The impact of proxy selection strategies on a millennium-long ensemble of hydroclimatic records in Monsoon Asia

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Abstract

Large-scale palaeoclimate reconstructions can be very sensitive to the proxy records they are based on, and hence to the criteria used to select proxy records. Data selection rarely follows objective criteria that are applicable to all types of proxies, including both low- and high-resolution records. Thus, there is a need for a uniform and transparent approach to assess the suitability of input proxy data for a reconstruction. Here, we develop classification criteria that are applicable to multiple proxy types and evaluate different selection strategies using a network of 62 millennium-long terrestrial hydroclimate proxy records from Monsoon Asia. Our results reveal that robust evidence for a coherent climate signal and high dating accuracy are important criteria for benchmarking the suitability of each proxy record. We determine these criteria by reviewing the literature for each record (rather than screening against instrumental data). We show that the proposed selection approach can yield a network with a stronger common signal. By evaluating the uncertainty and centennial variability of composite reconstructions, from differently selected subsets of the proxy network, it appears beneficial to use suitable proxies stemming from different archives, as well as having a dense network of proxy sites. We suggest that future large-scale palaeoclimate reconstructions might be improved by evaluating proxy networks according to the universal categories presented here and, if indicated, removing less suitable records. This will strengthen the climate signal in the final reconstruction, allowing more precise inferences about past climate variability and more robust comparisons with climate model simulations.

Keywords

Holocene; Paleoclimatology; Eastern Asia; Data treatment; Large-scale reconstruction; Low resolution; Expert assessment; Spatial decorrelation length; Multi-proxy

1. Introduction

Our ability to reconstruct the Earth's climatic history and assess the impacts of past climate changes on human history is dependent on identifying and interpreting archives of past climate variability (e.g. Masson-Delmotte et al., 2013; Xoplaki et al., 2016; Ljungqvist, 2017; Xoplaki et al., 2018). The field of palaeoclimatology has advanced over the past decade through the increase of the spatial coverage and density of temperature and hydroclimate proxy records on a regional basis, the development of new multi-proxy reconstruction methodologies as well as the increasing number of quantitative palaeoclimate reconstructions covering the past one to two millennia (Christiansen and Ljungqvist, 2012; Ljungqvist et al., 2012; PAGES2k Consortium, 2013; Neukom et al., 2014; Schneider et al., 2015; Stoffel et al., 2015; Ljungqvist et al., 2016; Luterbacher et al., 2016; Wilson et al., 2016; Xing et al., 2016; PAGES2k Consortium, 2017). With the growing proxy network, significantly different evaluations of past climates can be obtained, depending on individual choices during the proxy selection step (Frank et al., 2010; Smerdon and Pollack, 2016; Christiansen and Ljungqvist, 2017). Despite a common spatial target, authors may impose criteria constraining the number of proxy records by requiring a minimum temporal length and resolution of proxy time-series (Schneider et al., 2015; PAGES2k Consortium, 2017; Esper et al., 2018). Focusing only on a single proxy type can increase homogeneity among records. At the same time, it can accentuate limitations associated with this proxy type and further confine the size of the proxy network. For investigations on hemispheric to global scales, these selection strategies can alter the number of eligible proxy records from below 20 (Schneider et al., 2015) to almost 700 (PAGES2k Consortium, 2013, 2017) to include in large-scale temperature reconstructions.

The difference in the size of proxy networks raises the question whether there is a threshold beyond which the addition of more, but noisier, records is not useful anymore. To answer this question, the strengths and weaknesses of individual records need to be communicated clearly in order to facilitate the selection of palaeoclimate data (Frank et al., 2010; Esper et al., 2016; Christiansen and Ljungqvist, 2017; Esper et al., 2018). Defining objective and universal measures for this purpose is nontrivial.

Large-scale reconstructions often include a screening (e.g. Zhang et al., 2018) and/or weighting (e.g. Cook et al., 2002; Pauling et al., 2003; Luterbacher et al., 2004; Xoplaki et al. 2005; Luterbacher et al., 2016; Wang et al., 2017) of records based on the correlation between proxy and instrumental observations. Although this is arguably the most objective measure it also bears a number of shortcomings. First, the climate signal strength often cannot be determined conclusively, due to short instrumental data, meteorological information that is remote from the proxy location or lower quality of early measurements (Parker, 1994; Moberg et al., 2003; Frank et al., 2007; Dienst et al., 2017). Second, the proxy data often have a limited temporal resolution and terminate in the year of sampling further reducing the degrees of freedom in any calibration approach (e.g. Yao et al., 1996). Third, the quality of the proxy record can change over time. This can be due to changing temporal resolution, increasing age uncertainty (Kaspari et al., 2007; Kuo et al., 2011) or human impact (Liu et al, 2008). Tree-ring records usually have a decreasing replication back in time and thus an increasing uncertainty (Esper et al., 2007; Esper and Frank, 2009; Esper et al., 2016). Likewise, the spatial coverage for documentary data gets sparser in the more distant past (Brázdil et al., 2005, 2018).

The choice of only annually dated proxy records will resolve some of these problems and would, in principle, allow for a relatively robust screening, but with the price of reducing the number of available proxy records further back in time (e.g. Luterbacher et al., 2016; Zhang et al., 2018). Moreover, instrumental data from some regions are much shorter than 100 years. For example, observations at most sites on the Tibetan Plateau did not start before 1950 CE (e.g. Duan et al., 2017). Successful calibration with a short overlapping period depends strongly on the high frequency signal. At these frequencies, annually resolved documentary records and tree-ring chronologies often have a high fidelity while multi-centennial or millennial variability can be underestimated due to discontinuity of data sources (Cook et al., 1995; Brázdil et al., 2005; Dobrovolný et al., 2010; Wetter and Pfister, 2011; Brázdil et al., 2018; Pfister et al., 2018). Although there are different methods to consider or moderate this bias (Esper et al., 2003; Melvin and Briffa, 2008; Glaser and Riemann, 2009), it remains difficult to quantify the extent to which low-frequency variability may be lacking in these records. The combination with records from continuous archives, but with lower temporal resolution (from lake and marine sediments, peat bogs or speleothems), can help to overcome deficits in the low frequency domain while impeding calibration and validation. Additionally, blending annually resolved time-series with records of lower resolution can improve spatial coverage, which is of particular concern for studies targeting hydroclimate (Smerdon et al., 2017). Compared to temperature, precipitation and drought are much more variable across space (Büntgen et al., 2010; Cook et al., 2010), in particular over complex terrain (Feng et al., 2013), and have much shorter correlation decay lengths (Datta et al., 2003; Wan et al., 2013; Ljungqvist et al., 2016). This requires a denser proxy network in combination with a smaller search radius for meteorological stations with long observational time-series. Consequently, there may be less confidence regarding past hydroclimate variability in space and time than for temperature (Büntgen et al., 2010; Bunde et al., 2013; Franke et al., 2013; Masson-Delmotte et al., 2013; Ljungqvist et al., 2016; Smerdon et al., 2017).

In this study, we address the challenge of proxy selection and evaluation in a region rich in documentary and natural proxy records, but with short instrumental data: Monsoon Asia. We analyze hydroclimate variability as the most relevant parameter from a societal perspective in this part of the world and target the entire last millennium (1000–1999 CE). Precipitation and drought variability have been investigated across Eastern Asia for the 1300 - 2000 CE period using the region's dense network of tree-ring chronologies and documentary records (Cook et al., 2010; Feng et al., 2013; Zhang et al. 2015; Shi et al., 2017, 2018). Extending a spatial field reconstruction before 1300 CE will require the inclusion of additional archives and proxy types to maintain a full spatial coverage. Rather than presenting a new quantitative hydroclimate reconstruction, we use alternative proxy selection strategies to filter the noisy network and to evaluate the impact of the proxy network's composition. Our approach overcomes the limitations of a screening based on instrumental data while relying on a combination of metadata analysis and the "expert assessment" of the original authors (Frank et al., 2010; Wilson et al., 2016; Christiansen and Ljungqvist, 2017). The 62 hydroclimate records used in this study stem from lake sediments, speleothems, historical documentary data, tree-rings and ice-cores

(Fig. 1). The variety of archives and proxy types introduces significant differences among individual records regarding the evolution and the characteristics of time-series, which are most likely not only driven by regional hydroclimatic changes, but also indicate varying levels of precision. We hypothesize that the common signal will be stronger among more suitable records than among less suitable ones, and that careful scrutiny and selection of the proxy records based on metadata will, therefore, yield a more robust reconstruction. In order to test this hypothesis, we define suitability measures that can be derived from the individual source publications. We emphasize the reproducibility of the procedure by using criteria that can be transferred to a wide range of palaeoclimate records. We evaluate the reliability of the resulting classification and assess its impact for subsequent proxy selection on regional means. We close by suggesting that the choice between a comprehensive or a selective proxy network should be based on transparent and measurable characteristics.

