

1 Dear Prof. Luterbacher,

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3 we have responded to the points raised by the Reviewer #2, and hereafter you can find all the details.
4 After treating the data as suggested by the Reviewer, the quality of the reconstruction has increased
5 and some figures were redrawn accordingly. We also added a correlation map with precipitation
6 (Fig. 7), as tree-ring MXD from the study region holds also a strong signal of drought conditions
7 and precipitation (Fig. 3).

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9 We hope that now the ms. has reached the quality standard of CP.

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11 Kind regards,
12 Giovanni Leonelli

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18 Reviewer#2 comments - received 17 July 2017

19 [Our responses in BLUE](#)

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21 The authors addressed and clarified many of my initial comments in a sufficient manner, but still a
22 couple of issues persist, where the authors fall short to make the best out of their analysis, results
23 and discussion.

24 [Thank you for giving us this further opportunity to improve the ms.](#)

25
26 **Major comments:**

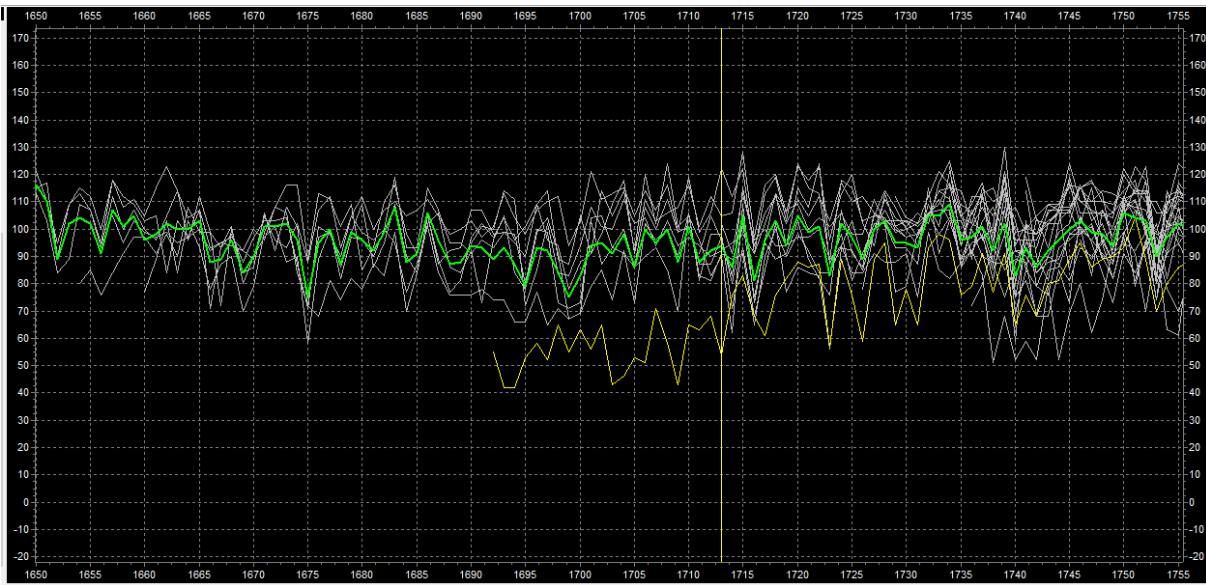
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28 P6 L36: Why didn't you use the more commonly used bi-weight-robust mean to average your
29 chronologies? There are two series in ital015x (around the year 1700) and one of the long series
30 (620012) in ital012x that have extremely low values over a prolonged period of time, dragging your
31 chronology values down heavily (I presume they are left in the HSTC approach). That is usually no
32 big issue if you have a high sample replication. But in your case those 3 series have a huge impact
33 on your reconstruction when your replication is only around 10 or lower. Using bi-weight over
34 arithmetic mean buffers significantly against those outliers. Your earliest 50 years would actually be
35 quite a bit closer to Trouet and Klesse (you "greyed-out" your chronology before 1710, I know).

36 [We tested several combinations of HSTC MXD chronologies constructed following the suggestions](#)
37 [given in this and the following comment. The best combination in terms of model stability for](#)
38 [temperature reconstruction also with the scaling method was: normalize the indexed series; apply](#)
39 [an arithmetic mean; perform average stabilization. All the other combinations \(also including the](#)
40 [biweight mean\), resulted in less stable models for temperature reconstruction and were therefore](#)
41 [discarded.](#)

42 [We found several authors simply applying an arithmetic mean in the construction of the mean](#)
43 [chronology \(e.g., with MXD series, Klusek et al., 2015, Dendrochronologia; with multi parameters](#)
44 [series, Esper et al., 2006, Trace\), probably this is the best way with the HTSC approach.](#)

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47 [Portion of the chronology with low sample replication \(\$< 10\$ \).](#)

48 [In the early portion of the chronology, one \(not 3\) indexed series shows low MXD values that indeed](#)
49 [may influence the mean; this is particularly evident especially after normalizing the series \(see](#)
50 [series #630071 in the following figure\). The series #620012 plus probably other two series](#)
51 [mentioned by the Referee are not part of the HSTC group used for the construction of the MXD](#)
52 [chronology.](#)



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2 Indexed normalized MXD series considered for the HSTC chronology. Yellow line, the series #630071,
3 *itrdbital015*, a *P. leucodermis* sample); green line the arithmetic mean; the vertical yellow line demarks the
4 year 1713.

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6
7 In order to improve the HSTC approach over the early period with the chronology showing an $EPS < \sim 0.8$
8 (i.e. before 1713 in the first version of the HSTC chronology, the greyed-out portion), we
9 considered the yearly difference of the indexed normalized series from the mean and discarded the
10 early portion of the series exceeding 2.5 standard deviations in a given year. The series exceeding
11 this threshold is only the #630071 since 1713 included, whereas all the other fall within a common
12 variability. Therefore we discarded the values of the #630071 series for the period 1692-1713, we
13 re-normalized it and we recalculated the final version of the HSTC chronology used for the
14 temperature reconstruction.

15 The issue related to the influence of outliers in the arithmetic mean computation in presence of low
16 sample replication was described above. We posed a threshold to acceptable variability in the
17 indexed series: all indexed series (one) exceeding 2.5 standard deviations from the mean were
18 truncated. As alternative option, we could simply discard the whole portion of chronology showing
19 an $EPS < \sim 0.8$.

20
21 The resulting final HSTC chronology put in the ms. has now an $EPS > 0.791$ since 1714 (thus we
22 greyed-out and discarded the early portion before 1714 in Fig. 6). From 1714 to 1980 the
23 chronology has a sample replication ≥ 10 and a good signal stability with an $EPS > 0.85$ since
24 1735.

25

year	# of samples	EPS
...		
1710	7	0.726
1711	8	0.752
1712	8	0.752
1713	9	0.773
1714	10	0.791

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1 Furthermore, by simply averaging across all sites, you don't account for systematic differences
2 between sites, when samples and sites drop out of your reconstruction. Probably more robust would
3 be to normalize all individual series over the common period (e.g. 1880-1980) and then apply the
4 bi-weight mean. This way the chronology is much more buffered against sudden site/series/species
5 replication changes. It definitely affected the long-term slope of the chronology when I use all 7
6 sites.

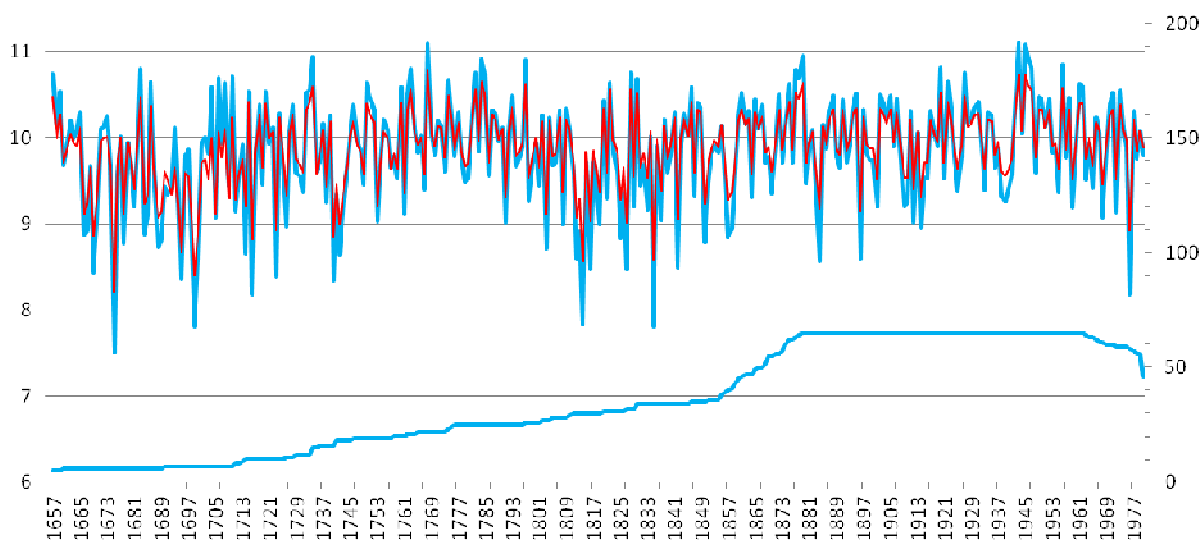
7
8 The indexed normalized series are rather synchronous and present similar MXD values: this probably
9 explains why applying a single arithmetic mean is a valid approach. Furthermore, having discarded
10 the problematic portions in the early period with low sample replication and low EPS, we have now
11 ameliorated also the 'greyed-out' early portion of the reconstruction showing less than 10 samples
12 per year (this portion, however, lies in the period already discarded for the low EPS value in the
13 chronology).

14 All indexed series are now normalized before averaging, as reported above.

15
16
17
18 Additionally, and equally - if not more - important for constructing the chronology for climate
19 reconstruction purposes, I do not see you using variance stabilization, which should be a standard
20 step producing a valid reconstruction. Using all of the 7 ITRDB MXD sites and using the arithmetic
21 mean without variance stabilization, the 30-year running standard deviation increases from ~0.03 to
22 ~0.05 from 1870 back to 1750, simply due to the decrease in replication (from close to 100 to only
23 30 samples). I'm pretty sure this effect appears similarly with only the HSTC series (~half of the
24 dataset I tested) and the negative CE using the scaling approach could be a result of this.

25 In the construction of the HSTC chronology used for the temperature reconstruction, we now applied an
26 arithmetic mean to average the indexed series after normalizing them over the resulting common
27 period 1879-1962. We also applied a variance stabilization of the chronology, following Osborn et
28 al., 1997.

29 The obtained HSTC MXD chronology (blue line in the figure hereafter) shows an EPS > ~0.8 since
30 1714 (EPS = 0.791; 10 trees) and >0.85 since 1734 (15 trees). The blue line depicts the new
31 chronology used for temperature reconstruction, the red line depicts the chronology used in the
32 previous version of the ms.



37
38 *Blue line, the new MXD HSTC chronology (corrected in the early period with low sample replication, normalized*
39 *indexed series and variance stabilization); red line the previous version of the HSTC chronology. Bottom*
40 *line: sample replication (secondary y axis).*

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3 The reconstruction is now satisfying in both the one-century-long (inverted) calibration-verification
4 periods and it is stable over time, with CE values showing always positive values (see new Table 3
5 in the ms). We also tested the possibility of using a biweight mean to average the indexed and
6 normalized series, but the temperature reconstruction showed a higher instability of the model (with
7 CE showing slightly negative values over the verification period 1781-1880: -0.078).

8 As an overall consideration we are more concerned of anomalous fluctuations in the most recent periods
9 like those around 1913 and especially 1977 as tracked, e.g., by the Trouet's (2014) reconstruction,
10 that underline late summers nearly as cold as in the 1810s (i.e., Little Ice Age peak period), than in
11 the early period, with the chronology showing lower sample replication and lower EPS (Fig. 6C).

12
13 P10 L25-27: It might be better to say: "Additionally to the stronger AS temp influence on MXD in the
14 northern chronologies the effect of summer precipitation/drought becomes equally stronger at the
15 southern sites." I wouldn't stress the elevation influence here in the second sentence, because I
16 assume the main effect is actually latitude/longitude, that causes your gradient in average
17 precipitation. You simply don't have the trees at high/low elevations in northern/southern locations.
18 With elevation, temperature should decrease, and precip increase. The increasing drought
19 correlation with increasing elevation is likely the result of the "unbalanced" tree-ring network.

20 Ok. We modified the text.

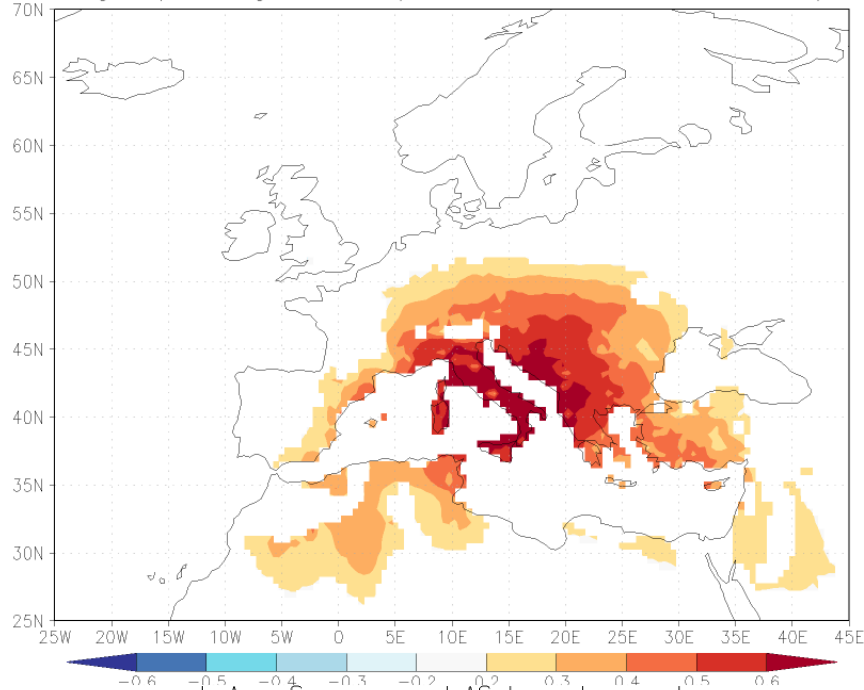
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22
23 Did you check what the pure ABAL MXD HSTC chronology would look like? Isn't your analysis
24 suggesting a cleaner and purer temperature signal there? Makes all sense to me, that when the
25 average precip levels go up, the sensitivity towards precip/drought variation decreases. Again,
26 KNMI (using only ABAL samples) tells me it would improve!

