u>China</u>	<u>CHIN054</u>	<u>TRW</u>	<u>711</u>	<u>2003</u>
<u>Asi 094</u>	<u>37.32</u>	<u>98.40</u>	<u>China</u>	<u>CHIN060</u>	<u>TRW</u>	<u>943</u>	<u>2003</u>
<u>Asi 095</u>	<u>37.03</u>	<u>98.63</u>	<u>China</u>	<u>CHIN061</u>	<u>TRW</u>	<u>857</u>	<u>2003</u>
<u>Asi 096</u>	<u>37.03</u>	<u>98.67</u>	<u>China</u>	<u>CHIN062</u>	<u>TRW</u>	<u>845</u>	<u>2001</u>
<u>Asi 097</u>	<u>36.75</u>	<u>98.22</u>	<u>China</u>	<u>CHIN063</u>	<u>TRW</u>	<u>681</u>	<u>2001</u>
<u>Asi 098</u>	<u>36.68</u>	<u>98.42</u>	<u>China</u>	<u>CHIN064</u>	<u>TRW</u>	<u>900</u>	<u>2001</u>
<u>Asi 119</u>	<u>30.33</u>	<u>130.45</u>	<u>Japan</u>	<u>JAPA018</u>	<u>TRW</u>	<u>1141</u>	<u>2005</u>
<u>Asi 125</u>	<u>40.17</u>	<u>72.58</u>	<u>Kyrgyzstan</u>	<u>KYRG007</u>	<u>TRW</u>	<u>1157</u>	<u>1995</u>
<u>Asi 127</u>	<u>39.92</u>	<u>71.47</u>	<u>Kyrgyzstan</u>	<u>KYRG009</u>	<u>TRW</u>	<u>1019</u>	<u>1995</u>
<u>Asi 129</u>	<u>39.83</u>	<u>71.50</u>	<u>Kyrgyzstan</u>	<u>KYRG011</u>	<u>TRW</u>	<u>694</u>	<u>1995</u>
<u>Asi 145</u>	<u>48.35</u>	<u>107.47</u>	<u>Mongolia</u>	<u>MONG021</u>	<u>TRW</u>	<u>996</u>	<u>2002</u>
<u>Asi 175</u>	<u>27.78</u>	<u>87.27</u>	<u>Nepal</u>	<u>NEPA030</u>	<u>TRW</u>	<u>856</u>	<u>1996</u>

<u>Asi 195</u>	<u>36.33</u>	<u>74.03</u>	<u>Pakistan</u>	<u>PAKI006</u>	<u>TRW</u>	<u>1032</u>	<u>1993</u>
<u>Asi 196</u>	<u>36.33</u>	<u>74.03</u>	<u>Pakistan</u>	<u>PAKI007</u>	<u>TRW</u>	<u>1141</u>	<u>1993</u>
<u>Asi 202</u>	<u>36.58</u>	<u>75.08</u>	<u>Pakistan</u>	<u>PAKI009</u>	<u>TRW</u>	<u>476</u>	<u>1990</u>
<u>Asi 203</u>	<u>36.58</u>	<u>75.08</u>	<u>Pakistan</u>	<u>PAKI010</u>	<u>TRW</u>	<u>968</u>	<u>1990</u>
<u>Asi 204</u>	<u>36.58</u>	<u>75.08</u>	<u>Pakistan</u>	<u>PAKI011</u>	<u>TRW</u>	<u>554</u>	<u>1990</u>
<u>Asi 205</u>	<u>36.58</u>	<u>75.08</u>	<u>Pakistan</u>	<u>PAKI012</u>	<u>TRW</u>	<u>1069</u>	<u>1990</u>
<u>Asi 211</u>	<u>35.17</u>	<u>75.50</u>	<u>Pakistan</u>	<u>PAKI015</u>	<u>TRW</u>	<u>736</u>	<u>1993</u>
<u>Asi 212</u>	<u>35.17</u>	<u>75.50</u>	<u>Pakistan</u>	<u>PAKI016</u>	<u>TRW</u>	<u>388</u>	<u>1993</u>
<u>Asi 221</u>	<u>31.12</u>	<u>97.03</u>	<u>China</u>	<u>CHIN046</u>	<u>TRW</u>	<u>449</u>	<u>2004</u>
<u>Asi 222</u>	<u>29.07</u>	<u>93.95</u>	<u>China</u>	<u>CHIN044</u>	<u>TRW</u>	<u>1047</u>	<u>1993</u>
<u>Asi 224</u>	<u>30.30</u>	<u>91.52</u>	<u>China</u>	<u>CHIN048</u>	<u>TRW</u>	<u>1080</u>	<u>1998</u>
<u>Asi 227</u>	<u>24.53</u>	<u>121.38</u>	<u>Taiwan</u>	<u>TW001</u>	<u>TRW</u>	<u>907</u>	<u>2007</u>
<u>Asi 229</u>	<u>12.22</u>	<u>108.73</u>	<u>Vietnam</u>	<u>VIET001</u>	<u>TRW</u>	<u>1030</u>	<u>2008</u>
<u>Eur 003</u>	<u>68.00</u>	<u>25.00</u>	<u>Finland</u>	<u>NSCAN</u>	<u>MXD</u>	<u>1</u>	<u>2006</u>
<u>Eur 004</u>	<u>49.00</u>	<u>20.00</u>	<u>Slovakia</u>	<u>Tatra</u>	<u>TRW</u>	<u>1040</u>	<u>2011</u>