2. Data and Methods

The proxy records analyzed in this study (Fig. 1, Table 1) have been published in the peer-reviewed literature. If possible the data for the 62 records were obtained from online repositories or, if unavailable, via personal communication with authors and data contributors. All records were originally described as indicative of local variations in hydroclimate. The term hydroclimate incorporates variations in precipitation, moisture, streamflow or drought. Although some of these parameters integrate temperature conditions as well, this generalization was necessary to warrant a sufficiently large network. The region spans 20-50°N and 70-130°E (Fig. 1), which includes areas impacted by the Indian Summer Monsoon, the East Asian Summer Monsoon and the Westerlies that interact with the northern monsoon limit. To preserve multi-decadal to multi-centennial variability during the last millennium, we retrieved only data matching the following criteria: a start date of proxy records before 1001 CE, a minimum temporal resolution of 50 years (at least two data points per century) and one fixed dating point in the last millennium (compare Ljungqvist et al., 2016). The final network consists of 17 lake sediment (excluding pollen), 14 documentary, 13 speleothem, nine tree-ring (including two reconstructions based on tree-ring isotopes), 7 pollen[1] and 2 ice-core records (Fig. 1, Table 1). The proxy types are not homogeneously distributed over the study area. Eastern China is rich in documentary data (e.g. Ge et al., 2008) while moisture sensitive tree-ring records are numerous over the northern fringe of the Tibetan Plateau, where slow growth enables trees to grow particularly old (Yang et al., 2014a). Lake sediments are least regionally confined and can be found all over the study region. With 15 different analyzed parameters – e.g. grainsize (Conroy et al., 2017), $CaCO_3$ content (Li et al., 2004), total organic carbon amount (Xiao et al., 2008) – lake sediments reveal the greatest variety of proxy types within a specific archive.

While the initial selection criteria mentioned above ensure a minimum amount of common climate information in the proxy records, a further screening based on their correlation with local observations is not possible in most cases. Only 10 out of 62 records (two documentary, two speleothems and six tree-ring chronologies) have annual resolution; 40 records have two or less data points per decade. This results in – at best – about 10 degrees of freedom for calibrating records from the Himalayas, the Tibetan Plateau and northwestern China where very few stations were running before the 1950s (Cook et al., 2010; Krusic et al., 2015). In Eastern China, where many instrumental records are longer, the majority of proxy records are based on documentary data. For this archive, a screening is challenging because historical observations were usually replaced by measurements from meteorological stations after their start during the course of the 20th century. Thus, documentary datasets are often complemented using instrumental observations (e.g. Zheng et al., 2006; Zhang et al., 2008) making it impossible to evaluate these data based on the instrumental overlap.

Not all of the 62 records are similarly suitable for reconstructing hydroclimate over the last millennium because the various studies address very different frequency domains from multi-millennial to multi-

[1] Pollen records are usually derived from lake sediments. However, we chose to separate pollen records here, because they represent a large and important group of parameters that can be measured in lake sediments. This classification is in accordance with the one used by NOAA's National Centers for Environmental Information database.

decadal. We acknowledge that all records might be skillful predictors regarding their originally targeted time scale and, therefore, we use the term “suitability” as a measure of relevance for each record in our context. To assess the suitability while avoiding calibration with instrumental data, we defined two categories that address: (1) the dating accuracy (DA), and (2) the evidence for a climate signal (EC) in the original publications. As both measures cannot be directly quantified, we use an ordinal scale with three classes for each category.

(1) The DA is “good” (+1) for documentary records and for natural archives with visually discernible annual layers. Records of “intermediate” (0) DA either offer layer counting or a comprehensive age model that has 5 or more dating points in the correct chronological order (within uncertainties) during the past millennium. “Insufficiently” (−1) dated records do not fulfill these requirements. The estimate is based on the longer sequence, if DA changed within the last millennium, for example due to the fading of laminae (e.g. Paulsen et al., 2003).

(2) There is “good” (+1) EC in the proxy record if the source publication contains a robust calibration against instrumental data. If the temporal resolution is low and/or the instrumental record short, the climatic sensitivity of the proxy needs instead to be described theoretically – ideally confirmed by a monitoring experiment. If the authors present a mechanistic understanding of the relationship between proxy and climate and if the time-series is evaluated with respect to other climate reconstructions from the same region, we grade this as an “intermediate” (0) EC. Studies that only address one of these lines of argument have “insufficient” (−1) EC.

Although a “good” EC again requires a comparison with instrumental data, the category is different from regular quantitative screening approaches in large-scale network evaluations. Longer and/or closer station measurements might have been available to the original authors to verify a climate signal, whereas a standardized computation of correlations with interpolated and infilled observations is more prone to biases.

Time-series with irregularly spaced time-steps need an adjustment to a common time-scale for comparisons. Following the approach of Ljungqvist et al. (2016), records were linearly interpolated to annual resolution. For the analysis of centennial to millennial scale climate signals, records were low-pass filtered with a 100-year cubic spline and a 50 percent frequency cutoff (Cook and Peters, 1981; Bunn, 2010). Climate signals in the range of decades were emphasized by subtracting the low-pass filtered series from the original records and smoothing the remainder with a 20-year spline and 50 percent frequency cutoff. These low- and band-pass filtered time-series with annual time-steps were normalized with respect to the common 1000–1900 CE period and subsequently subsampled in 10- and 50-years intervals to account for the fact that most of the original records were not annually resolved. Subsequent analyses were performed separately with time-series of 10- and 50-years resolution to better capture time-scale dependent behavior (Fig. 2 and 3).

Initial approaches to evaluate the proxy records and their categorization using gridded climate data, such as CRU TS3.10 (Harris et al., 2014) and the Twentieth Century Reanalysis (20CR) (Compo et al., 2011; Slivinski et al., 2019), failed due to insufficient data overlap. Instead, we use an existing 530-year climate reconstruction for China (Shi et al., 2017; henceforth Shi17). The precipitation reconstruction is based on a dense set of 491 tree-ring and 108 documentary records and shows good verification skills over large parts of China. Most of the Shi17 documentary records belong to a 530-year long structured compilation of data from 120 subregions that cover Eastern China (Academy of Meteorological Science, 1981). The Shi17 tree-ring sites are predominantly located on the Tibetan Plateau or the surrounding highlands. The tree-ring chronologies are of variable length, but mostly shorter than 530 years, so that the reconstruction quality most likely decreases back in time. The Shi17 data also include millennial-long records that overlap with the dataset analyzed herein (Fig. 2). Hence, the majority of tree-ring and documentary records used in this study cannot act as fully independent samples. The correlation between Shi17 and the proxy network was calculated between each proxy site and the closest grid point of the precipitation reconstruction.

A Spearman rank-difference correlation between each proxy record and an average of its six closest neighbors yields estimates of the coherency within the proxy network and of the spatial correlation decay length (Fig. 3). Although Pearson correlations between hydrological parameters are expected to yield similar results (McDonald and Green, 1960), we used the Spearman correlation to account for the fact that it is more robust against outliers observed in the proxy data. The number of neighbors considered was optimized in order to maximize the mean of all correlations. Tests with five or less neighbors resulted on average in lower correlations presumably because of a less effective noise cancelation in the neighbors average. More than six neighbors required an increased search radius. Considering more distant sites for the neighbors average likewise decreased correlations overall. Neighbors were chosen independent of the proxy type. Considering only records with good DA and EC as neighbors also increased the average distance of neighbors and, more importantly, reasoning will be circular because we aim at testing the DA- and EC-classification using the resulting coherency estimates.