27 So, I'm really curious how the correlation stats would change, maybe even increase, if you created an
28 ABAL-only chronology? I find that diving a little more into this matter would strongly increase the
29 value of this paper, together with an outlook statement that thanks to the RDA you find (that
30 although it might be easier to find old and still standing dead PILE trees on/around Monte Pollino –
31 ok RDA doesn't tell you that but you get what I'm aiming at I hope), the MXD signal there is
32 potentially "confounded" by drought. Updating ABAL MXD + finding more old ABAL trees and
33 extending present data with building material (? Not familiar with dendroarcheology in central
34 Italy, but I guess there should be houses built with ABAL?) in central Italy seems a promising line
35 of research for the coming years. That's in my opinion the most exciting message I get from your
36 paper. It deserves more room in the discussion and would certainly contribute the most to the
37 advance of dendro-paleo-climatology in central Italy. P11 L28-32 is a bit thin in this respect.

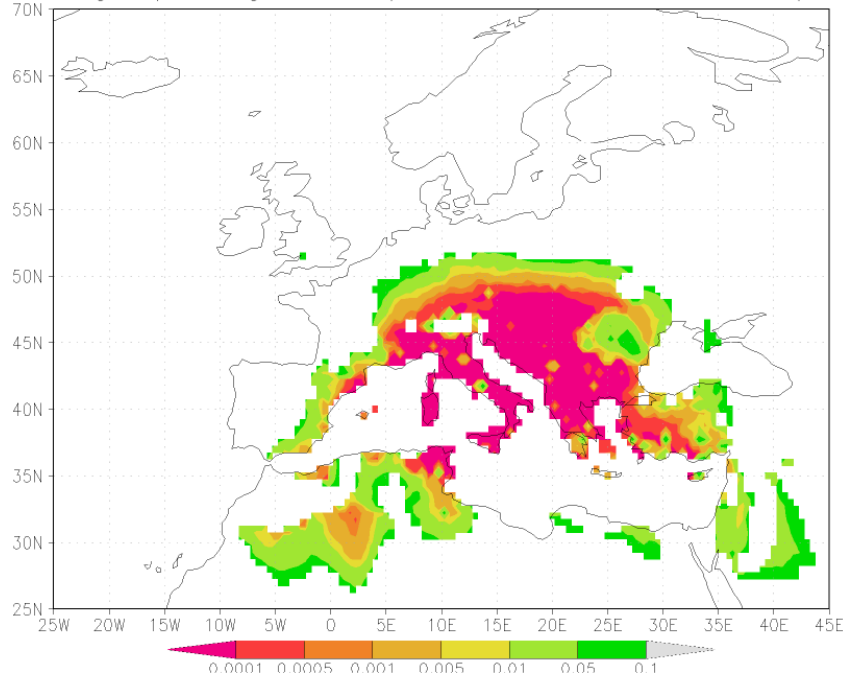
38 One of the purposes of this paper is to reconstruct a temperature signal valid for the whole Italian
39 Peninsula. In this view, removing *P.leucodermis* specimens would further drop the sample
40 replication in the early period, thus likely resulting in higher instability of the signal in the
41 chronology and a shorter period of temperature reconstruction. Future research could take in
42 account what the Referee suggests here above, hopefully also with the effort of more research
43 groups.

1 Given the change in the reconstructed temperature series, we re-computed also the spatial correlations.
 2 Unfortunately the CRU TS/E-OBS 13.1 dataset was not available anymore in the KNMI, and with
 3 the newly available version CRU TS/E-OBS 15.0, we noticed locally some unexpected responses
 4 that were not present in the 13.1 version and that are likely due to problems in the climatic dataset.
 5

corr Aug–Sep averaged AS temp temperature
 with Aug–Sep averaged CRU TS/E–OBS 15.0 Tmean 1901:1980 $p < 10\%$



6 prob Aug–Sep averaged AS temp temperature
 with Aug–Sep averaged CRU TS/E–OBS 15.0 Tmean 1901:1980 $p < 10\%$



7 *Spatial correlation of the MXD HSCT and the CRU TS/E-OBS 15.0: r values (top) and their statistical*
 8 *significance (bottom).*

11 We therefore preferred to use another dataset, namely the CRU TS 4.0 and compared our AS
 12 temperature reconstruction with both AS mean temperature and AS mean precipitation (see new
 13 Fig. 7).
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15 We also updated Table 4 and all the analysis performed in online materials.
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P10 ~L37-41: Is the climate signal in RW also instable if both tree-ring chronologies and climate data are high-pass filtered? I already raised that topic in the first round and the authors actually responded they would discuss that in the new ms (“*deepening on correlation coefficient trends, as suggested by Refereee2, will be added in the revised version of the ms*”). I really would like to see this additional analysis here, as you don’t discuss the detrending issue at all in this section. Because you use RCS with a dataset that is not really fit for it, one could assume that there might be some artificial low-frequency trends in the HSTC RW chronology (due to site and sample replication changes that your simple averaging approach simply cannot deal with) that decrease your climate correlation before 1900 in the conifers. Or is it also the high-frequency signal that is weaker to non-existent (due to early “bad” climate data, few records, higher uncertainty of interpolation of climate data, or because of points you did discuss)? Please discuss this!

The detrending approach used at the site level is common to many other researches already published, however there are no other possible ways if high-quality data availability is scarce in a given site. We remind that at each site, we selected only highly correlating series showing a common signal, in order to avoid large amount of samples bringing different signals than climatic ones (see Methods — *Site chronologies*). Averaging the indexed series using an arithmetic mean is also common (see references here above reported), and probably the best approach for the HSTC, given the good results obtained in the reconstruction.

‘Early “bad” climate data’ issue: for what concerns the climate series, they are based on

35 thermometric stations with data before 1900, of which 16 are below 44° N of latitude.

17 thermometric stations with data before 1870, of which 5 below 44° N of latitude.

8 thermometric stations with data before 1850, of which 1 below 44° N of latitude.

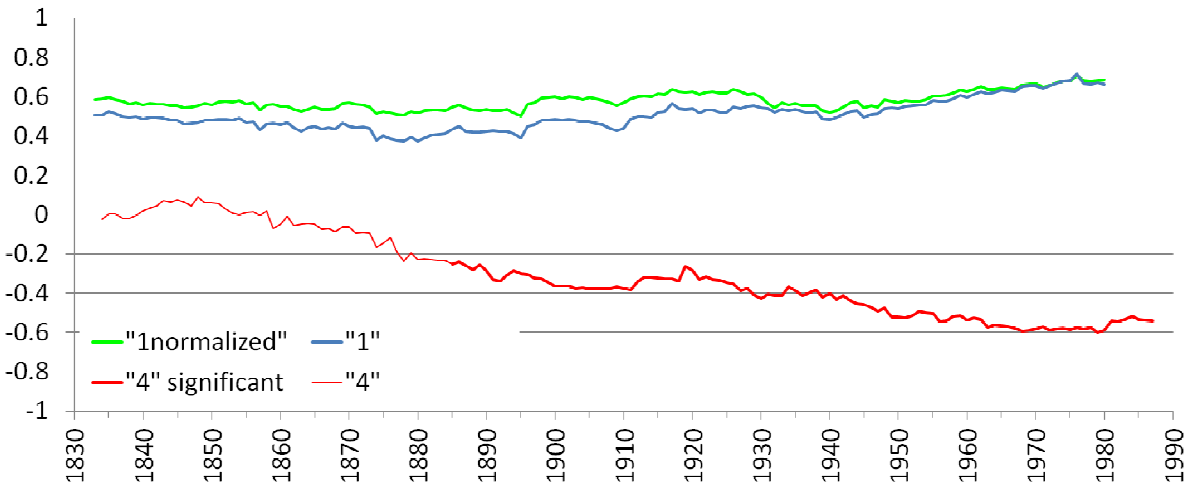
For precipitation, data availability is much larger.

1 As suggested by the Referee, we high-pass filtered the series (with a 20 yr gaussian, $\sigma = 4$ yr), and
 2 obtained the following correlations, showing no great changes between original and high-pass
 3 filtered series.
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HSTC code	Climate variable	Correlation coefficient	Period
1	AS temp	0.53	1774-1980
high-pass filtered series		0.54	
1 normalized series*	AS temp	0.66	1774-1980
high-pass filtered series		0.61	
2	JJA precip sum	-0.56	1811-1980
high-pass filtered series		-0.53	
3	JJAS SPI	-0.55	1811-1980
high-pass filtered series		-0.57	
4	A-1 temp	-0.23	1775-1987
high-pass filtered series		-0.3	
5	JJ precip sum	0.39	1857-2013
high-pass filtered series		0.42	
6	JJA SPI	0.36	1857-2013
high-pass filtered series		0.4	

6
 7 * this is the MXD HSTC series used for the AS temperature reconstruction.
 8
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10 Following the Referee suggestion, we also performed moving interval analysis on the HSTC
 11 chronologies “1”, “1 normalized series” (the HSTC chronology used for temperature
 12 reconstruction), and the “4” (i.e. the chronology showing the greatest changes in significance of the
 13 correlation coefficients).
 14



15 *Bootstrapped moving correlation analysis with a 60 yr time window, performed over the maximum period*
 16 *available for the **high-pass filtered** HSTC chronologies “1”, “1 normalized”, “4” and their respective **high-***
 17 ***pass filtered** climate variables (AS temperature, AS temperature and A-1 temperature, respectively). Bold*
 18 *lines depict statistically significant values ($p < 0.05$) of r .*
 19
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21 No great changes can be noticed between r patterns in the original series and the high-pass filtered ones
 22 (see Fig. 5 for comparison). Conifer MXD (“1” and “1 normalized”) are always significantly
 23 correlated with AS temperature over the whole period of analysis, with a slight fluctuation towards

1 higher r values in the late periods, although with lower absolute values. A slightly more stable
2 pattern in correlation coefficients around 0.6 is noticed for the “1 normalized” (i.e. the MXD HSTC
3 used for temperature reconstruction) with respect to the “1”, but the patterns are the same.

4 Conifer RW (“4”) passes from non-significant values in the early period to significant ones, even though
5 with high pass filtered series. This pattern is the same as in Fig. 5, although with high-pass filtered
6 series, the passage to significant values happens since the time windows ending in 1885 and not in
7 1900.

8 As already underlined, the temporal stability in climate correlations was tested on HSTC chronologies
9 of RW (broadleaf and conifer) and MXD (conifer), for evaluating the reconstruction potentials and
10 the possible biases in past climate reconstructions. As we found the same patterns of r in high-pass
11 filtered series, we are confident that the approach here used is solid.

12
13 Furthermore: Is the conifer RW (lag1) and conifer MXD actually negatively correlated? How about
14 conifer MXD and broadleaf RW? Could there be a way of disentangling drought effects on MXD in
15 the future using drought sensitive RW from different species? I’m aware of different auto-
16 correlative structures of the two parameters, but discussing or hypothesizing about these issues
17 could be an interesting addition to the discussion section.

18 The Referee asks to compare two different objects, as the two HSTC chronologies “1” and “4” derive
19 from trees located in different site over Italy, that are sensitive to AS temperature (chronology 1)
20 and A-1 temperature (chronology 4), respectively. Probably the relation the Referee is referring to
21 is valid for same trees from the same sites.

22 Just to be sure, we also checked for possible correlation and obtained the following results:

HSTC code	lag 0	mxl lagged -1	mxl shifted +1
"1" vs. "4"	0.04	0.14	-0.11
"1 normalized series" vs. "4"	0.05	0.16	-0.09

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1 Forgive me if I constantly keep over-looking it, but what is the final temperature target? You do not
2 specify exactly the region over which you averaged the climate in the methods. Or is it simply the
3 average of the site-corrected climate data? At the end of 2.2 this description is missing.

4 The MXD-based reconstruction is performed using the driving climate variable (DCV) ‘AS
5 temperature’ (p. 6, l. 23 and following) constructed from the different AS temperature series at the
6 various MXD sites showing significant correlation in the site-level analysis on site chronologies
7 (Fig. 3). The target is therefore a mean August September temperature for the whole Peninsula,
8 since MXD sites are distributed in the whole Peninsula. In particular, the regional AS temperature
9 series used for the reconstruction was build starting from the climate series specific of the following
10 sites (i.e. the sites showing significant correlations between reference chronologies and August and
11 September temperature):

12 ITRDBITAL008

13 ITRDBITAL009

14 ITRDBITAL010

15 ITRDBITAL011

16 ITRDBITAL012

17 ITRDBITAL015

18
19 The climatic data from the following sites (of *P. nigra*) were not included in the construction of the
20 regional climatic series, as we found no significant correlation between site chronologies and
21 August or September temperature:

22 ITRDBITAL013

23 ITRDBITAL016

24
25
26 We modified some parts of the paragraph.

27
28 And what’s the R^2 for the full period? You only report it for the split periods.

29 We added the R^2 for the full period in Table 3

30
31 Figure update: Figure 4B was updated, as some series were wrongly assigned in the computation of the
32 Site Fitness.

33 34 35 **Minor comments:**

36
37 P4 L17: This is a rather abrupt change to describe the purpose of your study. I would give it one or two
38 more sentences. Something along the lines of: “As separate climate (temperature) reconstruction for
39 Italy has been published to date the goal of this study was to screen the ITRDB for suitable data. we
40 make use of the ITRDB to investigate RW and MXD climate signals across Italy. After screening
41 ... -> temperature reconstruction ...
42 Our main objectives are: i) ... ii) ...”

43 Ok. thank you.

44
45 P6 L16: “variables” instead of “variable”

46 Ok.

47
48 P6 L21: delete [in presenting HSTC trees], simply say “... we calculated the Site Fitness, representative
49 of the percentage of selected HSTC series of conifer MXD with respect to ...”

50 Ok

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52
53 P8: Please consider revising the first 8 lines. There are some unnecessary repetitions.

54 Something along the lines: “We find that the strength of the AS signal correlates positively with latitude

1 (mean precip) and negatively with elevation (longitude).. The RDA analysis reveals that both
2 parameters are on opposing sides of the first two axes explaining NNN% of the variance of the
3 dataset. ...”

4 Ok

5
6 P8 L9: Concerning the site fitness – instead of “for what concerns”

7 Ok

8
9 P8 L38-40: Something wrong in that sentence, maybe easier something like: “... the MXD
10 reconstruction matches very well the temperature variability in Italy south of the Po plane and the
11 western Balkan area ($r>0.6$). Correlations above (e.g.) 0.4 are still found throughout the Alpine arc, the
12 central Balkan, as well as Tunisia.”

13 Ok

14
15 P9 L4-5: do you mean: strong signal in MXD independent of species?

16 Yes

17
18 P10 L4: Pinatubo did not erupt in 1914! Do you maybe mean Novarupta 1912? There’s no $VEI\geq 6$ in
19 1914, to my knowledge (and your figure 6).