<u>Eur 007</u>	<u>46.40</u>	<u>7.80</u>	<u>Switzerland</u>	<u>Lötschental</u>	<u>MXD</u>	<u>755</u>	<u>2004</u>
<u>Eur 008</u>	<u>44.00</u>	<u>7.50</u>	<u>France</u>	<u>French Alps</u>	<u>TRW</u>	<u>969</u>	<u>2007</u>
<u>NAm 001</u>	<u>35.30</u>	<u>-111.40</u>	<u>USA</u>	<u>San Francisco Peaks</u>	<u>TRW</u>	<u>1</u>	<u>2002</u>
<u>NAm 002</u>	<u>67.10</u>	<u>-159.60</u>	<u>USA</u>	<u>Kobuk/Noatak</u>	<u>TRW</u>	<u>978</u>	<u>1992</u>
<u>NAm 003</u>	<u>60.50</u>	<u>-148.30</u>	<u>USA</u>	<u>Prince William Sound</u>	<u>TRW</u>	<u>873</u>	<u>1991</u>
<u>NAm 007</u>	<u>36.50</u>	<u>-118.20</u>	<u>USA</u>	<u>Flower Lake</u>	<u>TRW</u>	<u>898</u>	<u>1987</u>
<u>NAm 008</u>	<u>36.30</u>	<u>-118.40</u>	<u>USA</u>	<u>Timber Gap Upper</u>	<u>TRW</u>	<u>699</u>	<u>1987</u>
<u>NAm 009</u>	<u>36.30</u>	<u>-118.20</u>	<u>USA</u>	<u>Cirque Peak</u>	<u>TRW</u>	<u>917</u>	<u>1987</u>
<u>NAm 011</u>	<u>37.20</u>	<u>-118.10</u>	<u>USA</u>	<u>Sheep Mountain</u>	<u>TRW</u>	<u>1</u>	<u>1990</u>
<u>NAm 013</u>	<u>37.80</u>	<u>-119.20</u>	<u>USA</u>	<u>Yosemite National P.</u>	<u>TRW</u>	<u>800</u>	<u>1996</u>
<u>NAm 018</u>	<u>36.30</u>	<u>-118.30</u>	<u>USA</u>	<u>Boreal Plateau</u>	<u>TRW</u>	<u>831</u>	<u>1992</u>
<u>NAm 019</u>	<u>36.40</u>	<u>-118.20</u>	<u>USA</u>	<u>Upper Wright Lakes</u>	<u>TRW</u>	<u>1</u>	<u>1992</u>
<u>NAm 026</u>	<u>51.40</u>	<u>-117.30</u>	<u>Canada</u>	<u>Athabasca</u>	<u>MXD</u>	<u>1072</u>	<u>1991</u>
<u>NAm 029</u>	<u>52.70</u>	<u>-118.30</u>	<u>Canada</u>	<u>Bennington</u>	<u>TRW</u>	<u>1104</u>	<u>1996</u>
<u>NAm 030</u>	<u>50.80</u>	<u>-115.30</u>	<u>Canada</u>	<u>French Glacier</u>	<u>TRW</u>	<u>1069</u>	<u>1993</u>
<u>NAm 032</u>	<u>60.20</u>	<u>-138.50</u>	<u>Canada</u>	<u>Landslide</u>	<u>TRW</u>	<u>913</u>	<u>2001</u>
<u>NAm 044</u>	<u>45.30</u>	<u>-111.30</u>	<u>USA</u>	<u>Yellow Mountain Ridge</u>	<u>TRW</u>	<u>470</u>	<u>1998</u>
<u>NAm 045</u>	<u>46.30</u>	<u>-113.20</u>	<u>USA</u>	<u>Flint Creek Range</u>	<u>TRW</u>	<u>999</u>	<u>1998</u>
<u>NAm 046</u>	<u>46.00</u>	<u>-113.40</u>	<u>USA</u>	<u>Pintlers</u>	<u>TRW</u>	<u>1200</u>	<u>2005</u>
<u>NAm 049</u>	<u>40.20</u>	<u>-115.50</u>	<u>USA</u>	<u>Pearl Peak</u>	<u>TRW</u>	<u>320</u>	<u>1985</u>
<u>NAm 050</u>	<u>38.50</u>	<u>-114.20</u>	<u>USA</u>	<u>Mount Washington</u>	<u>TRW</u>	<u>825</u>	<u>1983</u>

<u>NAm 071</u>	<u>37.00</u>	<u>-116.50</u>	<u>USA</u>	<u>Great Basin Composite</u>	<u>TRW</u>	<u>1</u>	<u>2009</u>
<u>NAm 104</u>	<u>68.70</u>	<u>-141.60</u>	<u>USA</u>	<u>Firth River 1236</u>	<u>MXD</u>	<u>1073</u>	<u>2002</u>
<u>NAm 151</u>	<u>52.20</u>	<u>-117.20</u>	<u>Canada</u>	<u>Athabasca Glacier 2</u>	<u>TRW</u>	<u>920</u>	<u>1987</u>
<u>NAm 203</u>	<u>41.40</u>	<u>-106.20</u>	<u>USA</u>	<u>Sheep Trail</u>	<u>TRW</u>	<u>1097</u>	<u>1999</u>