Chen et al. (2015b) show that our study area can be divided in 3 clusters with different evolutions of hydroclimate over the past millennium. Guided by these clusters and with a focus on regions with the densest proxy coverage (northeastern Tibetan Plateau and Eastern China), we subdivided our region into three subregions (Fig. 1) that are expected to have a similar hydroclimate history (Chen et al. 2016b). The three different subregions are represented by n_{all} = 14-18 proxy records each, feature a comparable density of proxy sites and the 6 closest neighbors to each site are at an average distance[2] of less than 500 km. For the three clusters Northeastern (NE) Tibetan Plateau, Northcentral (NC) China and Southeastern (SE) China we calculated arithmetic means with different subsets of proxy data. By using a simple arithmetic mean for spatial aggregation, we have not taken advantage of more complex aggregation strategies as employed in some reconstruction methods in order to keep the impact of single records as transparent as possible. In order to estimate the overall suitability of proxy records,

[2] With exception from the borderline records #7, #25 and #55 (see Tab. 1).

we average records from the previously defined classes (good = +1; intermediate = 0; insufficient = –1) of DA and EC. Besides the average of all records within each of the subregions (ave_{all}), we also calculated an average with the most suitable records indicated by a classification index >0 (ave_{suit}). This procedure reduced n_{all} to n_{suit}=6-7. To illustrate the range of variability when subsampling a small population (i.e. all proxy records from one subregion) we calculated spatial averages from random subsets of the proxy network. In a bootstrapped resampling with replacement, we made 1000 draws of the size n_{suit} from n_{all} available records. We use the expressed population signal (EPS), a measure adapted from dendrochronological applications (Wigley et al., 1984), to estimate how well the selected records are able to represent the common signal of different subregions in the 1000-1900 CE period. EPS is sensitive to the number of underlying records and to the mean correlation between these records. For positive mean interseries correlations, it varies between 0 and 1, where 1 indicates a perfect representation of the common signal.

3. Results and discussion

3.1 Classification of proxy records

Terrestrial proxies from Monsoon Asia differ significantly with respect to their DA (Table 1 and Fig. 2). The highest DA was, unsurprisingly, found for documentary and tree-ring data. In documentary records, dates are reported together with the observations, ruling out almost entirely the potential for dating inaccuracy. However, some of the documentary records are of lower temporal resolution because of the integration of observed extreme events over a certain time period (e.g. Zheng et al. (2006) present a time-series with data every 20 years). In tree-ring chronologies a dating error due to false counting or missing rings can be ruled out by cross-dating many trees from multiple sites (Anchukaitis et al., 2012; Büntgen et al., 2018). The dating precision of other proxy archives differs considerably. Some lake records derive their age-models from radiocarbon dating on bulk sediment leading to age errors potentially in the range of multiple centuries (e.g. Liu et al., 2009) due to reservoir effects in the water column. Laminations, in contrast, can decrease the age uncertainty of radiocarbon or U/Th dates significantly. The U/Th-dated chronology of the speleothem record from Heshang cave (Hu et al., 2008), for example, is validated by additional lamina counting. Such features can remain unnoticed if only quantitative information about the age model (i.e. number and precision of dates) are taken into account to assess the DA of a proxy record. Here, they are considered by lowering (reservoir effects) or raising (lamination) the DA class by one step.

Regarding the EC, tree-ring records rank high again (Table 1). Annual resolution usually warrants sufficient overlap with instrumental data and allows a straightforward verification of the climatic signal. The same applies, but to a somewhat lesser extent, to other high-resolution natural proxy records from speleothems or ice cores. For records with lower resolution, the climatic interpretation is often based on a mechanistic understanding of the proxy. However, the effort made to verify the climate signal varies significantly among different studies. All speleothem records in this study use $\delta^{18}O$ as a proxy for precipitation. This relationship is relatively well understood and in two studies supported by evidence from monitoring experiments (Paulsen et al., 2003; Kuo et al., 2011), which results in an intermediate EC ranking. Additionally, all speleothem studies illustrate the agreement with other, nearby proxy records, which gives more confidence in their climate signal. Records from lake sediments reveal a large variety of proxy types. Although some studies present a solid mechanistic framework, regional comparisons are often more difficult because not only the proxy but also the targeted hydrological parameter (e.g. precipitation, drought or runoff) can be different. This might result in a different course of past hydroclimate and might impact the probability distribution and/or frequency spectra of the data. All pollen records used in this study are derived from lake records. Most of them are calibrated to annual precipitation amounts via today's pollen distributions. If only pollen ratios are presented (e.g. Lake Aibi and Wulungu), there is a risk of underestimating the complexity of pollen/climate interactions (Herzschuh, 2007). Hence, the EC for these pollen records was -1 or 0.

3.2 Comparison with 530 years of gridded precipitation

To test whether the DA and EC classification is meaningful for the suitability of proxy records, we assess the agreement with Shi17 in the low (>= ~100 years) and mid (~10-100 years) frequency domains. Almost all documentary and tree-ring records from our setup correlate significantly with Shi17 in the mid-frequency domain (p=0.1, one-sided Spearman), which is likely in some, but not all, cases a result of data overlap (Fig. 2). However, half of the documentary data – those with EC ≤ 0 – do not agree with the target at centennial frequencies, supporting our suitability classification. This illustrates the difficulty to reconstruct frequency domains beyond the length of the instrumental calibration period (Fig. 2a-b). Among the records independent from Shi17, variability at time-scales greater than 100 years correlates significantly with Shi17 in 32% of the proxy records (Fig. 2a-b). Insufficiently dated speleothem records show the lowest correlation values with Shi17 which is an indication that a good dating is of importance also on longer time-scales.

Records from archives without a precise age-control are mostly limited in their ability to reflect decadal scale variability in the precipitation data from Shi17 (Fig. 2c-d). Besides dating errors, this can be related to the nonlinear influence of temperature changes (e.g. Paulsen et al., 2003). Likewise, the precipitation reconstruction itself is likely not independent from temperature since the tree-rings used for the reconstruction are drought sensitive in some regions. Further, the documentary data are not precipitation measurements but presented as “drought and flood” events (Qian et al., 2003; Zheng et al., 2006). Despite differences in the hydroclimatic target, six out of 18 lake sediment records show significant correlations with Shi17 in the mid frequency domain, although their DA was ranked as insufficient (Fig. 2c).

The overall weak correlation of lake sediment, speleothem, pollen and ice core records with reconstructed precipitation (Fig. 2) is likely a result of uncertainties in the precipitation reconstruction and in the proxy time-series. Slight differences regarding the targeted hydroclimatic parameter further complicate the relationship. Reducing the length of the correlation period does not improve the results, although the reconstruction is presumably more robust in the more recent centuries with a more complete proxy network (results not shown).

3.3 Correlation within the proxy network

If DA and EC can inform about the suitability, those records with good DA and EC performance should correlate more strongly with their neighbors than those records with a low suitability. Indeed, we find higher correlations among more suitable records (Fig. 3). However, the discrimination between classes is not distinct. A few records that scored high in the suitability classification (Fig. 2) reveal low correlations with their neighbors and vice versa. A low correlation does not necessarily indicate that the record has a weak climate signal or an incorrect dating. A mismatch can also be the result of poor quality hydroclimate proxies among the neighboring records and/or spatially inhomogeneous hydroclimate variability. Tree-ring and documentary data exhibit a decorrelation pattern in the 10-100 years frequency domain, indicating that the spatial relationship between records is limited to 500-700 km for decadal to multi-decadal variability (Fig. 3c,d), which is in agreement with previous results for these latitudes (Ljungqvist et al., 2016; Talento et al., 2019). Orographic features and the spatial extent of climate regimes can alter the length of correlation decay as shown with tree-rings (Cook et al., 2010). Our results reveal that the decorrelation pattern also depends on the analyzed frequency domain (Fig. 3a,c). At centennial frequencies, the correlation decay becomes less distinct and significant correlations are found even between records that are on average almost 1000 km away. Significantly negative correlations in both frequency domains could reflect the high spatial variability of hydroclimate within this region or records with insufficient DA and/or EC could spuriously correlate with their neighbors (Fig. 3a,b).

For decadal to multidecadal variability, only tree-ring and documentary records yield significant correlations with their neighbors (Fig. 3c,d). Records from these archives often correlate strongly in the low frequency domain, too (Fig. 3a,b). Many lake sediment records agree well with their neighbors on long timescales, despite low DA (Fig. 3a). Among speleothem data, high and low DA roughly separates strongly and weakly correlating records (Fig. 3a), confirming the tendency found in the correlations with Shi17 (Fig. 2). Records with low EC show no significant ($p \leq 0.01$) positive correlations in the low and mid frequency domain (Fig. 3b,d). Correlation results in this experiment have to be interpreted with caution: a low correlation with neighboring records can be caused by too much noise in the neighbors' average and does not necessarily imply that the record of interest is unsuitable.