20 Yes, of course... Ms. modified accordingly.

21
22 P10 L26/27: no commas after MXD

23 Ok

24
25 P10 L26: P. leucodermis

26 Ok

27
28 P10 L36: concerning the temperature signal

29 Ok

30
31 Figure 6: Mount Pinatubo is not on your axis, as your graph ends in 1980.

32 Yes

33
34 Figure 7: Is the E-OBS/CRU TS a spliced product? E-OBS usually starts only in 1950, I can’t find a
35 clear description on KNMI what this actually is. The correlation picture (RCS with all 7 sites and 160
36 MXD series) looks almost the same compared to using CRU TS4.0, which makes me wonder, what
37 exactly the benefit of the HSTC approach is, since you shorten your potentially “reliable” chronology
38 by 80 years (using all series you would have an $EPS>0.85$ back to 1650).

39 CRU TS/E-OBS is a combination of datasets. In the current version, given the problems raised with
40 CRU TS/E-OBS v 15.0, we now choose the CRU TS 4.0. The HSTC approach is a tree-based approach
41 that has the advantage of focusing the reconstruction only on trees whose sensitivity to climate has been
42 checked over centuries.

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50 The Authors, 25 August 2017

Climate signals in a multispecies tree-ring network from central and southern Italy and reconstruction of the late summer temperatures since the early 1700s

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Abstract. A first assessment of the main climatic drivers that modulate the tree-ring width (RW) and maximum latewood density (MXD) along the Italian Peninsula and north-eastern Sicily was performed using 27 forest sites, which include conifers (RW and MXD) and broadleaves (only RW). Tree-ring data were compared using the correlation analysis of the monthly and seasonal variables of temperature, precipitation and standardized precipitation index (SPI, used to characterize meteorological droughts) against each species-specific site chronology and against the highly sensitive to climate (HSTC) chronologies (based on selected indexed individual series). We find that climate signals in conifer MXD are stronger and more stable over time than those in conifer and broadleaf RW. In particular, conifer MXD variability is directly influenced by the late summer (August, September) temperature and is inversely influenced by the summer precipitation and droughts (SPI at a timescale of 3 months). The MXD sensitivity to AS temperature and to summer drought is mainly driven by the latitudinal gradient of summer precipitation amounts, with sites in the northern Apennines showing stronger climate signals than sites in the south. Conifer RW is influenced by the temperature and drought of the previous summer, whereas broadleaf RW is more influenced by summer precipitation and drought of the current growing season. The reconstruction of the late summer temperatures for the Italian Peninsula for the past 300 yr, based on the HSTC chronology of conifer MXD, shows a stable model performance that underlines periods of climatic cooling (and likely also wetter conditions) in 1699, 1740, 1814, 1914, 1938 and well follows the variability of the instrumental record and of other tree-ring based reconstructions in the region. Considering a 20 yr low-pass filtered series, the reconstructed temperature record consistently deviates $<1^{\circ}\text{C}$ from the instrumental record. This divergence may be due also to the precipitation patterns and drought stresses that influence the tree-ring MXD at our study sites. The reconstructed late-summer temperature variability is also linked to summer drought conditions and it is valid for the west-east oriented region including Sardinia, Sicily, the Italian Peninsula and the western Balkan area along the Adriatic coast.

1 Introduction

Reconstructions of climate for periods before instrumental records rely on proxy data from natural archives and on the ability to date them. Among the available proxies, tree rings are one of the most used archives for reconstructing past climates with

1 annual resolution in continental areas and they often **come** from the temperature-limited environments with high latitudes
2 and altitudes (e.g., Briffa et al., 2004; Rutherford et al., 2005). **Tree-ring data** can be used at regional to global scales (IPCC,
3 2013) and long chronologies covering millennia, **going** back as far as the early Holocene, are available (for Europe: Becker,
4 1993; Friedrich et al., 2004; Nicolussi et al., 2009).

5 The reconstruction of past climate variability and the analysis of its effects on forest ecosystems are crucial **elements** for
6 understanding climatic processes and for predicting what responses should be expected in ecosystems under the ongoing
7 climatic and global changes. In particular, the Mediterranean region is a prominent climate change hot spot (Giorgi, 2006;
8 Turco et al., 2015), and by the end of this century, it will likely experience a regional warming higher than the global mean
9 (up to +5 °C in summer) and a reduction of the average summer precipitation (up to -30 %; Somot et al., 2007; IPCC, 2013).
10 As a consequence of the poleward expansion of the subtropical dry zones (e.g., Fu et al., 2006), subtropical environments
11 under climate change are already facing strong hydroclimatic changes due to **lower** precipitation and human exploitation
12 (e.g., in southwestern north America, Seager et al., 2007; Seager and Vecchi, 2010). Moreover, in these environments
13 (**including also** the Mediterranean region), soil moisture will likely drop, resulting in a contraction of temperate drylands **by**
14 **approximately a third** (converting into subtropical drylands), and longer periods of drought in deep soil layers are expected
15 (Schlaepfer et al., 2017). The increase in droughts **conditions** during the growing season is already negatively impacting tree
16 growth, especially at xeric sites in the southwestern and eastern Mediterranean (e.g., Galván et al., 2014). At the ecosystem
17 level, in the near future, the responses to climate changes will impact **the various forest species in a different way**, depending
18 on their physiological ability to acclimate and adapt to **the** new environmental conditions (e.g., Battipaglia et al., 2009;
19 Ripullone et al., 2009), and on their capacity to grow, accumulate biomass, and contribute as sinks in the terrestrial carbon
20 cycle. Natural summer fires in the Mediterranean area are also expected to increase in frequency over the coming decades as
21 a response to increasingly frequent drought conditions, assuming a lack of additional fire management and prevention
22 measures (Turco et al., 2017).

23 **1.1 Tree-ring Response to Climate**

24 Climate-growth relationships have been studied for several species in the Mediterranean region, with different objectives:
25 forest productivity (e.g., Biondi, 1999; Boisvenue and Running, 2006; Nicault et al., 2008; Piovesan et al., 2008; Babst et al.,
26 2013), tree ecophysiology, wood formation and related dating issues (Cherubini et al., 2003; Battipaglia et al., 2014),
27 sustainability of forest management (e.g., Boydak and Dogru, 1997; Barbati et al., 2007; Marchetti et al., 2010; Castagneri et
28 al., 2014), provision of ecosystem services (e.g., Schröter et al., 2005) such as carbon sequestration (e.g., Scarascia-
29 Mugnozza and Matteucci, 2014; Calfapietra et al., 2015; Borghetti et al., 2017), effective biodiversity conservation (e.g.,
30 Todaro et al., 2007; Battipaglia et al., 2009), and climate reconstruction (see next heading), which has led to a variety of
31 associations between climate variables and growth responses in conifers and broadleaves from different environments and
32 ecosystems. Mainly considering the species of this study, we report the main findings on the climate-growth responses found
33 in this region.

34 — *Conifers*. Studies on silver fir (*Abies alba* Mill.) growth in the Italian Peninsula reveal high sensitivity to the climate of
35 the previous summer, August₋₁ in particular, positive correlations with precipitation and negative correlations with
36 temperature (Carrer et al., 2010; Rita et al., 2014). Moreover, tree growth in this region is moderately negatively correlated
37 **with** the temperature of the current summer (unlike that in stands located in the European Alps; Carrer et al., 2010), namely,
38 high temperatures in July and August negatively affect tree growth. A dendroclimatic network of pines (*Pinus nigra* J.F.
39 Arnold and *P. sylvestris* L.) in east-central Spain shows that drought (namely, the Standardized Precipitation-
40 Evapotranspiration Index - SPEI; Vicente-Serrano et al., 2010) is the main climatic driver of tree-ring growth (Martin-Benito
41 et al., 2013). In a *P. uncinata* network from the Pyrenees, an increasing influence of summer droughts (SPEI) on tree-ring
42 widths (RW) during the 20th century and the control of May temperatures on maximum latewood density (MXD) is found

1 (Galván et al., 2015). However, in the above-mentioned analyses, the possible influences of the summer climate variables
2 from the year prior to the growth were not considered. Elevation, and particularly the related moisture regime, in the eastern
3 Mediterranean region is the main driver of tree-ring growth patterns in a multispecies conifer network comprised of *P. nigra*,
4 *P. sylvestris* and *P. pinea* L. specimens (Touchan et al., 2016). A dipole pattern in tree-ring growth variability is reported for
5 Mediterranean pines ranging from Spain to Turkey, with a higher sensitivity to summer drought in the **East** than in the **West**,
6 and with higher sensitivity to early summer temperature in the **West** (Seim et al., 2015). A strong correlation between
7 autumn-to-summer precipitation and between summer drought and tree-ring growth is reported for sites (mainly of conifers)
8 in northern Africa-western Mediterranean, with trees from Morocco also responding to the North Atlantic Oscillation Index
9 (Touchan et al., 2017).

10 — *Broadleaves*. In the western Mediterranean (northern Morocco, Algeria, Tunisia, Italy and southern France), deciduous
11 oaks, including *Quercus robur* L., reveal a direct response of tree-ring growth to summer precipitation and an inverse
12 response to summer temperature (Tessier et al., 1994). Beech (*Fagus sylvatica* L.) is particularly sensitive to soil moisture
13 and air humidity; in past decades, long-term drought **conditions** have been shown to be the main factor causing a growth
14 decline in the old-growth stands in the Apennines (Piovesan et al., 2008). Beech shows different responses to climate at high-
15 vs. low-altitude sites (Piovesan et al., 2005), with these latter being positively affected by high May temperatures. Despite an
16 expected higher drought sensitivity stress close to the southern limit of the distribution area, a late twentieth century tree-ring
17 growth increase in beech has been reported in Albania (Tegel et al., 2014), thus underlining the different climate-growth
18 responses in the Mediterranean region. Beech, indeed, presents complex climate growth-responses and also appears to be a
19 less responsive species in the Mediterranean area when compared to conifers such as *P. sylvestris*, *P. nigra*, *P. uncinata* or *A.*
20 *alba* (as found in south-east France; Lebourgeois et al., 2012).

21 **1.2 Tree-ring Based Climate Reconstructions**

22 One of the most powerful tools in terrestrial paleoclimatology is obtaining dated information about the past climate and past
23 environmental conditions in a region by analyzing the tree rings. However, in the Mediterranean region, the low temporal
24 stability of the recorded climatic signals (e.g., Lebourgeois et al., 2012; Castagneri et al., 2014), the scarcity of long
25 chronologies, and the high variability of climatic and ecological conditions (Cherubini et al., 2003) often make this analysis
26 difficult. Ring widths are among the most used variables for climate reconstruction but **they** usually show a higher temporal
27 instability in their relationship with climate than that of maximum latewood density (for the Pyrenees, see Büntgen et al.,
28 2010).

29 The potential to analyze relatively long chronologies in the Mediterranean region has allowed for the reconstruction of the
30 past climate (mainly precipitation and droughts). Several reconstructions of May-June precipitation have been performed,
31 mainly over the last 300-400 yr, in a region **including** northern Greece, Turkey **and** Georgia: in northern Aegean-northern
32 Anatolia a tree-ring network of oaks was used for reconstructing precipitation variability since 1089 CE (Griggs et al., 2007);
33 in the Anatolian Peninsula a mixed conifer-broadleaf tree-ring network (mainly *P. nigra*, *P. sylvestris* and oaks; Akkemik et
34 al., 2008), a *P. nigra* network (Köse et al., 2011) and a multi-species conifer network (mainly *P. nigra*, *P. sylvestris* and *Abies*
35 *nordmanniana* (Steven) Spach; Köse et al., 2013) were used. In western Mediterranean, in central Spain, a higher frequency
36 of exceptionally dry summers has been detected since the beginning of the 20th century using a mixed tree-ring network of
37 *Pinus sylvestris* and *P. nigra* ssp. *salzmannii* covering the past four centuries (Ruiz-Labourdette et al., 2014), whereas a 800
38 yr temperature reconstruction from southeastern Spain using a site of *P. nigra* underlined predominantly higher summer
39 temperatures during the transition between the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA) (Dorado
40 Liñán et al., 2015). A recent reconstruction of spring-late summer temperature from the Pyrenees by means of a *P. uncinata*
41 MXD network dating back to 1186 (Büntgen et al., 2017), underlines warm conditions around 1200 and 1400 and after 1850.
42 Reconstructions of past droughts and wet periods over the Mediterranean region have been created using climatic indices

1 such as the Standardized Precipitation Index (SPI; McKee et al., 1995) in Spain (modeling 12-month July SPI using several
2 species of the *Pinus* genre; Tejedor et al., 2016), and in Romania (modeling 3-month August standardized SPI using *P. nigra*;
3 Levanič et al., 2013), which allows for the identification of common large-scale synoptic patterns. Droughts have been
4 reconstructed using the Palmer Drought Severity Index (PDSI; Palmer 1965). Using actual and estimated multispecies tree-
5 ring data, Nicalut et al. (2008) found that the drought episodes at the end of the 20th century are similar to those in the 16th-
6 17th century for the western Mediterranean, whereas in the eastern parts of the region, the droughts seem to be the strongest
7 recorded in the past 500 yrs.

8 Early summer temperature has been reconstructed for 400 yr in Albania, from a *P. nigra* tree-ring network, finding stable
9 climate-growth relationships over time and a spatial extent of the reconstruction spanning over the Balkans and southern
10 Italy (Levanič et al., 2015). Currently, two summer temperature reconstructions close to the study area and based on
11 maximum latewood density (MXD) chronologies are available: (1) a reconstruction of AS temperature published by Trouet
12 (2014) covering the period 1675–1980 and centered on the northeastern Mediterranean-Balkan region includes sites from the
13 Italian Peninsula (used in this paper), the Balkan area, Greece and sites from the central and eastern European Alps to central
14 Romania and Bulgaria, the latter areas being characterized by continental climates; (2) a reconstruction of JAS temperature
15 published by Klesse et al. (2015), covering the period 1521–2010 and based on a chronology from Mt. Olympus (Greece).

16 As separate climate (temperature) reconstructions for northeastern Mediterranean-Balkan region including also Italy have
17 been published to date, the goal of this study was to collect dendrochronological data from Italian research groups and screen
18 the ITRDB for suitable data for climate reconstructions. We therefore investigate RW and MXD climate signals across Italy.

19 After carefully testing the climatic signals recorded in the tree-ring RW and MXD from different sites and different species,
20 the reconstruction that is proposed in this study is the first one including only forest sites from the Italian Peninsula.