Evaluating proxy records based on "expert assessment" from the source publications yields, on average, a reasonable suitability estimate. However, correlations with Shi17 and within the proxy network reveal a considerable chance for incorrect classifications. Remarkably, many lake sediment records from the lowest DA class showed strong coherency to Shi17 and/or within the proxy network on centennial timescales implying that records with high dating uncertainty may still be dated properly. Overestimating the suitability is likewise possible, if, for example, studies report a good EC, while the records' climate signal becomes weaker back in time. This is typical of many tree-ring records because the calibration period is normally based on a large number of trees (Esper et al., 2018) but the sample size declines further back in time because of the limited availability of old living trees, historical timbers or subfossil tree-trunks (Esper et al., 2016). For the cluster of speleothem records in southern China, EC can be overestimated, too: in most studies, validation is achieved via high coherency with neighboring speleothem records, but this coherency might arise from a coherent isotopic signal due to common moisture sources in this region (Maher, 2008), rather than coherent rainfall amounts. Such a conclusion is supported by the fact that the only southern China speleothem record with a high intra-network correlation (#13) is the one in the center of multiple other speleothem isotope records. In contrast, the lake sediment records with high intra-network correlations are spread over the entire study region and cohere with records from different archives.

Classifying the suitability seems particularly valid for studying climate variability at multi-centennial to millennial time-scales. At decadal to multidecadal scales performance is mainly determined by the proxy type, i.e. only tree-ring chronologies and documentary data revealed robust evaluation results (Fig. 2c,d; Fig. 3c,d). For longer-term variability, in contrast, the suitability classification seems to be relevant for the choice of speleothem, documentary and tree-ring records. Both categories, DA and EC, contribute important information and it is not possible to favor one criterion over the other based on the results of this study. EC discriminated well, for example, between documentary records with and without a significant correlation with Shi17 at low frequencies. DA performed better regarding the classification of speleothem records. Thus, we combined the information from DA and EC in one suitability measure for proxy selection.

3.4 Autocorrelation in filtered and resampled time-series

After smoothing and resampling the proxy data for the above analyses, the data are more homogeneous regarding their frequency spectra. However, the proxy type still strongly affects the autocorrelation of the low-pass filtered data (Fig. 4a), indicating that millennium-long trends might be estimated differently depending on the dominating proxy-type. Averaged over all records from the same archive, autocorrelation at lag 1 (i.e. 10 and 50 years for band- and low-pass filtered series) ranges from 0.06 for tree-rings to 0.74 for lake sediments (Fig. 4a). Records from speleothems, pollen and ice-core records reveal significant autocorrelations in the low frequency domain, too, whereas documentary data can reach as low autocorrelations as tree-rings although the mean is slightly higher. These findings may reflect an underestimation of long-term trends in documentary (Brázdil et al., 2005) and tree-ring data (Cook et al., 1995; Klippel et al., 2019) as mentioned earlier. For the high autocorrelation values in the other archives it cannot be ruled out that there is additional memory induced by long-term processes in the hydrological, ecological or geological system that are not primarily under climatic control. However, it is unlikely that high autocorrelation values in lake sediment data are purely the result of non-climatic biases, because the low frequency signal in some of these records revealed considerable coherency with Shi17 and with neighboring proxy records. Potentially, higher autocorrelation is the result of a redder temperature frequency spectrum (Franke et al. 2013, Zhang et al., 2015) that affects some, but not all records. Tree-rings from the Northeastern Tibetan Plateau which are known to be partly temperature sensitive (Shao, 2005; Zhang et al., 2011; Cook et al., 2013; Yang et al., 2014b; Duan et al., 2017; Duan et al. 2018) still reveal very low autocorrelation values.

Diverging autocorrelation patterns are also visible in records classified based on the suitability criteria. In particular, DA resembles the previously described pattern (Fig. 4a,b), because in DA mainly tree-ring and documentary records return the highest suitability grade. For band-pass filtered data the overall results are the same, although autocorrelation is generally lower in this domain for all cases (Fig. 4a-c). The distinct offset in autocorrelation seems to be mostly a result of proxy characteristics. Therefore, it is not possible to determine whether the lower autocorrelation in higher suitability classes or the higher autocorrelation in lower suitability classes is closer to the truth. Only a combination of different proxy types and archives might overcome such constraints.

3.5 Effects of proxy selection based on the suitability assessment

By separating Monsoon Asia into subregions, we assess where and when constraining the number of proxy records using DA and EC classes is useful. Based on the better evaluation results in the low frequency domain (Fig. 2a,b; Fig. 3 a,b), we test the effects of using full versus reduced proxy networks for only the low-pass filtered data. For each subregion, the full and reduced regional means are discussed with respect to their archive composition, their long-term trends and their EPS-values.

The first subregion is located over the NE Tibetan Plateau (Fig. 1) and is represented by six lake sediment, one pollen and seven tree-ring records (Fig. 5a). The average of all records from this region indicates a long-term wetting trend from the onset to the end of the last millennium, as found by Chen et al. (2015b) and Ljungqvist et al. (2016). If records of “insufficient” or “intermediate” suitability are removed, the region is only represented by tree-ring data. The homogeneous hydroclimate signal among tree-ring chronologies results in an increased EPS value despite using fewer records (Table 2 and Fig. 5a,b). The most pronounced difference between the reduced (only suitable records) and the full (all records) average occurs around 1400 CE, when tree-rings indicate a pluvial period and most other records imply dry to very dry conditions (Fig. 5a). Despite yielding a high EPS value, dismissing non-tree-ring proxy records is problematic in this example for the following reasons. First, tree-rings are not distributed over the entire subregion, so that the reduced average increases the risk of missing climate variability of areas not covered by tree-rings. Second, the reduced average has a less distinct millennial trend (Fig. 5b). This could be closer to the true climatic signal, but it could likewise result from tree-ring data processing, that often confines the ability of tree-rings to represent trends on these time-scales (Cook et al., 1995). Esper et al. (2016) showed that the characteristics of tree-ring samples from the Tibetan Plateau would limit their ability to reproduce millennial length trends. An average of the five lake sediment records from this region has a significant trend towards wetter conditions, indicating that the tree-ring estimate is probably insufficient in this case (Fig. 5a). Thus, in this region an average of all records seems the better choice despite the lower EPS value.

The second subregion covers NC China (Fig. 1) and is represented by four lake sediment, four speleothem, seven documentary and three pollen records (Fig. 5c). The region overlaps with the northern pole of the "North-South mode of hydroclimate variability" (Chen et al., 2015b) and accordingly reveals a trend towards dryer conditions over the past millennium. Using only "suitable" records yields an abrupt shift in the 15th century from a pluvial first half of the last millennium to a drier second half (Fig. 5c,d). Considering all records, this transformation becomes more gradual with wettest conditions around 1200 CE and driest around 1500 CE, while the amplitude remains the same. At the same time, variability at centennial timescales is smaller for the full average. Together, these findings indicate a limited ability of less suitable sediment archives or speleothems to resolve such fluctuations, possibly due to longer-term environmental adjustments (Cai et al., 2010; Kasper et al., 2012). Despite a lower EPS value (Table 2), the significantly enhanced centennial scale variability is an argument for using the reduced average for this subregion, including 4 documentary, 1 pollen and 1 speleothem records.

The third subregion in the SE Chinese lowlands (Fig. 1) features seven documentary and five speleothem records as well as two southern lake sediment records from coastal locations (Fig. 5e). The southern counterpart of the "North-South mode of hydroclimate variability" is expected to show a relatively dry onset of the last millennium and a wetting trend towards the Little Ice Age (Chen et al., 2015b), which is confirmed by the full average of the proxy network in this region (Fig. 5f). The reduced average, a mix of documentary and speleothem data, mimics the average of all data most closely compared to the other two subregions (Fig. 5 b,d,f). The wettest and driest conditions occur in the same epochs and both averages feature a similar millennial-long trend. In contrast to the NE Tibetan Plateau, the records in the reduced average represent two different archives, which gives more confidence in the results. However, the difference between the reduced and full average are rather small throughout much of the last millennium so that both approaches seem valid for this example, although the EPS value is significantly smaller for the reduced average.

The three subregions reveal that proxy filtering can only improve the common hydroclimate signal of the network if high quality proxies are distributed over most of the spatial extent and if the region features high quality proxies from various archives. Although these conditions were met in two out of three subregions, the full average can still have a higher signal strength as indicated by the higher EPS value. However, the EPS values in this study are generally weak and should not be over interpreted. Compared to an application of EPS in a dendrochronological context, the sample size is rather small, the number of time steps very limited and the signal to noise ratio low.

Proxy selection based on our suitability classes apparently requires a denser proxy network encouraging further initiatives to sample and analyze more proxy archives. This is particularly important for proxy systems sensitive for hydroclimatic changes. Our results reveal distinct divergence between different archives in all subregions even though Monsoon Asia currently contains one of the densest networks of millennial long hydroclimatic proxy records.

4. Conclusions

Proxy selection constitutes an important step in large-scale paleoclimatology. Relying solely on a screening against instrumental data can penalize proxies that are of low temporal resolution. Including all available data, in contrast, might introduce excessive amounts of noise from unsuitable proxy records. We here suggest a method for proxy record evaluation that is based on meta information derived from the associated publications. With the evaluation categories "dating accuracy" (DA) and "evidence for a climate signal" (EC), two transparent and universal categories are developed that help to identify records that contain a useful hydroclimatic signal over the last millennium. We test the DA and EC classification using a partly independent hydroclimatic reconstruction as well as intra-network correlations. Suitability estimates for tree-ring, speleothem and documentary records contain valuable information. The classification of lake sediments is more prone to an underestimation of their actual suitability. Some significant correlations with records from other archives are achieved despite large dating uncertainties. Documentary and tree-ring data reveal the best classification results for DA and EC. However, their weak autocorrelation on centennial timescales is likely associated with inherent limitations of these proxy types. The existence of long-term memory in hydroclimate is suggested by the robust intra-network correlations found in some lake sediment records.

In order to reproduce climate variability at all timescales we encourage the application of multi proxy compilations in our Monsoon Asia study region. Besides improved frequency spectra, the integration of various proxy archives will also increase the spatial coverage. A dense proxy network is of particular importance for hydroclimate reconstructions due to the short correlation decay length, which we proofed with intra-network correlations of documentary and tree-ring data. Our analyses of different, well-sampled subregions corroborates that only a well balanced mix of different proxies yields favorable characteristics of spatial averages. Selecting a subset of records based on the previously defined suitability classes does not improve the signal strength, but it might reveal noteworthy differences between the full and the reduced average.

Although the millennium long hydroclimatic proxy network in Monsoon Asia is not yet dense enough for a proxy selection based on our suitability criteria, this approach can be transferred to other large-scale paleoclimate studies. The global proxy network is constantly growing. DA and EC offer guidance in the process of proxy selection. They can be assessed for many different types of paleoclimate records and their specification can be adjusted to different problems.

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Table and figure captions

Table 1: Millennial long proxy records for hydroclimate investigations in Monsoon Asia. Site numbers as in Fig. 1. Abbreviations: Lon=Longitude, Lat=Latitude, DA=Dating accuracy, EC=Evidence for climate signal, TRE= Tree-rings, LAK=Lake sediments, POL=Pollen, SPE=Speleothems, ICE=Ice-cores, DOC=Documentary, ISO=Tree-ring isotopes, TRW= Tree-ring width, TOC=Total organic carbon.

Table 2: EPS-values for the subregions as defined in Fig. 1.

Figure 1: Millennial-long proxy network for hydroclimate investigations in Monsoon Asia covering the area 70°-130°E and 20°-50°N. The three regions indicated by dashed circles are used for spatial data aggregation (NE Tibetan Plateau=Northeastern Tibetan Plateau; NC China= Northcentral China; SE China= Southeastern China; see section "Effects of proxy selection based on the suitability assessment"). See Table 1 for details on the proxies.

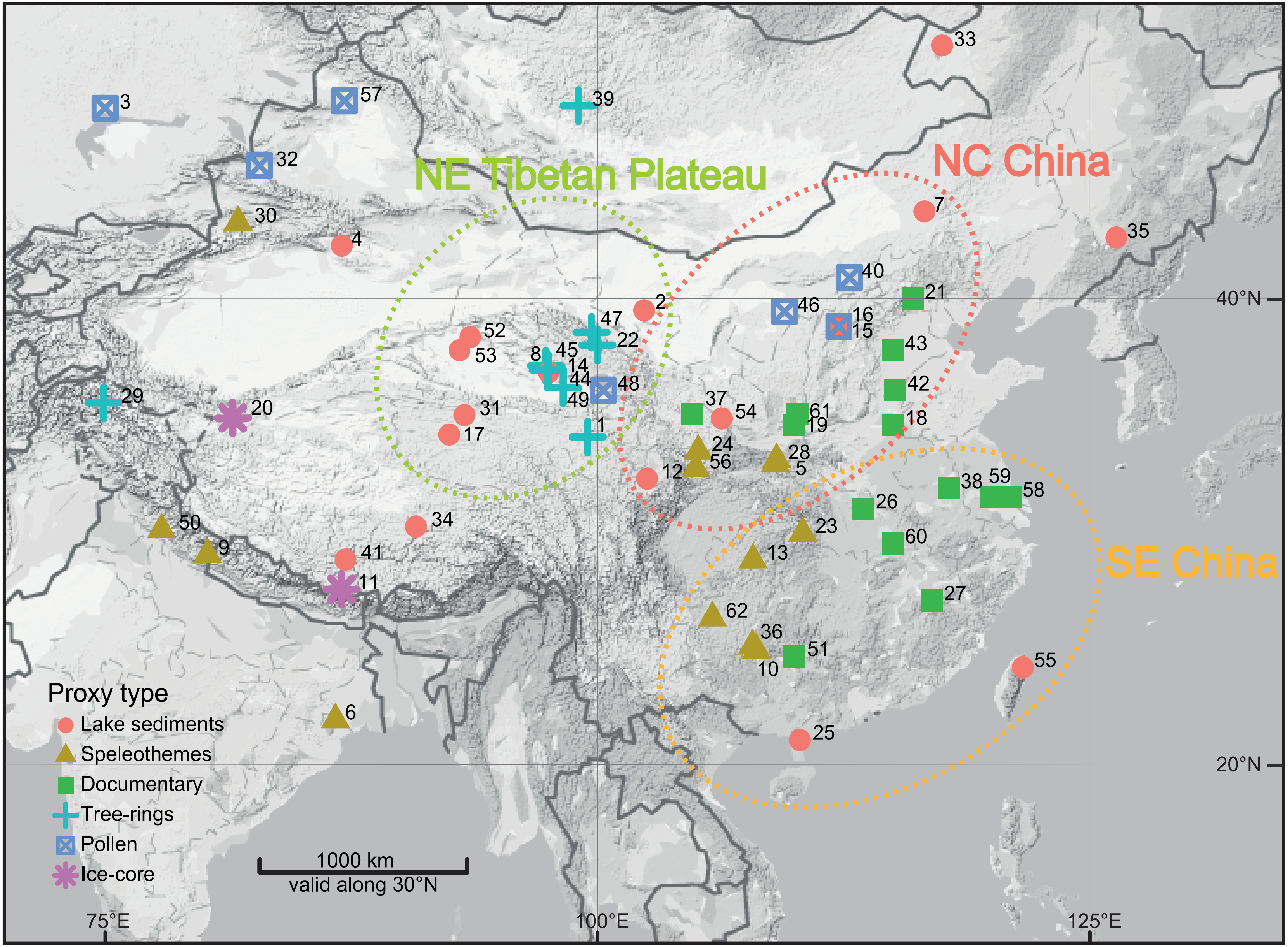
Figure 2: Spearman correlation of proxy records with the gridded precipitation field of Shi17 for the period 1470-1950 CE. (a) Low-pass filtered data, colors indicate DA class. (b) Low-pass filtered data, colors indicate EC class. (c) Band-pass filtered data, colors indicate DA class. (d) Band-pass filtered data, colors indicate EC class. Dashed lines indicate the p=0.1 significance threshold. Records marked with grey bars are not fully independent from Shi17. The independence of three studies (in Chinese) could not be evaluated (question marks below the top margin). The records are indicated by their number (Table 1) and ordered into groups: LAK=Lake sediments, SPE=Speleothems, POL=Pollen, ICE=Ice-cores, ISO=Tree-ring isotopes, TRE= Tree-rings, DOC=Documentary.

Figure 3: Correlation of proxy records with a mean of their six closest neighbors plotted against the mean distance of the neighbors. (a) The correlation is calculated with low-pass filtered data for the period 1100-1900 CE. Colors refer to DA classification. (b) Same as (a), but colors refer to EC. (c) Same as (a), but for band-pass filtered data. (d) Same as (c), but colors refer to EC. Symbols indicate the type of proxy being tested, not the type of their neighbors. Dotted and dashed lines refer to the 95% and 90% significance levels. Records 29 and 44 are tree-ring isotope records.