21
22 Overall, the main objectives of this paper are:

23 (i) to identify the most important climatic drivers modulating tree-ring width (RW) and tree-ring maximum latewood density
24 (MXD) variability in forest sites from central and southern Italy. To our knowledge, this is the first attempt performed in
25 Italy with the clear objective to find common response patterns in conifer and broadleaf species using a multispecies tree-
26 ring network and site-specific historical climatic records;

27 (ii) to estimate the temporal stability of the climate-growth and climate-density relationships;

28 (iii) to perform a climatic reconstruction based only on trees *highly sensitive to climate* (HSTC); and

29 (iv) to estimate the spatial coherence of the obtained reconstruction in the region.

30 2. Data and Methods

31 2.1 Study area and study sites

32 The study region includes the whole Italian Peninsula and eastern Sicily and covers a latitudinal range from 37° 46' N to 44°
33 43' N (Fig. 1). The peninsula is roughly oriented NW-SE and its longitudinal axis is characterized by the Apennines that
34 reach their maximum altitude at their center (Corno Grande Mt., 2912 m a.s.l., Gran Sasso Massif); a higher altitude is
35 reached in eastern Sicily by the Etna Volcano (3350 m a.s.l.). The study region is surrounded by the Tyrrhenian and Adriatic
36 Seas and is characterized by a typical Mediterranean climate, with high temperatures and low precipitation during the
37 summer (from June to September), and by a Mediterranean-temperate regime at the higher altitudes of the Apennines (Fig.
38 2). Considering the climatic means at all the study sites (at a mean elevation of 1225±520 m a.s.l.) over the period 1880-
39 2014, the temperatures over the study region range from 0.2 °C (January) to 17.6 °C (in July and in August) and only 11 %
40 of the total annual precipitation falls during the summer (from June to August: 155 mm), whereas 34 % falls during winter
41 (from December₋₁ to February: 493 mm). Autumn is the second wettest season (31 % of total annual precipitation) and spring

1 is the third wettest (24 % of total annual precipitation) (Fig. 2).

2 The total forest cover in Italy, excluding the regions of the European Alps, is approximately 5.8 M hectares (Corpo Forestale
3 dello Stato, 2005) which is 28 % of the considered surface. Forests characterize the landscape of the inner portion of the
4 Apennine range, at mid to high elevations, and an additional 1.4 M hectares are covered by woodlands and shrublands,
5 which are the so called Mediterranean ‘macchia’ that border the forests at low elevations and in areas relatively close to the
6 sea. Overall, broadleaf species are much more abundant in the study region than conifer species, accounting for
7 approximately $\frac{3}{4}$ of the forest cover (Dafis, 1997).

8 The study sites are distributed along the whole latitudinal range of the Italian Peninsula and tree-ring proxies include both
9 RW and MXD series collected within the NEXTDATA project, from Italian Universities, and from the ITRDB
10 (www.ncdc.noaa.gov site consulted on September 2015; see Table 1 for full bibliographic references). The dataset is based
11 on 27 forest sites composed of several species (conifers at 16 sites, and broadleaves at 11 sites), from which tree-ring series
12 of conifers (RW and MXD) and of broadleaves (RW) were prepared (Fig. 1, Table 1).

13 2.2 Climate variables

14 The availability of long and reliable time series of meteorological variables, possibly from stations located very close to
15 forest sites, is crucial for estimating the climate-growth relationships. However, global or regional climatological datasets
16 frequently lack local resolution, especially in remote sites. We, therefore, reconstructed synthetic records of monthly
17 temperature and precipitation series to be representative of the sampled sites using the anomaly method (New et al., 2000;
18 Mitchell and Jones, 2005), as described in Brunetti et al. (2012). Specifically, we reconstructed independently climatological
19 normals (following the procedure described in Brunetti et al. (2014) and Crespi et al. (2017), by estimating a local
20 temperature (precipitation) - elevation relationship, and exploiting a very high density data set from time series that are
21 at least 30-year long). We also estimated the deviations from the normals by means of a weighted average of neighboring
22 series, by exploiting the great amount of very long and high quality temperature and precipitation series available for Italy
23 over the past 200/250 years (obtained from an improved version of Brunetti et al. (2006)). Finally, by the superposition of
24 the two fields, we obtained temporal series in absolute values for each sampling site. The climate series start in different
25 years due to data availability; however, most of the series start around the mid-19th century. Finally, in order to characterize
26 meteorological drought conditions, we calculated the monthly Standardized Precipitation Index (SPI) at timescales of 1, 2, 3,
27 6, 9 and 12 months for all sites, based on the monthly values of precipitation, using the SPI_SL_6 code of the National
28 Drought Mitigation Center at the University of Nebraska (<http://drought.unl.edu>).

29 2.3 Chronology construction, climate sensitivity and climate reconstructions

30 — *Raw data*. We examined all individual series of RW and MXD for correct dating using visual and statistical crossdating.
31 In particular, we used statistical techniques to remove potential dating errors by comparing each individual series from one
32 site against the mean site chronology, which was constructed excluding the analyzed individual series. Using the COFECHA
33 software (www.ldeo.columbia.edu), the individual series were moved forward and backward 10 yr from their initial
34 positions, and similarity indices were calculated over a 50-yr time window, thus highlighting the potential dating errors.

35 — *Site chronologies*. We used the Regional Curve Standardization approach (RCS; Briffa et al., 1992; Briffa and Melvin,
36 2011; Esper et al., 2003) both with the RW and MXD series to preserve the low-frequency variability in the site
37 chronologies. We used the ARSTAN software (ver. 44 h3, www.ldeo.columbia.edu) and did not consider the pith offset
38 estimates between the first measured ring and the actual first year of growth (Esper et al., 2009; Leonelli et al., 2016). The
39 regional curve (RC) for the mean chronology, which was obtained after the series alignment to the first measured ring, was
40 smoothed using a cubic spline with a width of 10 % of the chronology length (Büntgen et al., 2006). We computed ratios of
41 raw measurements vs. the values of growth predicted by the RC for all years of the individual series, and the resulting

1 indexed series were averaged by a biweight robust mean to obtain the site chronologies of RW and of MXD. We constructed
2 the RW and MXD site chronologies only for sites with at least 10 individual series fulfilling the following conditions: i) the
3 individual series length was >100 yr; ii) the individual series correlation with the respective site chronology had $r > 0.3$; iii)
4 the mean interseries correlation (MIC) had $r > 0.3$; and iv) the expressed population signal (EPS; Wigley et al., 1984; Briffa
5 and Jones, 1990) was > 0.7 . We used only the individual series fulfilling these conditions to construct the site chronologies.
6 However, we accepted some exceptions in order to maximize the number of sites and chronologies available for analysis (see
7 exceptions in Table 1).

8 — *Climate sensitivity*. We assessed species-specific climate sensitivity for the constructed RW and MXD site chronologies
9 over the common period of 1880-1980 using correlation analysis and the site-specific monthly variables of temperature,
10 precipitation and Standardized Precipitation Index, from March of the year prior to growth to September of the year of
11 growth. We computed correlations using the DENDROCLIM software (Biondi and Waikul, 2004), applying a bootstrap with
12 1,000 iterations, and the obtained results were analyzed by grouping together conifer and broadleaf species.

13 — *Testing for climate-growth relationships at the site level*

14 To assess the influence of environmental settings on climate-growth relationships, for the **conifer** MXD site chronologies
15 (i.e. the chronologies holding the strongest climatic signal; see Results), we performed a redundancy analysis (RDA)
16 selecting as response variables the bootstrapped correlation coefficients of climate-growth relationships (Fig. 3) and as
17 explanatory variables the environmental variables (geographical characteristics and climatic averages over the period 1880-
18 1980). In order to attenuate co-variation within the environmental variables, we ran a PCA before the RDA and the following
19 variables were finally chosen: Elevation (co-varying with Longitude: our sites are placed at higher elevation at increasing
20 longitude (Table 1); average AS temperature; average JJA precipitation (co-varying with Latitude: higher latitude means
21 higher precipitation amounts); average JJAS SPI_3 (at timescale of 3 months, i.e., the timescale resulting most significant;
22 see Results). Moreover, for each of the MXD site chronologies, we calculated the Site Fitness (SF; Leonelli et al., 2016),
23 **representative of the percentage of selected HSTC series of conifer MXD** with respect to the total of series available at each
24 site.

25 We used the results of the climate sensitivity analysis to detect the *driving climate variables* (DCV; of temperature,
26 precipitation and SPI) for each of the three groups of chronologies: MXD conifer, RW conifer and RW broadleaf.
27 Specifically, for each group of chronologies and for each climate variable, we **first** identified the months with significant
28 correlations at most sites (>50 %) and with mean correlation values of $|\bar{r}| > 0.25$ (black-filled squares in Fig. 3). **Starting**
29 **from the monthly climatic averages of the sites presenting significant correlations with these selected months, we**
30 **constructed regional climate series by z-scoring the monthly series of each site and calculating regional mean departures; the**
31 **series of each site were then completed over the maximum period covered by data and re-converted in original units (based**
32 **on regional mean departures and their specific means and standard deviations), and finally averaged between sites. We**
33 **calculated the DCVs as means of two to four consecutive months of the regional series, except for August₁ temperature vs.**
34 **conifer RW (according to what was obtained in the site-level analysis of Fig. 3).**

35
36 — *HSTC chronologies*. Based on the available RW and MXD indexed individual series from all of the sites, we constructed
37 six HSTC chronologies, as in Leonelli et al. (2016). However, given the smaller number of datasets available in this study
38 and the shortness of the time series, a modified version of the method was applied. Specifically, we tested all of the RW
39 (conifer and broadleaf) and MXD (only conifer) indexed individual series against each of the above-defined six DCV, and
40 we used only the individual tree-ring indexed series with correlation values of $|\bar{r}| > 0.25$ in both of the 100 yr subperiods of
41 the climatic dataset (1781-1880 and 1881-1980) for building each of the six HSTC chronologies (which was done by simply
42 averaging together the selected indexed series). We constructed the six HSTC chronologies starting from all of the indexed
43 individual series of conifer MXD (148 series), of conifer RW (245) and of broadleaf RW (140), which were previously

1 obtained, while constructing the site chronologies (also, the indexed individual series from sites not meeting the fixed quality
2 standards for a site chronology were included at the beginning of the selection).

3 — *Climate sensitivity through time.* To test the stability of the climate signals recorded in the HSTC chronologies, we
4 conducted a moving correlation analysis between the six HSTC chronologies and their respective DCV, computing
5 bootstrapped correlation coefficients with DENDROCLIM over 60 yr time windows that were moved one year per iteration
6 over the longest available periods.

7 — *Climate reconstruction.* We used only the HSTC chronology showing the highest absolute values of correlation and the
8 most stable signal over time (i.e., the conifer MXD for late summer temperature; see Results) for the climate reconstruction.
9 To extend this HSTC chronology as far back in time as possible, we also added the oldest available individual MXD indexed
10 series with correlations of $|\bar{r}| > 0.25$ with this chronology and that had a minimum length of 100 yr. For constructing the
11 chronology for climate reconstruction we applied an arithmetic mean to the indexed series, after having normalized all
12 individual series over the common period 1879-1962. Moreover, to account for the changing sample size through time, a
13 variance stabilization of the resulting chronology was performed using Briffa's RBAR- weighted method (Osborn et al.,
14 1997). In order to improve the HSTC chronology over the early period showing an EPS $< \sim 0.8$ (i.e. before 1713 in the first
15 version of the HSTC chronology), we considered the yearly difference of the indexed normalized series from the mean and
16 discarded the early portion of the series exceeding the threshold of 2.5 standard deviations in a given year (one series was
17 truncated at 1713, whereas the other nine felled within a common variability). Finally, we re-normalized all series and
18 recalculated the final version of the HSTC chronology used for the temperature reconstruction as described above. We
19 calibrated and verified linear regression and scaling models (Esper et al., 2005) over the 100 yr periods 1781-1880 and 1881-
20 1980, respectively, and then the same was done over the inverted periods, in order to estimate model performances and
21 stability. We computed Reduction of Error (RE; Fritts, 1976) and Coefficient of Efficiency (CE; Briffa et al., 1988) statistics
22 to assess the quality of the reconstructions. We then used the reconstructed series of late summer temperatures over the
23 period 1901-1980 to build a spatial correlation map with the KNMI Climate Explorer (<https://climexp.knmi.nl/>; Trouet and
24 Oldenborgh, 2013), using the 0.5° grid of August-September average temperature and of AS average precipitation (CRU TS
25 4.0, Climatic Research Unit, University of East Anglia Harris et al., 2014). We used this independent dataset instead of the
26 Italian one, as our primary goal was to analyze how far from the Italian Peninsula the reconstructed climatology is still
27 representative.

28 **3 Results**

29 — *Site chronologies.* We obtained fifteen RW site chronologies (11 from conifers and 4 from broadleaves) and eight MXD
30 site chronologies (from conifers) and we used them to estimate climate sensitivity at the site level and to detect the most
31 important climatic drivers over the study region (for species percentages, see boxes in Fig. 3A, 3A' and 3A''). We performed
32 the construction of the HSTC chronologies (for the analysis of the temporal stability of climate signals and for climate
33 reconstruction) using also the individual series from the twelve sites (5 from conifer and 7 from broadleaves; see Table 1,
34 grey-shaded areas in Table 2 and Methods) for which the site chronologies did not meet the quality standards. The maximum
35 time span of tree-ring data covers the period from 1415 (ITRDBITAL015) to 2013 (QFIMP1 and QFIMP2). However, the
36 mean chronology length is 215 ± 130 yr for conifers and 175 ± 25 yr for broadleaves (values rounded to the nearest 5 yr; Table
37 2). Over the common period considered (1880-1980 for all MXD and RW chronologies), the mean series intercorrelation and
38 expressed population signal are approximately 0.5 and 0.8, respectively.

39 — *Tree-ring sensitivity to climate.* The site-specific sensitivity analysis performed over the common period of 1880-1980
40 revealed that MXD in conifers records stronger climatic signals than RW in either conifers or broadleaves, in terms of the
41 average correlation coefficient, the number of months showing statistically significant values ($p < 0.05$) and the fraction of

1 chronologies (over the maximum number available) responding to the same climatic variable (Fig. 3). In particular, all
2 conifer MXD chronologies were found to be positively influenced by late summer temperatures (August and September),
3 whereas precipitation from June to August is negatively correlated with most of them (Fig. 3A and 3B). In terms of SPI, the
4 highest correlations (for both MXD and RW) were obtained for the indices calculated at the timescales of 2 and mainly of 3
5 months (SPI_3; only the latter is reported in the Results), while longer timescales showed fewer significant correlation
6 values. Most conifer MXD were found to be negatively correlated with SPI_3 from June to September, highlighting that low
7 index values, i.e., drought periods, are associated with high MXD in the tree rings, and vice versa (Fig. 3C).
8 For conifer RW, significant correlation coefficients, i.e., those exceeding the mean value of $|\bar{r}| > 0.25$ for more than 50 % of
9 the available chronologies, were obtained only for the August temperatures of the year prior to growth (a negative
10 correlation; Fig. 3A'). In the other months, correlations are generally low and sometimes show opposite signs for the same
11 climatic variable. However, a slightly stronger influence from the climatic variables for the summer months prior to growth
12 can be noted (black areas in Fig. 3A', 3B' and 3C').