Figure 4: Autocorrelation at lag 10 and 50 year, respectively, of the filtered and resampled proxy records for the period 1000-1900 CE. Left (right) bars indicate the autocorrelation for low(band)-pass filtered time-series. (a) Grouped by proxy type. (b) Grouped by DA. (c) Grouped by EC. TRE includes the isotope records.

Figure 5: Spatial aggregation of Monsoon Asian proxy records, after smoothing and resampling with 50-years resolution to account for irregular time-steps in the original records. (A) Northeastern Tibetan Plateau proxy records averaged by archive type, (B) Northeastern Tibetan Plateau proxy records averaged by suitability classification, (C) Northcentral China proxy records averaged by archive type, (D) Northcentral China proxy records averaged by suitability classification, (E) Southeastern China proxy records averaged by archive type, (F) Southeastern China proxy records averaged by suitability classification.

Shaded areas in (B), (D) and (F) represent the results of a bootstrapping experiment for a reduced average using a subsampling over all proxy-records in each region (5th and 95th percentile: dark grey; 1st and 99th percentile: light grey). Records are only shown until 1950 because many datasets terminate in the late 20th century. All proxy records are standardized over the common period 1000-1900 CE. Dashed lines in the left-hand column indicates an archive size <3.


NE Tibetan Plateau
NC China
SE China
Proxy type
Lake sediments
Speleothemes
Documentary
Tree-rings
Pollen
Ice-core
1000 km
valid along 30°N
75°E
100°E
125°E
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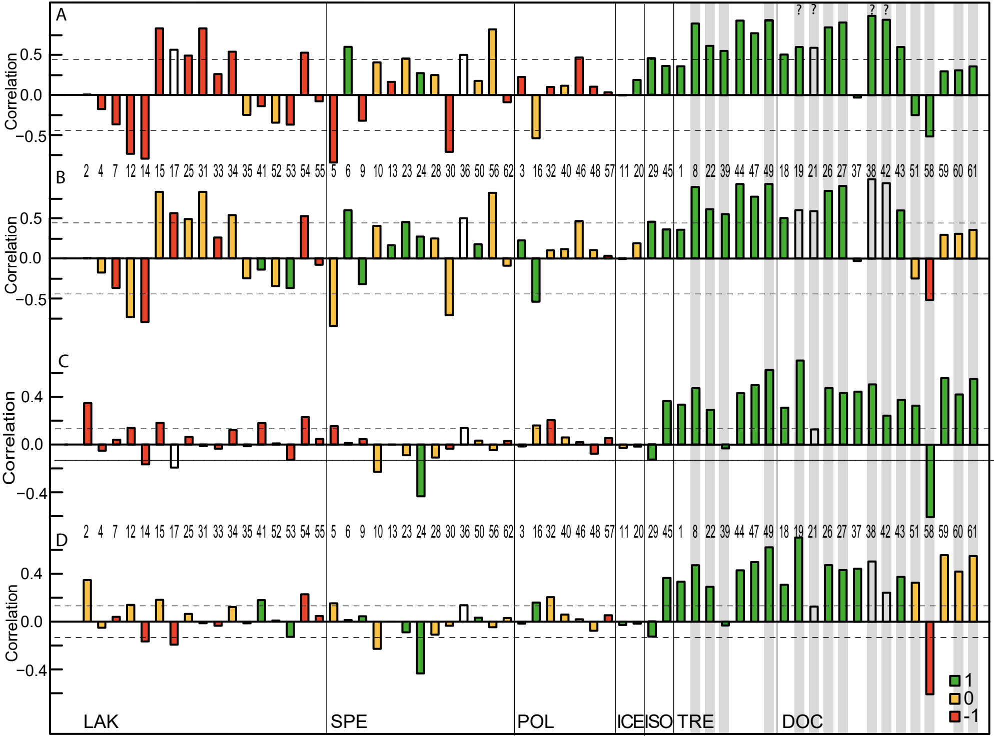
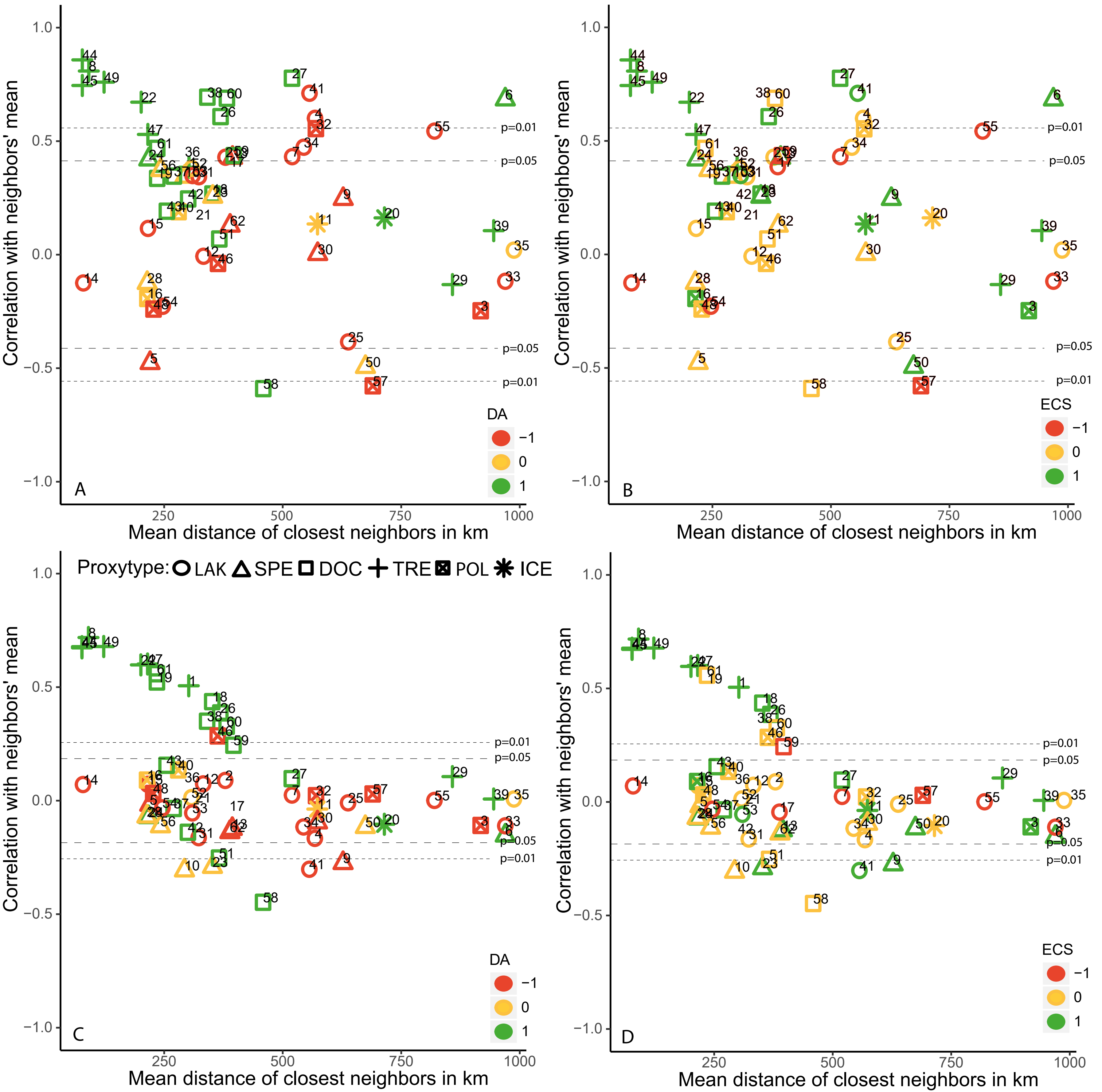
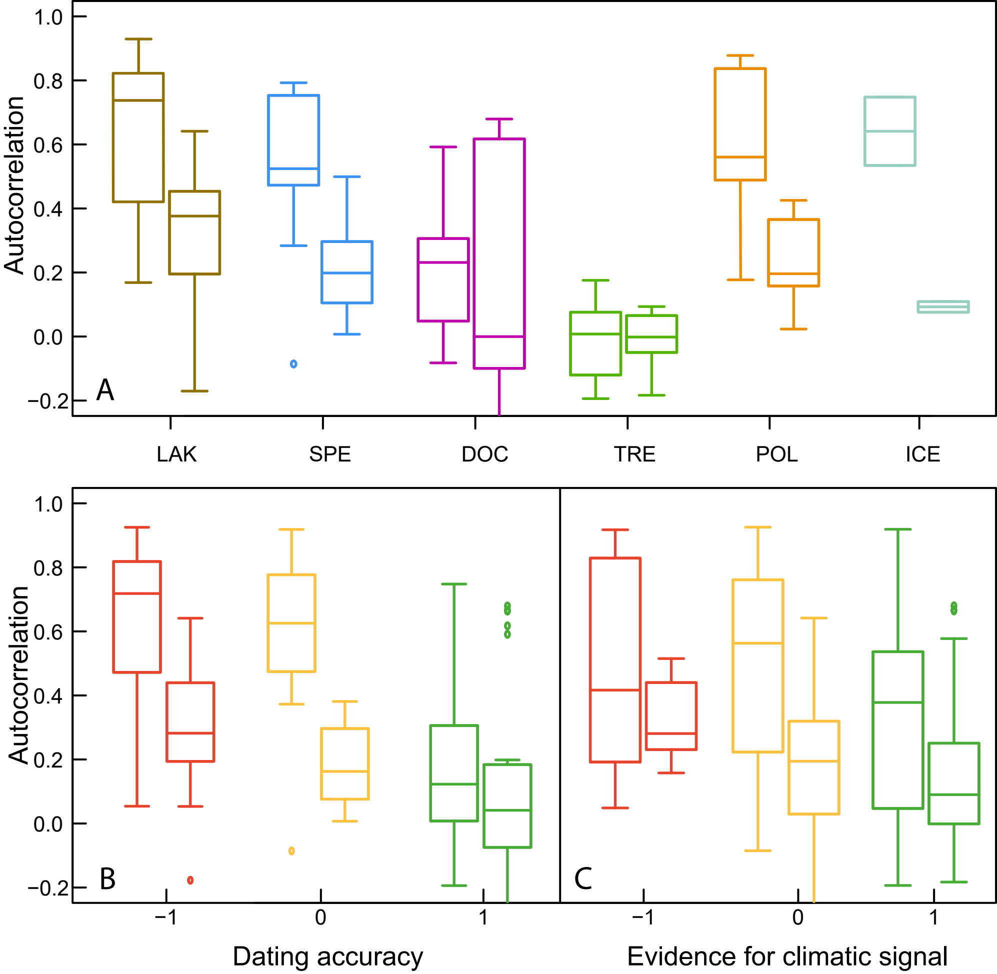
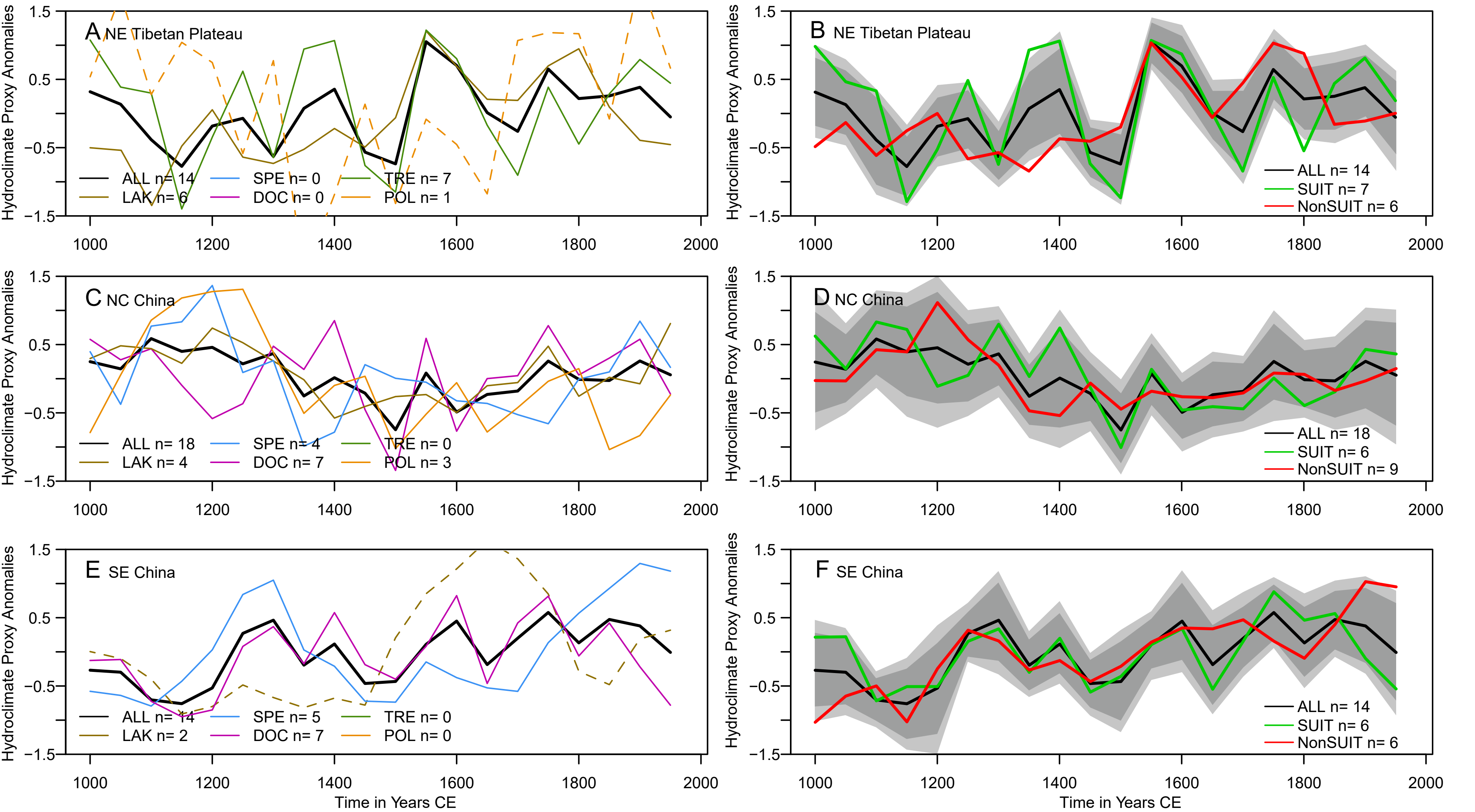