13 Broadleaf RW were found to be positively influenced by high precipitations and low drought occurrences (high SPI_3
14 values) during the summer months (June and July precipitation and June to August SPI_3; Fig. 3B'' and 3C''), whereas the
15 temperature did not show a significant influence (Fig. 3A'').

16 — *Influence of environmental settings on climate-growth relationships & Site Fitness.* We found that the strength of the AS
17 signal correlated positively with latitude (mean precipitation) and negatively with elevation (longitude) (Fig. 4A). Summer
18 precipitation amounts and elevation correlated negatively in our dataset of MXD, revealing the dominance of the latitudinal
19 gradient of larger precipitation in northern areas over the expected altitudinal gradient of higher precipitation at higher
20 altitudes: sites in northern areas, even if at lower altitudes, receive more summer precipitation than sites in southern regions
21 at higher altitude. The RDA analysis revealed that both parameters were on opposing sides of the first two axes explaining
22 89.55 % of the variance of the dataset: the F1 axis alone explains up to 72% of the variance in response variables, and
23 especially in AS temperature and JJAS SPI_3 signals. Concerning Site Fitness, especially sites located at higher latitudes, in
24 particular northern of 42° N (all of *Abies alba*) presented values of SF > 80%, and up to 86% (Fig. 4B). South of 42° N, all
25 sites (including also two sites of *Abies alba*) presented a SF of approximately 10%, with the *Pinus leucodermis* site showing
26 the highest SF value (52%) and a *P. nigra* site the lowest (0 %).

27 — *Stability of the climatic signal over time.* The six comparisons performed between the HSTC chronologies and the DCV
28 were deemed important to understand the influence of temporal climatic variability on conifers MXD and RW and on
29 broadleaf RW (Fig. 5). The moving-window correlation analysis revealed that the HSTC conifer MXD chronology held the
30 strongest and most stable climatic signal of late summer temperature over time, with values of correlation coefficient ranging
31 from approximately 0.4 to nearly 0.8 in the more recent periods analyzed (#1 in Fig. 5). In the other two HSTC chronologies
32 based on conifer MXD (#2 and #3 in Fig. 5), starting from the time window 1881-1940 up to recent periods, we always
33 found higher absolute values for SPI_3 than for precipitation, with values of correlation reaching approximately -0.7 and -
34 0.6, respectively, (#3 and #2 in Fig. 5). For the conifer RW, a strong change in the temperature signal of August prior to
35 growth was found (#4 in Fig. 5), with correlation values shifting from positive (and statistically non-significant) in the early
36 period of analysis to negative (approximately -0.5) in the mid to late analysis period. The two HSTC chronologies of
37 broadleaf RW showed nearly the same correlation values and similar patterns with both the June and July precipitation and
38 the June to August SPI_3, with values at approximately +0.5 (#5 and #6 in Fig. 5).

39 — *Climate reconstruction.* The reconstruction of the late summer temperature for the Italian Peninsula was, therefore, based
40 on the HSTC chronology of conifer MXD, while the conifer RW chronology was disregarded due to its low signal stability
41 over time. The reconstructed series based on the scaling approach starts in 1657 and has a minimum sample replication of ten
42 trees since 1713 (Fig. 6A); it reproduces well the variability of the instrumental record and underlines the periods of climatic
43 cooling (and likely also wetter conditions) in the years 1699, 1740, 1814, 1914, 1938. The low-pass filtered series emphasize

1 the mid-length fluctuations and show evidence of periods of temperature underestimations (centered around 1799, 1925 and
2 1952) and of overestimations (around 1846) (Fig. 6B); however, the differences from the instrumental record were always
3 found to be within 1° C for both scaling and regression approaches. The two models tended to have higher values when they
4 were calibrated over the period 1781-1880 and lower values when they were calibrated over the period 1881-1980 (Table 3).
5 The CE statistics showed similar patterns of RE and its values were always positive for both the regression and the scaling
6 model.

7 — *Spatial coherence of the reconstruction.* The spatial coherence of the late summer temperature reconstruction of the Italian
8 Peninsula performed over the Mediterranean region indicated that, for the period of 1901-1980 (defined by the beginning of
9 the CRU TS 4.0 climate series and the end of the MXD series), the reconstructed temperature series matched very well the
10 temperature variability in Italy south of the Po Plane, Sardinia and Sicily and the western Balkan area ($r > 0.6$). Correlations
11 above 0.4 were still found throughout the Alpine arc, the central Balkan, western Anatolia, as well as in northwestern
12 Maghreb. (Fig. 7A, 7B). In detail, the reconstructed temperature highly correlated westward up to Sicily and Sardinia, and
13 eastward to the western Balkan area along the Adriatic Sea up to northern Greece, whereas r values were already lower than
14 0.5 in a wide arch including northern Tunisia, southern France, the inner range of the European Alps, Turkey and southern
15 Anatolia. The reconstructed AS temperature series significantly correlated also with mean AS precipitation, especially in a
16 wide belt between 35° and 50° N of latitude centered over Croatia (negative correlations, below -0.6) and the Balkan region
17 up to the Black Sea. For Italy, correlations above 0.4 were found in the southern portion of the Peninsula, whereas weaker
18 correlations were found westward up to the eastern Pyrenees and northern Maghreb. Positive correlations, above 0.3, were
19 found in a belt in northern Europe at approximately 55° N of latitude, centered over Ireland, Scotland and Wales, and up to
20 Denmark and the southern Scandinavian Peninsula (Fig. 7C, 7D).

21 4 Discussion

22 The climate signals recorded in the multispecies and multiproxy tree-ring network from the Italian Peninsula revealed a
23 general coherence with other climate-growth analyses performed in Mediterranean environments. As found in the Pyrenees
24 for a conifer tree-ring network (Büntgen et al., 2010), we found generally strong and coherent signals in MXD, independent
25 of species. In particular, in our record, the late summer temperature was well recorded in MXD chronologies, and the
26 correlations with climate were stable over time. The MXD chronologies were mainly related to temperature; however, we
27 found clear signals of the influence of summer precipitation and droughts. In the Mediterranean area, especially during
28 summer, high temperature is often associated with low precipitation and drought; therefore, when interpreting the
29 temperature reconstructions based on tree-ring MXD in the Mediterranean area, also the associated influence of precipitation
30 and droughts on MXD should be taken in account. The SPI, which was used here to represent drought conditions, was found
31 to have higher correlations with both MXD and RW for the index calculated at the timescales of 2 and mainly of 3 months,
32 whereas lower correlations were found at lower (1 month) and higher (6, 9 and 12 months) timescales. Thus, trees respond to
33 the drought signal at this time scale, which reflects soil moisture droughts in the root zone (the SPI_3 is also the index used
34 for modeling agricultural droughts, see e.g., WMO, 2012). On the contrary, trees apparently do not respond strongly to the
35 signal of hydrological droughts at the catchment level (SPI at timescales of above 6 months).

36 The reconstructed series of the late summer temperatures for the Italian Peninsula were shown to have a strong coherence
37 with the instrumental record and with both the reconstruction of AS temperature proposed by Trouet (2014) for the
38 northeastern Mediterranean-Balkan region, and of JAS temperature proposed by Klesse et al. (2015), (Fig. 6C and Table 4).
39 The three reconstructions are highly consistent, and the reconstruction of Trouet (2014) also includes the sites used in this
40 paper. However, there are some differences between the Trouet's (2014) reconstruction and the one presented here: our
41 reconstructed AS temperature in the Italian Peninsula tends to generally show less negative fluctuations over time than the
42 reconstruction from the Balkan area. While common periods of climatic cooling were recorded in both areas in 1741 and

1 1814, similar events were seen in 1913 and in 1977 **only** in the Balkan area. Interestingly, the periods of the larger
2 differences between the reconstructed AS temperature and the instrumental record (around 1799, 1846, 1925 and 1952) are
3 also those with strong coherence between the two reconstructions, suggesting a regional consistency in the responses to
4 climate, possibly facilitated by similar precipitation patterns in the two regions during late summer. We also compared all
5 these tree-ring based temperature reconstructions (of AS and JAS) with the summer (JJA) temperature gridded dataset of
6 Luterbacher et al. (2004) (based on proxy, documentary, and instrumental data), for the gridpoints containing our MXD sites
7 and over the common period covered by instrumental data from Italy used in the present work, i.e. since 1763 (Online
8 Material 1). Both the instrumental data for Italy and the proxy-based reconstructions **showed** a good coherence with
9 Luterbacher et al. (2004) at the decadal scale, however in the 1790-1810 period they **showed** opposite trends (with generally
10 lower temperatures than in Luterbacher et al. (2004)) and more marked negative fluctuations in the 1810s.

11 **Contrary to what was found in our reconstruction and in the northeastern Mediterranean,** another late summer temperature
12 reconstruction from Corsica, based on tree-ring stable carbon isotopes (Szymczak et al., 2012), shows periods of high
13 temperature at the end of 1600 **and** beginning of 1700 and a very slight cooling during the 1810s, probably **owing** to the
14 effect of the surrounding seas.

15 An important factor influencing the tree-ring MXD is volcanism, especially in correspondence of highly explosive eruptions
16 that can change the intensity of the incoming solar radiation and that are able to change circulation patterns and cool the
17 climate at hemispheric to global scale (e.g., Briffa et al., 1998). The largest explosive eruptions (Volcanic Explosivity Index
18 ≥ 6 ; Siebert et al., 2011) correspond to local minimum densities in the tree rings (Fig. 6C and 6D), and some of them are well
19 known **to be associated with** years of famine and low crop yields. The year 1699 and the proceeding decades are known for
20 being **years of** recurrent explosive eruptions in Iceland and Indonesia (Le Roy Ladurie, 2004), inducing great famines around
21 Europe and North America (Mitchison, 2002). The 1809 eruption of **unknown** source (Guevara-Murua et al., 2014) and the
22 1815 eruption of Mount Tambora induced a decade of very low summer temperature and high precipitation (Luterbacher and
23 Pfister, 2015). This was the coldest decade of the so called Little Ice Age (Lamb, 1995), corresponding also to glacier
24 advance phases in the Alps, that reached their first maximum extent of the Holocene (the second and last, **was** around 1850;
25 e.g., Matthews and Briffa, 2005). **Eruptions of Mount Krakatoa in 1883 and of Novarupta (Aleutian Range) in 1912**
26 correspond to local minima in the MXD. But a straightforward correspondence between minimum values of MXD densities
27 and large eruption is lacking: some differences at regional scale with respect to global scale may occur **owing** to local
28 circulation patterns **and/or** the presence of seas, as it is the case of the 1783 Grímsvötn Volcano eruption (Iceland), that
29 corresponds to unexpected high MXD densities in tree rings from the Mediterranean area (Fig. 6) but not at the global scale
30 (see Fig. 1 in Briffa et al., 1998), or the local minimums of MXD density of 1740 and 1938 found in this paper that are not
31 linked to any particular large eruption.

32 The Apennines and the European Alps often show similar annual changes in precipitation amounts. However, in some
33 periods, they show opposite decadal trends, such as after 1830, when precipitation was increasing in **northern** Italy but
34 decreasing in the South, and after 2000, when the opposite behavior was observed (Brunetti et al., 2006). In the Italian
35 Peninsula, the summer (JJA) and the autumn (SON) precipitation in 1835-1845 showed local minimum values in the
36 instrumental record, likely inducing higher densities in the tree-ring latewood and, therefore, overestimations in model
37 temperature values (Fig. 6B). Moreover, uncertainties between the instrumental records and MXD may rise given that trees
38 do not respond linearly to high temperatures, resulting in a divergence between climatological and MXD records (e.g., for
39 the Alps and Europe, Battipaglia et al., 2010). As found in this study, MXD is influenced by both late-summer temperature
40 and summer precipitation and drought. In the Mediterranean, these variables are usually negatively correlated. Therefore, in
41 some periods, a given value of MXD could have been caused either by temperature and less by drought or vice versa. Of the
42 considered explanatory environmental variables, it is especially the latitudinal regime of summer precipitation that
43 modulates the MXD sensitivity to AS temperature and to summer drought (Fig. 4A): sites **in northern Italy** (more mesic and

1 at lower elevation) show stronger climate signals than sites in the southern areas (more xeric and at higher elevation). In
2 addition to the stronger AS temperature influence on MXD in the northern chronologies, the effect of summer
3 precipitation/drought becomes equally stronger at the southern sites. MXD sites from southern Italy present a markedly
4 lower SF than sites from central-northern Apennines. Considering the responses related to the type of species that in our
5 dataset the influence of AS temperature on MXD in *A. alba* is more affected by summer precipitation amounts than in *P.*
6 *lucodermis* and *P. nigra*. On the other hand, the influence of summer drought on MXD in pines is more affected by elevation.
7
8 Climatic signals recorded in RW tree-ring chronologies of conifers and broadleaves showed fewer clear common patterns in
9 their correlations with climate variables than conifer MXD, although some climatic signals, which were valuable for climate
10 reconstructions and for understanding climate impacts on tree-ring growth, were detected. In our records, the summer
11 drought signal was clearly recorded at all broadleaf sites (Fig. 3C''), with moist periods (low recurrence of drought, i.e., high
12 SPI_3 values) positively affecting tree-ring growth. The drought signal (as well as the precipitation signal) was fairly stable
13 over time (#6 and #5 in Fig. 5), suggesting the possibility for climate drought (and precipitation) reconstructions in the
14 Italian Peninsula with the availability of longer dendrochronological series. Differently from Levanič et al. (2015), we did
15 not find a stable signal in conifer RW associated with the temperature signal, even though our correlations are related only to
16 August₁ temperatures (#4 in Fig. 5). The signal of previous August temperatures recorded in conifer chronologies (Fig. 3A')
17 is too much variable through time to allow for a reconstruction (Fig. 5). Here, the change in sensitivity is probably related to
18 the negative effect of droughts in summer and autumn (June to October) prior to growth (see SPI_3 correlations; Fig. 3C').
19 The question of the temporal stability of climate-growth relationships is sometimes underestimated in climate
20 reconstructions, even though changes of climate signals over time have been identified in the Mediterranean region
21 (Lebourgeois et al., 2012; Castagneri et al., 2014) and in the European Alps (Leonelli et al., 2009; Coppola et al., 2012).
22 Tree-ring growth may be affected also by large-scale climate variability, such as the North Atlantic Oscillation (NAO), the
23 prominent mode of atmospheric circulation in the North Atlantic that affects temperature and precipitation patterns in Europe
24 (D'Arrigo et al., 1993; Cook et al., 2002). In the eastern Mediterranean region, a teleconnection with summer climate
25 conditions in the British Isles has been found in a summer temperature reconstruction for Bulgaria (Trouet et al., 2012),
26 where tree-ring growth patterns are strongly linked to drought conditions. For Greece and the region eastward (Klesse et al.,
27 2015), a prominent dipole pattern of summer NAO was found, whereas in Italy a major effect on tree growth was found for
28 winter NAO, that correlates negatively with winter precipitation, that in turn determines soil moisture during the growing
29 season (Piovesan and Schirone, 2000). Temporal instabilities of tree growth with climatic variables may be linked to several
30 environmental and physiological factors that may influence tree growth processes and tree-ring sensitivities to climate, such
31 as the still-debated fertilization effect due to increasing CO₂ concentration in the atmosphere (e.g., Brienen et al., 2012). On
32 the other hand, biomass production and tree growth in Mediterranean forests seem to be linked to nutrient availability and
33 environmental constraints rather than to the availability of CO₂ (e.g., Jacoby and D'Arrigo, 1997; Körner, 2003; Palacio et
34 al., 2013). Local low-energy geomorphological processes such as sheetfloods (e.g., Pelfini et al., 2006) may impact tree-ring
35 growth as well as the presence of an active volcano and its direct influence on local climate and atmospheric conditions
36 (such as the Vesuvio Volcano, Battipaglia et al., 2007, or the Etna Volcano, Sailer et al., 2017), or air/soil pollution linked to
37 SO₂, NO₂, or O₃ depositions and dust depositions from industrial plants or mines (in central Europe; Elling et al., 2009, Kern
38 et al., 2009; Sensula et al., 2015): all these environmental factors may lower the tree-ring sensitivity to climate. Emissions
39 from car traffic may also alter the tree-ring stable isotope signals and the related climatic signals (Saurer et al., 2004;
40 Leonelli et al., 2012). The species-specific physiological responses of tree growth to climate variability may be nonlinear
41 when high summer temperatures and low soil moistures exceed specific physiological thresholds, and can interrupt tree-ring
42 growth during the growing season in Mediterranean climates (Cherubini et al., 2003). In terms of ecological factors, the
43 recurrent attacks of defoliator insects (e.g., the pine processionary moth; Hódar et al., 2003), the occurrence of forest fires

1 (e.g., San-Miguel-Ayanz et al., 2013) or herbivory grazing and land abandonment (Herrero et al., 2011; Camarero and
2 Gutiérrez, 2004) may influence vegetation dynamics and tree growth in Mediterranean forests, thus potentially introducing
3 non-climatic effects into the chronologies.

4
5 Our reconstruction of the late summer temperature based on conifer MXD shows a clear stable climatic signal over time, and
6 we could define the spatial coherence of the temperature reconstruction, thus allowing for the determination of the regions
7 that could be included to extend the reconstruction further back in time. The late-summer temperature reconstruction of
8 Trouet (2014) is more appropriate for the region around the southern and inner Balkans; our reconstruction is the first fully
9 coherent late summer temperature reconstruction for Mediterranean Italy, extending in a west-east direction from Sardinia
10 and Sicily to the Western Balkan area. As also evidenced by the site-level analysis, MXD depends also on precipitation and
11 drought (Fig. 3B and 3C), especially in southern sites: our late-summer temperature reconstruction negatively correlates also
12 with late summer precipitation, more in southern than in the central and northern Italian Peninsula, in the whole Balkan
13 region up to the Black Sea, and especially in a region centered over Croatia. By contrast, it is positively correlate with
14 precipitation in Ireland and Scotland and southern Scandinavia. This spatial approach allows for the definition of areas
15 responding to climatic forcing in homogenous ways, which may also help predict the forest response to future climate
16 change in the Mediterranean region.

17 5 Conclusion

18 The climate sensitivity analysis of a multispecies RW and MXD tree-ring network from the Italian Peninsula reveals that
19 conifer MXD chronologies record a strong and stable signal of late summer temperatures and, to a lesser extent, of summer
20 precipitation and drought. In contrast, the signals recorded by both conifer and broadleaf RW chronologies are less stable
21 over time but are still linked to the summer climates of the year prior to growth (conifer) and the year of growth
22 (broadleaves). The MXD sensitivity to AS temperature and to summer drought is mainly driven by the latitudinal gradient of
23 summer precipitation amounts, with sites in northern areas (above 42° N, all silver fir sites, at lower altitudes) showing
24 stronger climate signals than sites in the South (below 42°N, mainly *P. leucodermis* and silver fir sites at higher altitudes).

25 The reconstruction of the late summer temperatures over the past 300 yr (up to 1980), based on the conifer MXD
26 chronologies, shows a strong coherence with the reconstruction performed by Trouet (2014) for the northeastern
27 Mediterranean-Balkan region and by Klesse et al. (2015) for Greece and the eastward region. With respect to the former
28 reconstruction, however, the temperatures reconstructed in our study show less negative fluctuations during the last century,
29 likely because all of our sites are located along the Italian Peninsula and are relatively close to the sea. According to our
30 reconstruction, 1699, 1740, 1814, 1914, and 1938 were years of particularly low late summer temperatures over the study
31 region (with some of them linked to large volcanic eruptions affecting climate at the global scale), whereas the highest
32 temperature was found in 1945. The late-summer temperature reconstruction proposed here is representative of a wide area
33 covering the Italian Peninsula, Sardinia, Sicily and the Balkan area close to the Adriatic Sea. These areas could be considered
34 to further enhance the regional reconstruction discussed here. Moreover, this reconstruction is correlated also with late-
35 summer precipitation in the central Mediterranean and the Balkan region, thus further helping in better assessing climate
36 change impacts on forests in homogenous areas within the Mediterranean climate change hot spot.

37
38 **Data availability.** Data will be available in the Online Material 2.

39
40 **Competing interests.** The authors declare that they have no conflict of interest.

41
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Table 1: References for all the dendrochronological data used in this research, information on site locations, types of parameter used at each site and the tree species. Sites are ordered along a decreasing latitudinal gradient, after differentiating between conifers and broadleaves (dotted line).

Database information and site location								Type of tree-ring parameter			
Dataset name	Database Source	Original contributor	Bibliographic reference	Location Name	Latitude N	Longitude E	Elevation (m a.s.l.)	RW chr.	RW series	MXD chr.	Species
ITRDBITAL017	ITRDB	Ori, G.G.	https://www.ncdc.noaa.gov/paleo/study/4079	Monte Cantiere	44° 16' 48"	10° 48' 00"	800	x			<i>Pinus sp.</i>
ITRDBITAL009	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4301	Abetone	44° 07' 12"	10° 42' 00"	1400		x	x	<i>Abies alba</i>
ITRDBITAL004	ITRDB	Biondi, F.	https://www.ncdc.noaa.gov/paleo/study/2753	Campolino	44° 06' 45"	10° 39' 44"	1650		x		<i>Picea abies</i>
ITRDBITAL008	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4540	Mount Falterona	43° 52' 12"	11° 40' 12"	1450	x		x	<i>Abies alba</i>
ITRDBITAL003	ITRDB	Biondi, F.	https://www.ncdc.noaa.gov/paleo/study/2760	Pineta San Rossore	43° 43' 12"	10° 18' 00"	5	x			<i>Pinus pinea</i>
ITRDBITAL022	ITRDB	Becker, B.	https://www.ncdc.noaa.gov/paleo/study/2706	Pratomagno Bibbiena - Appennini	43° 40' 12"	11° 46' 12"	1050		x		<i>Abies sp.</i>
ITRDBITAL012	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4374	Ceppo Bosque di Martese	42° 40' 48"	13° 25' 48"	1700	x		x	<i>Abies alba</i>
Abies-Abeti-Soprani	UNIMOL			Colle Canaliccio-Abeti Soprani	41° 51' 40"	14° 17' 51"	1350		x		<i>Abies alba</i>
ITRDBITAL016	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4536	Monte Mattone	41° 46' 48"	14° 01' 48"	1550	x		x	<i>Pinus nigra</i>
ITRDBITAL001	ITRDB	Biondi, F.	https://www.ncdc.noaa.gov/paleo/study/2752	Camosciara Mt. Amaro	41° 46' 12"	13° 49' 12"	1550	x			<i>Pinus nigra</i>
ITRDBITAL002	ITRDB	Biondi, F.	https://www.ncdc.noaa.gov/paleo/study/2759	Parco del Circeo	41° 19' 48"	13° 03' 02"	5	x			<i>Pinus pinea</i>
AAIBA	UNIBAS			Ruoti (PZ)	40° 42' 04"	15° 43' 43"	925		x		<i>Abies alba</i>
ITRDBITAL011	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4541	Mount Pollino	39° 54' 00"	16° 12' 00"	1720	x		x	<i>Abies alba</i>
ITRDBITAL015	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4644	Sierra de Crispo	39° 54' 00"	16° 13' 48"	2000	x		x	<i>Pinus leucodermis</i>
ITRDBITAL010	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4420	Gambarie Aspromonte	38° 10' 12"	15° 55' 12"	1850	x		x	<i>Abies alba</i>
ITRDBITAL013	ITRDB	Schweingruber, F.H.	https://www.ncdc.noaa.gov/paleo/study/4304	Aetna Linguaglossa	37° 46' 48"	15° 03' 00"	1800	x		x	<i>Pinus nigra</i>
ITRDBITAL019	ITRDB	Nola, P.	https://www.ncdc.noaa.gov/paleo/study/4042	Corte Brugnatella	44° 43' 12"	09° 19' 12"	900	x			<i>Quercus robur</i>
Fagus-Parco-Abruzzo	UNIMOL			Val Cervara	41° 49' 00"	13° 43' 00"	1780		x		<i>Fagus sylvatica</i>
Fagus-Gargano	UNIMOL			Parco Nazionale del Gargano Riserva Pavari	41° 49' 00"	16° 00' 00"	775		x		<i>Fagus sylvatica</i>
Fagus-Montedimezzo	UNIMOL			Riserva MaB Unesco Collemeluccio-Montedimezzo	41° 45' 00"	14° 12' 00"	1100	x			<i>Fagus sylvatica</i>
Cervialto-FASY	UNINA2			Monti Picentini	40° 50' 23"	15° 10' 03"	800		x		<i>Fagus sylvatica</i>
Fagus-Cliento	UNIMOL			Parco Nazionale del Cliento Ottati	40° 28' 00"	15° 24' 00"	1130		x		<i>Fagus sylvatica</i>
QCIBG	UNIBAS			Gorgoglione (MT)	40° 23' 09"	16° 10' 04"	820		x		<i>Quercus cerris</i>
QFIMP1	UNIBAS			San Paolo Albanese (PZ)	40° 01' 20"	16° 20' 26"	1050	x			<i>Quercus frainetto</i>
QFIMP2	UNIBAS			Oriolo (CS)	40° 00' 10"	16° 23' 29"	960	x			<i>Quercus frainetto</i>
Fagus-Sila	UNIMOL			Parco Sila	39° 08' 00"	16° 40' 00"	1680		x		<i>Fagus sylvatica</i>
Fagus-Parco-Aspromonte	UNIMOL			Aspromonte	38° 11' 00"	15° 52' 00"	1560		x		<i>Fagus sylvatica</i>
							1235 mean elevation	15 sites	12 sites	8 sites	

1 **Table 2:** Main characteristics of the chronologies used in this research, separating RW (comprised of both broadleaf and conifer
2 species) and MXD (only conifer species). For each site and parameter, the total number of series available and the number of
3 series showing a correlation value $0.2 < r < 0.3$ with the respective master chronology is reported. Grey-shaded areas depict
4 values that do not exceed the fixed thresholds of $MIC > 0.3$, $EPS > 0.7$ and a number of series > 10 , determining the exclusion of
5 the chronology from further analyses. Sites ordered as in Table 1.

6 a = Mean Interseries Correlation of raw series, calculated using the maximum period available at each site.

7 b = Expressed Population signal of indexed series in the common period of 1880-1980.

8 * series up to 80 yr included.

9 ** chronology built with less than 10 series (good EPS).

10 *** common period with later Start date or earlier End date.

11 **** sites without chronology [...] are not included in the computation.

1

Dataset name	RW series characteristics							MXD series characteristics on the maximum period available						
	Start date	End date	Time span	MIC ^a	EPS ^b	# series	# series 0.2 < r < 0.3 vs. master	Start date	End date	Time span	MIC1	EPS2	# series	# series 0.2 < r < 0.3 vs. master
ITRDBITAL017	1856	1989	134	0.43	0.76	14	0	-	-	-	-	-	-	-
ITRDBITAL009	[1846]	[1980]	[135]	[0.73]	[0.66]	13	0	1846	1980	135	0.76	0.86	21	0
ITRDBITAL004	[1836]	[1988]	[153]	[0.51]	[0.49]	11	0	-	-	-	-	-	-	-
ITRDBITAL008	1827	1980	154	0.62	0.70	12	0	1827	1980	154	0.66	0.87	12	0
ITRDBITAL003*; **	1861	1988	128	0.51	0.72	9	0	-	-	-	-	-	-	-
ITRDBITAL022***	[1539]	[1972]	[434]	[0.45]	[0.67]	6	1	-	-	-	-	-	-	-
ITRDBITAL012	1654	1980	327	0.57	0.85	26	0	1654	1980	327	0.59	0.91	25	0
Abies-Abeti- Soprani*	[1838]	[2005]	[168]	[0.53]	[0.50]	11	0	-	-	-	-	-	-	-
ITRDBITAL016	1844	1980	137	0.54	0.84	17	0	1844	1980	137	0.43	0.75	15	0
ITRDBITAL001	1750	1987	238	0.52	0.77	16	0	-	-	-	-	-	-	-
ITRDBITAL002*	1878	1988	111	0.51	0.72	16	0	-	-	-	-	-	-	-
AAIBA*	[1866]	[2007]	[142]	[0.51]	[0.55]	13	0	-	-	-	-	-	-	-
ITRDBITAL011	1800	1980	181	0.58	0.85	20	0	1800	1980	181	0.54	0.84	18	0
ITRDBITAL015	1415	1980	566	0.58	0.95	22	0	1441	1980	540	0.50	0.76	21	0
ITRDBITAL010	1790	1980	191	0.53	0.76	19	0	1790	1980	191	0.50	0.85	18	0
ITRDBITAL013	1773	1980	208	0.57	0.88	20	0	1795	1980	186	0.44	0.78	18	0
ITRDBITAL019	1779	1989	211	0.54	0.82	16	0	-	-	-	-	-	-	-
Fagus-Parco- Abruzzo	[1716]	[2008]	[293]	[0.36]	[0.73]	3	0	-	-	-	-	-	-	-
Fagus-Gargano	[1821]	[2009]	[189]	[0.23]	[0.42]	3	3	-	-	-	-	-	-	-
Fagus- Monte di mezzo Cervialto-FASY	1844	2005	162	0.67	0.85	15	0	-	-	-	-	-	-	-
Fagus-Ciento	[1837]	[2007]	[171]	[0.41]	[0.26]	7	1	-	-	-	-	-	-	-
QCBCG+; ***	[1897]	[2013]	[117]	[0.60]	[0.66]	9	0	-	-	-	-	-	-	-
QFIMP1	1851	2013	163	0.50	0.78	34	0	-	-	-	-	-	-	-
QFIMP2	1854	2013	160	0.55	0.79	34	0	-	-	-	-	-	-	-
Fagus-Sila	[1854]	[2009]	[156]	[0.30]	[0.21]	4	3	-	-	-	-	-	-	-
Fagus-Parco- Aspromonte	[1874]	[2009]	[136]	[0.27]	[-0.42]	5	2	-	-	-	-	-	-	-
TOTAL	1785****	1989****	205****	0.55****	0.80****	385	10	1750	1980	231	0.55	0.83	148	0
	mean	mean	mean	mean r	mean EPS	sum (all sites)	sum (all sites)	mean	mean	mean	mean r	mean EPS	sum	sum (all sites)