A
B
C
D
Correlation
0.5
0.0
−0.5
0.4
−0.4
? ?
? ?
2 4 7 12 14 15 17 25 31 33 34 35 41 52 53 54 55 5 6 9 10 13 23 24 28 30 36 50 56 62 3 16 32 40 46 48 57 11 20 29 45 1 8 22 39 44 47 49 18 19 21 26 27 37 38 42 43 51 58 59 60 61
LAK
SPE
POL
ICE
ISO
TRE
DOC
1
0
-1


Correlation with neighbors' mean
Mean distance of closest neighbors in km
1.0
0.5
0.0
−0.5
−1.0
250
500
750
1000
p=0.01
p=0.05
DA
−1
0
1
A
ECS
B
Proxytype: LAK SPE DOC TRE POL ICE
C
D



Autocorrelation
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
A
LAK
SPE
DOC
TRE
POL
ICE
B
C
−1
0
1
Dating accuracy
Evidence for climatic signal



A NE Tibetan Plateau
B NE Tibetan Plateau
C NC China
D NC China
E SE China
F SE China
Hydroclimate Proxy Anomalies
Time in Years CE
ALL n= 14
LAK n= 6
SPE n= 0
DOC n= 0
TRE n= 7
POL n= 1
SUIT n= 7
NonSUIT n= 6
ALL n= 18
LAK n= 4
SPE n= 4
DOC n= 7
TRE n= 0
POL n= 3
SUIT n= 6
NonSUIT n= 9
ALL n= 14
LAK n= 2
SPE n= 5
DOC n= 7
TRE n= 0
POL n= 0
SUIT n= 6
NonSUIT n= 6