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1 **Table 3:** Reconstruction statistics computed for both regressions and scaling over the inverted subperiods of calibration and
 2 verification. RE = Reduction of error; CE = Coefficient of efficiency.
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		R ²	Regression		Scaling		Full period R ²
			RE	CE	RE	CE	
Calib.	1781-1880	0.383					
Verif	1881-1980		0.484	0.305	0.533	0.371	
<hr/>							
Calib.	1881-1980	0.506					0.435
Verif	1781-1880		0.409	0.223	0.278	0.060	

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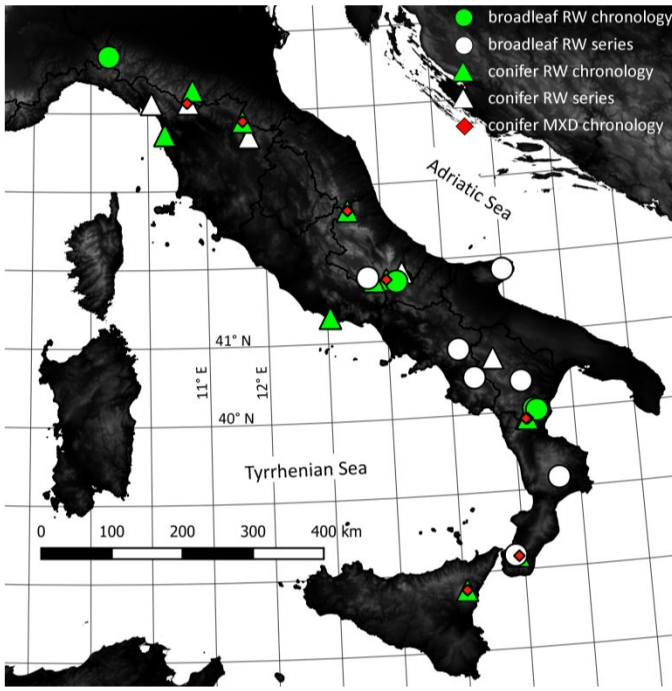
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Table 4: Intercorrelation between reconstructed temperature series of late summer (AS; Trouet, 2014; Leonelli et al., this study) and of summer (JAS; Klesse et al., 2015) based on tree-ring MXD in the study region. The correlation coefficients were calculated over the common period 1714-1980, for both z-scores and 20 yr filtered series.

	AS Temp - TROUET_MXD		AS Temp - LEONELLI_MXD_scaling	
	z-scores	20 yr gaussian	z-scores	20 yr gaussian
AS Temp - LEONELLI_MXD_scaling	0.85	0.74	-	-
JAS Temp - KLESSE_MXD	0.75	0.69	0.58	0.65

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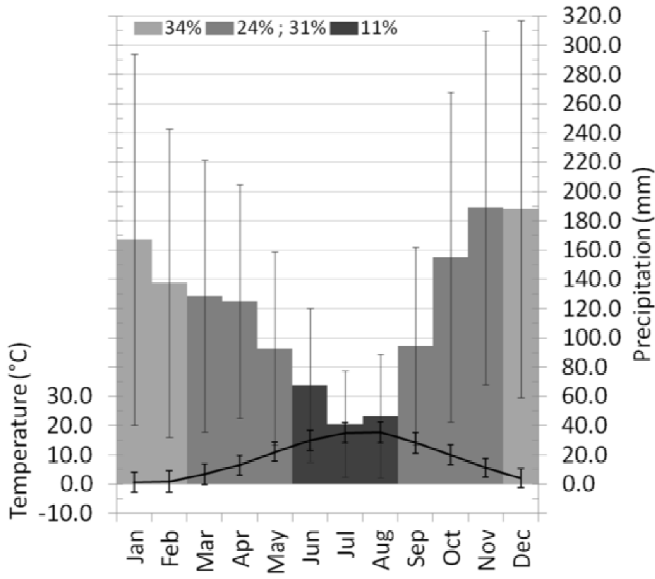


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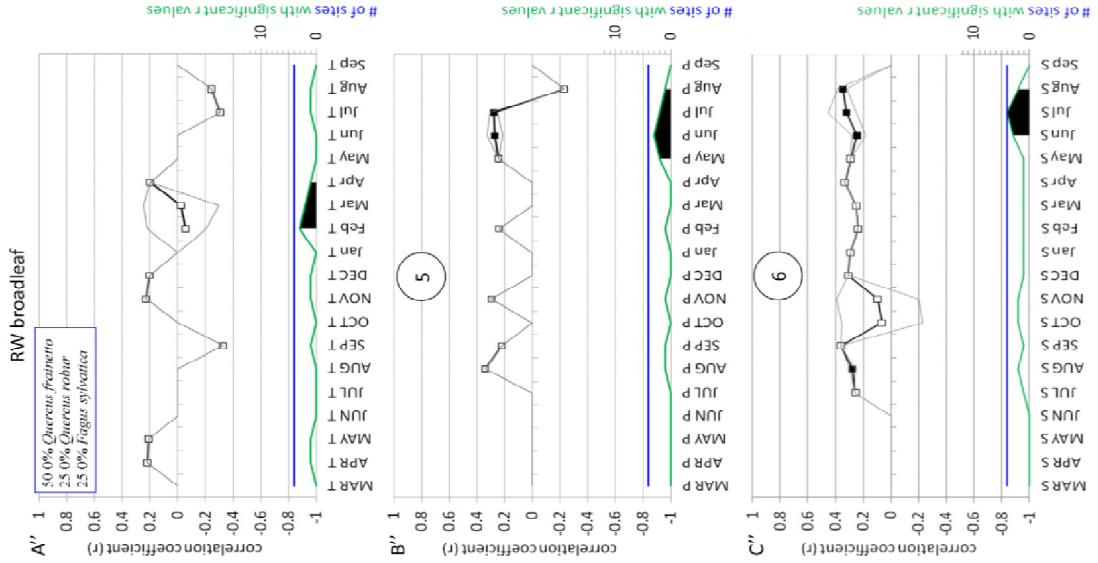
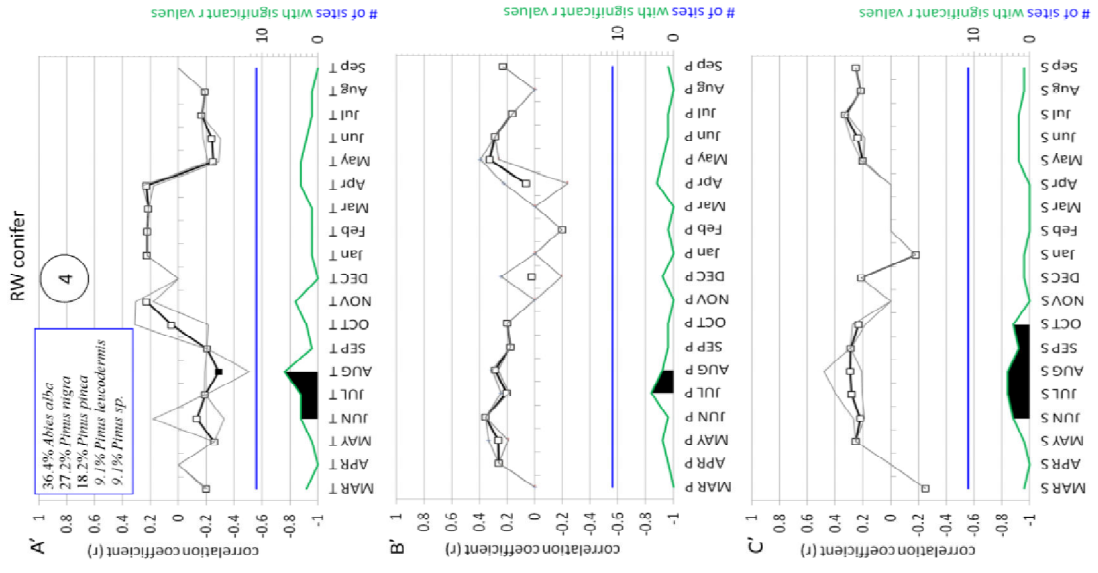
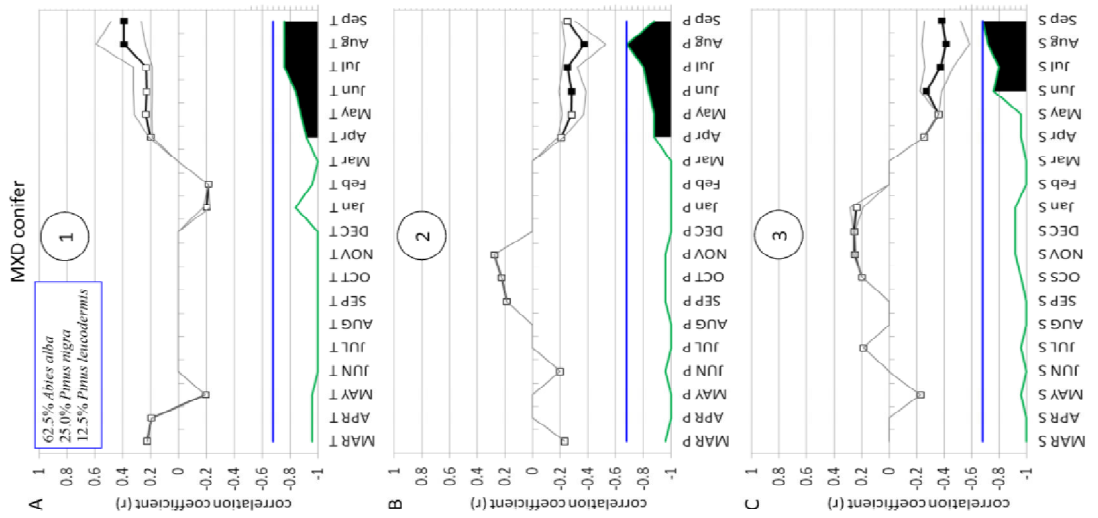
4 **Figure 1:** Distribution of the tree-ring sites from central and southern Italy available to the NEXTDATA project and used in
5 this study. Sites were subdivided by the type of tree (conifer or broadleaf), the type of parameter (RW or MXD) and the
6 type of data used (site chronology or only tree-ring series).
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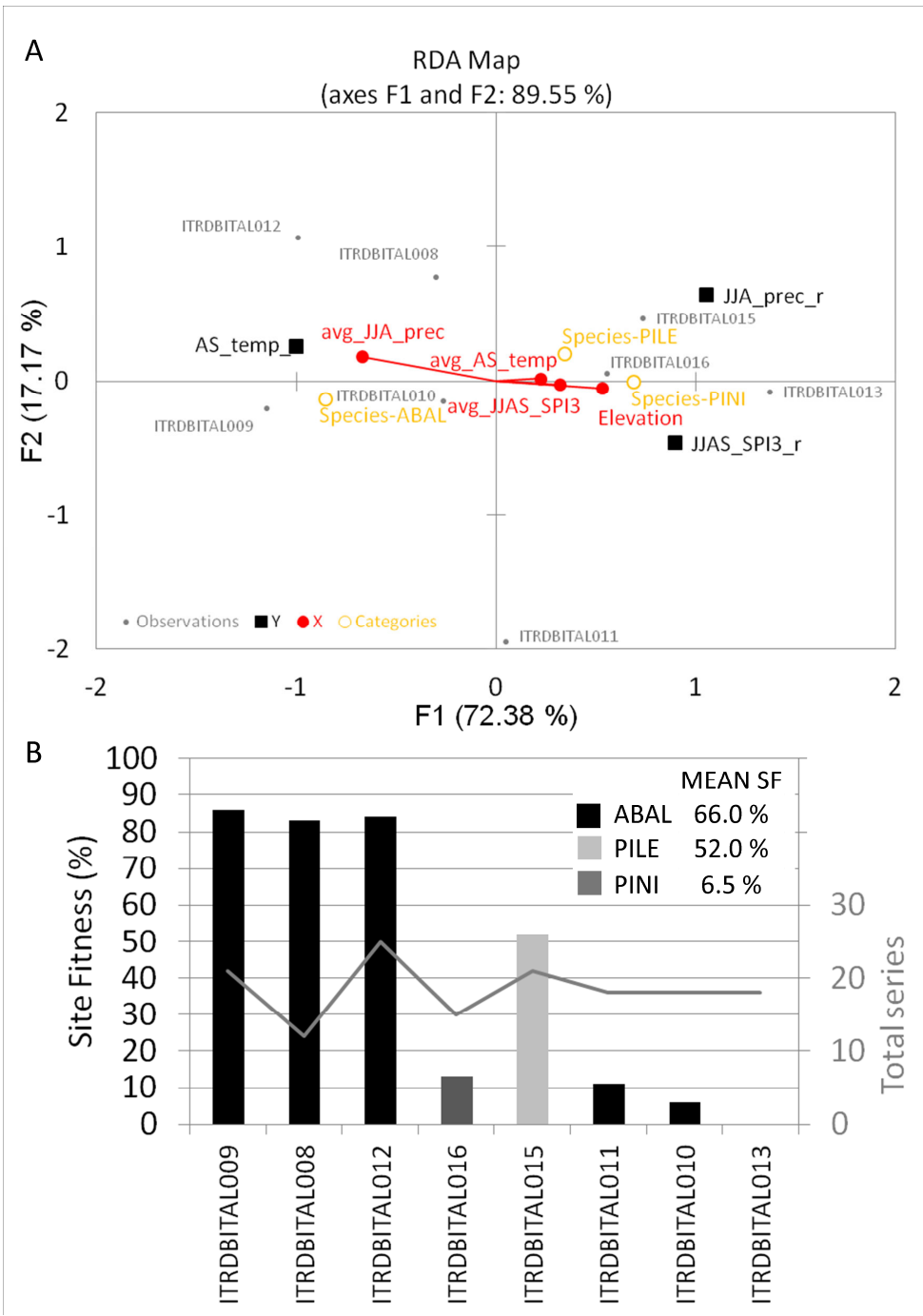


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3 **Figure 2:** Monthly mean temperatures and precipitations over the period of 1880-2014 for all sites considered in this study.
4 For both temperature and precipitation, the error bars indicate one standard deviation; for precipitation, the seasonal
5 percentages of precipitation with respect to the mean annual value (= 1433 mm) are reported.