Nr	Site	Sub-region	Lon	Lat	Archive	Proxy type	Start (Years CE)	End (Years CE)	Resolution (Years)	DA	EC	References
1	Anyemaqen Mountains	1	99.5	34.5	TRE	TRW	800	2004	1	1	1	Gou et al., 2010
2	Badain Jaran Desert	1	102.4	39.55	LAK	Chloride	815	1983	6	-1	0	Ma and Edmunds, 2006
3	Balkhash Basin		75	46.9	POL	Pollen	785	1950	11	-1	1	Feng et al., 2013
4	Bosten Lake[a]		87.0	42	LAK	Var.[a]	-39	2000	11	-1	0	Chen et al., 2006
5	Buddha Cave	2	109.1	33.4	SPE	$\delta^{18}O$	800	1996	2	-1	0	Paulsen et al., 2003
6	Central India composite[b]		86.7	22.1	SPE	$\delta^{18}O$	625	2007	1	1	1	Sinha et al., 2011
7	Dali Lake	2	116.6	43.26	LAK	TOC	-9	1921	27	-1	-1	Xiao et al., 2008
8	Delingha	1	97.4	37.38	TRE	TRW	-499	2011	1	1	1	Yang et al., 2014a
9	Dharamjali Cave		80.2	29.52	SPE	$\delta^{18}O$	794	1991	10	-1	1	Sanwal et al., 2013
10	Dongge Cave	3	108.1	25.28	SPE	$\delta^{18}O$	3	2000	4	0	0	Wang et al., 2005
11	East Rongbuk		87	28	ICE	dD	1000	1990	6	0	1	Kaspari et al., 2007
12	Eastern Tibetan Plateau	2	102.5	32.77	LAK	Humifi-cation	754	1900	76	-1	0	Yu et al., 2006
13	Furong Cave	3	107.9	29.29	SPE	$\delta^{18}O$	2	2005	7	-1	1	Li et al., 2011
14	Gahai Lake	1	97.5	37.13	LAK	%C37:4	-1	1962	5	-1	-1	He et al., 2013
15	Gonghai Lake	2	112.2	38.87	LAK	S-300[d]	842	2000	5	-1	0	Liu et al., 2011
16	Gonghai Pollen	2	112.3	38.93	POL	Pollen	-10	2008	20	0	1	Chen et al., 2015a
17	Goulucuo Lake	1	92.5	34.6	LAK	$CaCO_3$%	964	1992	11	?	-1	Li et al., 2004
18	Great Bend Yellow River	2	115	35	DOC	Documentary	804	1945	8	1	1	Gong and Hameed, 1991
19	Guanzhong Plain	2	110	35	DOC	Documentary	960	2010	1	1	?	Hao et al., 2017
20	Guliya		81.5	35.28	ICE	Glacial acc.	1000	1990	10	1	0	Yao et al., 1996
21	Haihe River Basin	2	116	40	DOC	Documentary	791	1976	12	?	?	Yan et al., 1993
22	Heihe River Basin	1	100	38.2	TRE	TRW	575	2008	1	1	1	Yang et al., 2012
23	Heshang_Cave	3	110.4	30.45	SPE	$\delta^{18}O$	0	2002	3	0	1	Hu et al., 2008
24	Huangye Cave	2	105.1	33.92	SPE	$\delta^{18}O$	138	2002	4	1	1	Tan et al., 2010
25	Huguangyan Lake	3	110.3	21.15	LAK	TOC	780	2004	12	-1	0	Zeng et al., 2012

26	Jianghuai	3	113.5	31.5	DOC	Documentary	773	1990	22	1	1	Zheng et al., 2006
27	Jiangnan	3	117	27.5	DOC	Documentary	776	1992	19	1	1	Zheng et al., 2006
28	Jiuxian Cave	2	109.1	33.57	SPE	$\delta^{18}O$	0	1998	4	0	0	Cai et al., 2010
29	Karakorum Mountains		74.9	35.9	TRE[c]	$\delta^{18}O$	1000	1998	1	1	1	Treydte et al., 2006
30	Kesang Cave		81.8	42.87	SPE	$\delta^{18}O$	14	1945	21	-1	0	Cheng et al., 2012
31	Kusai Lake	1	93.25	35.4	LAK	TOC	8	2006	13	-1	0	Liu et al., 2009
32	Lake Aibi		82.84	44.9	POL	A/C ratio	-21	1950	16	-1	0	Wang et al., 2013
33	Lake Hulun		117.5	49	LAK	$\delta^{18}O$	5	1955	38	-1	-1	Zhai et al., 2011
34	Lake Nam Co		90.8	30.73	LAK	Mineralogy	3	2007	5	-1	0	Kasper et al., 2012
35	Lake Xiaolongwan		126.4	42.3	LAK	$\delta^{13}C$	797	2002	14	0	0	Chu et al., 2009
36	Longquan Cave	3	107.9	25.48	SPE	$\delta^{18}O$	981	1911	7	?	?	Qin et al., 2008
37	Longxi area	2	104.8	35.45	DOC	Documentary	960	1990	11	1	1	Tan et al., 2008
38	Lower Huai River	3	117.8	32.36	DOC	Documentary	-5	1955	10	1	?	Man, 2009
39	Mongolia		99	47	TRE	TRW	900	2011	1	1	1	Pederson et al., 2014
40	Monsoonal Northern China	2	112.8	40.8	POL	Pollen	-202	2003	3	0	0	Li et al., 2017b
41	Ngamring Tso		87.2	29.3	LAK	Grainsize PC1	-70	2005	23	-1	1	Conroy et al., 2017
42	North China	2	115.1	36.4	DOC	Documentary	-5	1945	10	1	?	Man, 2009
43	North China Plains	2	115	38	DOC	Documentary	777	1990	28	1	1	Zheng et al., 2006
44	Qaidam Basin	1	97.5	37.2	TRE[c]	$\delta^{18}O$	998	2009	3	1	1	Wang et al., 2013
45	Qaidam Basin	1	97.5	37.2	TRE	TRW	566	2002	1	1	1	Yin et al., 2007
46	Qigai Nuur	2	109.5	39.5	POL	Pollen	784	1932	16	-1	0	Sun and Feng, 2013
47	Qilian Mountains	1	99.5	38.5	TRE	TRW	800	1950	1	1	1	Zhang et al., 2011
48	Qinghai Dalianhai	1	100.3	36.44	POL	Pollen	0	1994	24	-1	0	Li et al., 2017a
49	Qinghai Province	1	99	37	TRE	TRW	157	1993	1	1	1	Sheppard et al., 2004
50	Sahiya Cave		77.9	30.6	SPE	$\delta^{18}O$	-141	2006	1	0	1	Sinha et al., 2015

51	Southern China	3	110	25	DOC	Documentary	953	1996	5	1	0	Qian et al., 2003
52	Sugan Lake	1	93.9	38.5	LAK	Salinity	990	2002	11	0	0	Chen et al., 2009
53	Sugan Lake	1	93.9	38.85	LAK	%C37:4	794	2006	12	-1	1	He et al., 2013
54	Tianchi Lake	2	106.3	35.26	LAK	Redness	0	1995	5	-1	-1	Zhou et al., 2010
55	Tsuifong Lake	3	121.6	24.5	LAK	Diatoms	792	2006	12	-1	-1	Wang et al., 2013
56	Wanxiang Cave	2	105	33.19	SPE	$\delta^{18}O$	192	2003	3	0	0	Zhang et al., 2008
57	Wulungu Lake		87.15	47.15	POL	Pollen	56	1927	36	-1	-1	Liu et al., 2008
58	Yangtze Delta	3	120	32	DOC	Documentary	1000	2000	9	1	0	Jiang et al., 2005
59	Yangtze Delta	3	121	32	DOC	Documentary	1000	2000	5	1	-1	Zhang et al., 2008
60	Yangtze River	3	115	30	DOC	Documentary	942	1996	4	1	0	Qian et al., 2003
61	Yellow River	2	110	35	DOC	Documentary	950	1999	1	1	0	Qian et al., 2003
62	Zhijin Cave	3	105.8	26.73	SPE	$\delta^{18}O$	884	2004	2	-1	0	Kuo et al., 2011

[a] Chen et al. (2006) analyze carbon content, grain size and pollen for reconstructing the hydroclimate past of Bosten Lake. We use an average of the three indices $CaCO_3$% (inverted), mean grain size and pollen A/C ratio after linear interpolation between the time steps which vary among the three time-series.

[b] The Central India Composite is based on two stalagmites from spatially separated caves. The coordinates here represent an average of the two locations.

[c] Tree-ring isotope records.

[d] S_{-300} is a proxy for magnetic mineral concentrations.

Region	SE/SD-ratio	
	Full average	Subset average
NE Tibetan Plateau	0.76	0.89
NC China	0.51	0.33
SE China	0.60	0.21