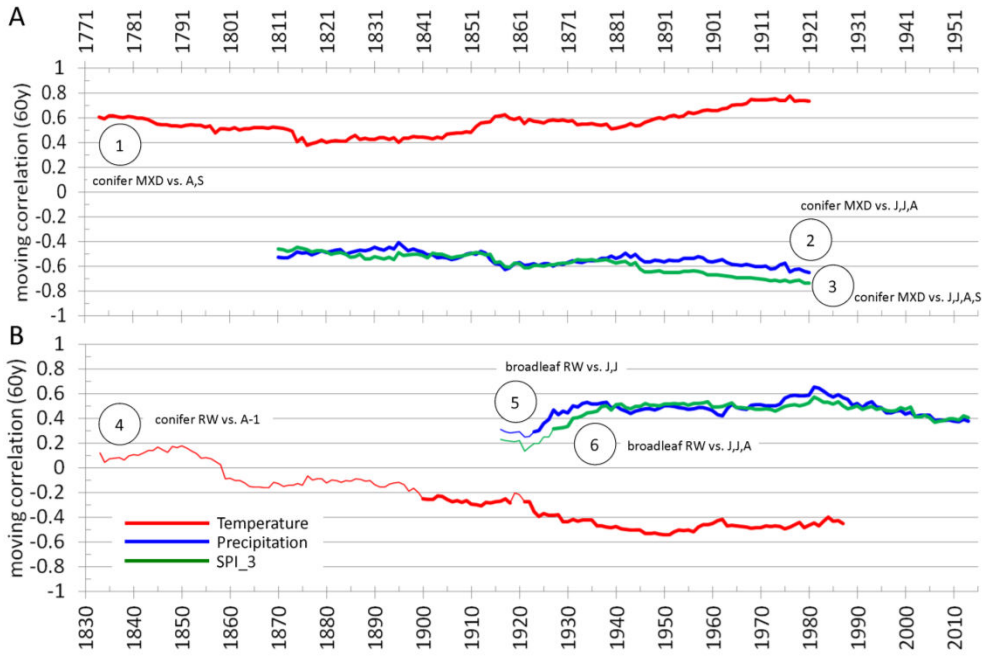
1 **Figure 3:** Bootstrapped correlation analysis performed over the common period of 1880-1980, considering chronologies of
2 conifer MXD (left column; 3A, 3B and 3C), of conifer RW (center; 3A', 3B' and 3C') and of broadleaf RW (right; 3A'',
3 3B'' and 3C'') vs. monthly temperature (A letters, first row), precipitation (B letters) and SPI_3 (C letters) from March of
4 the year prior to growth to September of the year of growth. In A, A' and A'' the percentages of the species composing the
5 pool for each site used for the analysis is reported.
6 Means of statistically significant ($p < 0.05$) correlation coefficient values (r) are depicted with squares, whereas maximum
7 and minimum significant r values are indicated with grey lines; the blue lines depict the total number of sites in each
8 comparison and the green lines indicate the total number of sites with statistically significant r values. Black-filled squares
9 are given for those variables that show significant correlation values for at least 50 % of the total sites and have $|\bar{r}| > 0.25$;
10 where both conditions occur, a circled number in the plot is given and the comparisons are selected for the following
11 moving correlation analysis (Fig. 5). In each plot the climate variables with the highest number of sites with significant r
12 values and nearby variables showing up to $\frac{1}{4}$ of this number are depicted with a black area.



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Figure 4: Ordination biplot (RDA analysis) of climate-growth relationships (response variables, Y) and environmental settings (explanatory variables X: elevation and climatic averages over the period 1880-1980) (4A). Site fitness evaluated on single indexed series included in the MXD HSTC chronology (SF; Leonelli et al., 2016) and total series per site (grey line) (4B). Sites are ordered with decreasing latitude along the x-axis. Mean SF values for each species are also reported. ABAL = *Abies alba*; PILE = *Pinus lucodermis*; PINI = *Pinus nigra*.

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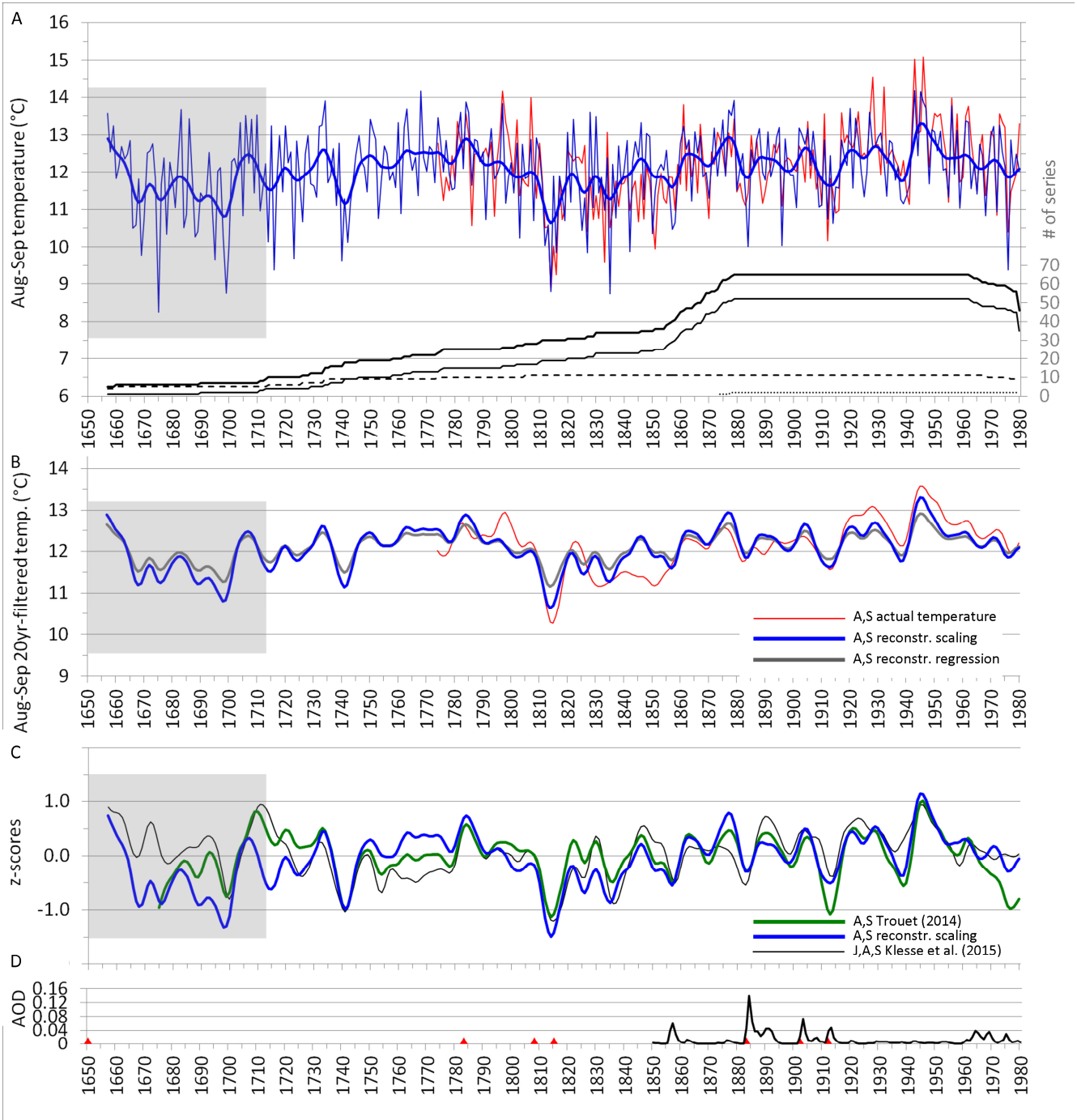


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3 **Figure 5:** Bootstrapped moving correlation analysis with a 60 yr time window, performed over the maximum period
4 available for the HSTC chronologies and their respective climate variables (temperature, precipitation and SPI_3) selected
5 in the previous analysis (circled numbers as in Fig. 3). The statistically significant values ($p < 0.05$) of r are depicted by bold
6 lines.

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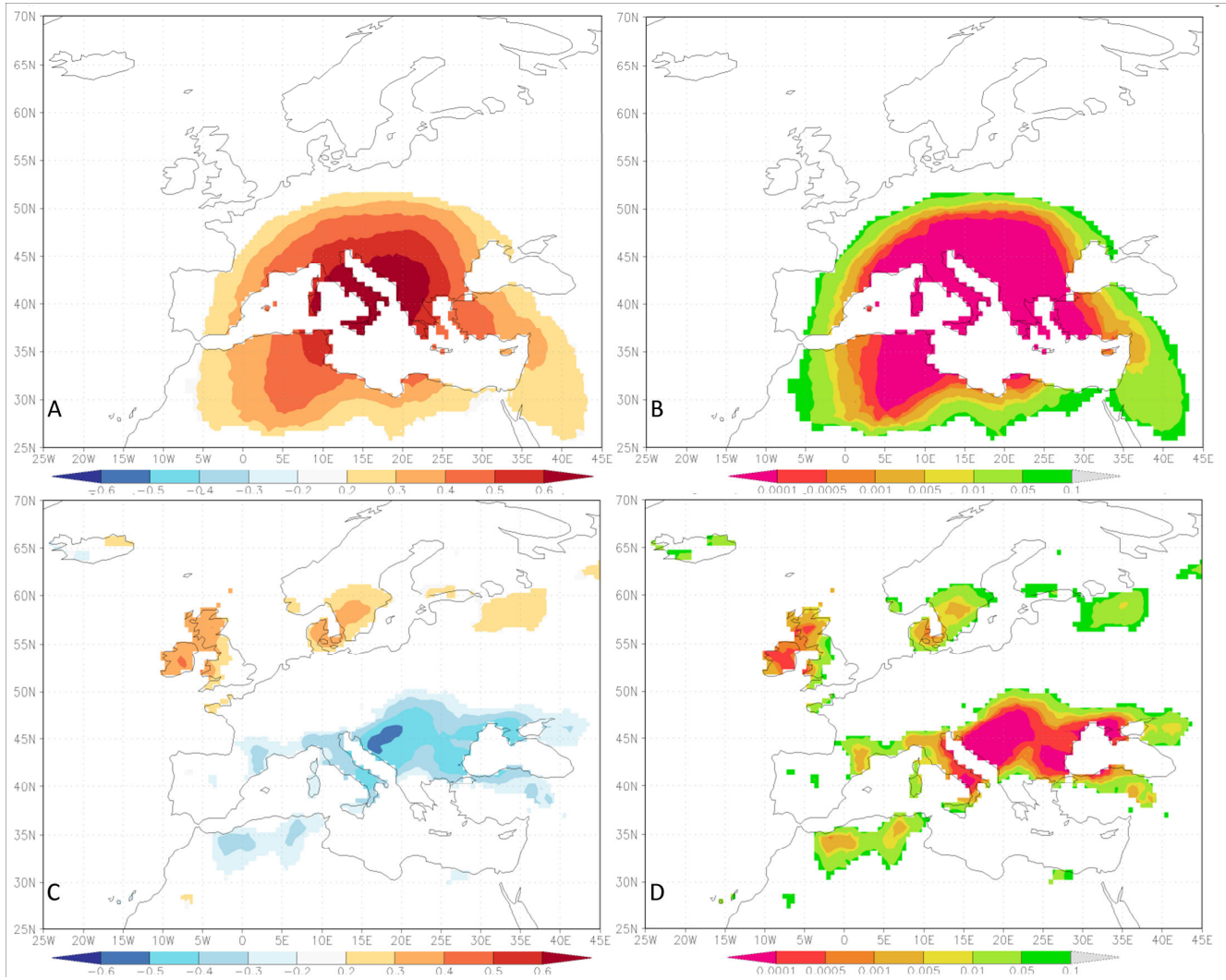
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Figure 6: Reconstruction of late summer (August and September) temperature using the conifer MXD chronology with the scaling approach for the period 1650-1980 (6A). The bold black line indicates the total number of series (composed by a number of *Abies alba* (thin black line), *Pinus leucodermis* (dashed line) and *P. nigra* (dotted line) specimens). The low-pass filtered series with a 20 yr Gaussian smoother for both the reconstructions based on scaling and regression are also depicted (6B). The reconstructions were truncated when there was fewer than 5 trees, and the grey areas in the graphs depict the period where the conifer MXD chronology shows an $EPS < 0.79$ (prior to 1714, less than 10 trees, $EPS > 0.85$ since 1734). A comparison of the reconstructed late summer temperature (this paper) with the ones of Trouet (2014) and Klesse et al. (2015) using z-scores series (calculated over the common period 1714-1980 with $EPS > 0.8$ in all the original chronologies), filtered with a 20 yr Gaussian low-pass filter (6C). At the bottom the annual mean of stratospheric aerosol optical depth (AOD) at 550 nm for the Northern Hemisphere is reported (6D); dataset available at <https://data.giss.nasa.gov/modelforce/strataer/>; site accessed 2017-05-30; the red triangles mark major volcanic eruptions (Volcanic Explosivity Index ≥ 6): in chronological order Kolumbo-Santorini, Grímsvötn, Source unknown, Mount Tambora, Krakatau, Santa María, Novarupta.

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Figure 7: Spatial correlation pattern of the reconstructed late summer temperature (using the MXD chronology from the Italian Peninsula) versus the 0.5° grid CRU TS 4.0 August-September mean temperature (A, B) and mean precipitation (C, D), over the period of 1901-1980. Left side (A, C) Pearson's correlation coefficients, right side (B, D) the associated p values.