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Evaluation of a modern-analogue methodology for reconstructing Australian palaeoclimate from pollen

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ABSTRACT

Quantitative palaeoclimate reconstructions are widely used to evaluate climate model performance. Here, as part of an effort to provide such a data set for Australia, we examine the impact of analytical decisions and sampling assumptions on modern-analogue reconstructions using a continent-wide pollen data set. There is a high degree of correlation between temperature variables in the modern climate of Australia, but there is sufficient orthogonality in the variations of precipitation, summer and winter temperature and plant–available moisture to allow independent reconstructions of these four variables to be made. The method of analogue selection does not affect the reconstructions, although bootstrap resampling provides a more reliable technique for obtaining robust measures of uncertainty. The number of analogues used affects the quality of the reconstructions: the most robust reconstructions are obtained using 5 analogues. The quality of reconstructions based on post-1850 CE pollen samples differ little from those using samples from between 1450 and 1849 CE, showing that European post-settlement modification of vegetation has no impact on the fidelity of the reconstructions although it substantially increases the availability of potential analogues. Reconstructions based on core top samples are more realistic than those using surface samples, but only using core top samples would substantially reduce the number of available analogues and therefore increases the uncertainty of the reconstructions. Spatial and/or temporal averaging of pollen assemblages prior to analysis negatively affects the subsequent reconstructions for some variables and increases the associated uncertainties. In addition, the quality of the reconstructions is affected by the degree of spatial smoothing of the original climate data, with the best reconstructions obtained using climate data from a 0.5° resolution grid, which corresponds to the typical size of the pollen catchment. This study provides a methodology that can be used to provide reliable palaeoclimate reconstructions for Australia, which will fill in a major gap in the data sets used to evaluate climate models.

1. Introduction

Quantitative palaeoclimate reconstructions are widely used to evaluate climate model performance because meteorological records only extend back for about 250 years and encompass a relatively modest range of climate variability (Braconnot et al., 2012; Harrison et al., 2013; Schmidt et al., 2014). The palaeo-record provides opportunities to examine model performance in intervals when the forcing and the climate response were large and comparable to the changes expected during the 21st century (Braconnot et al., 2012).

Pollen records are the most spatially extensive and widely accessible sources of data for quantitative reconstructions of past climates (Whitmore et al., 2005; Bartlein et al., 2011). Their usefulness reflects the fact that climate exerts a strong control on vegetation distribution (Harrison et al., 2010) and because the records can be dated using radiocarbon techniques (Prentice, 1988; Whitmore et al., 2005). There is a long history of reconstructing palaeoclimate from pollen using techniques such as inverse regression (Webb, 1980; Bartlein et al., 1984; Huntley and Prentice, 1988), transfer functions (Webb and Bryson, 1972), modern analogues (Howe and Webb, 1983; Overpeck et al., 1985; Jackson and Williams, 2004) and response surfaces (Bartlein et al., 1986; Gonzales et al., 2009). Large-scale reconstructions have been made for many regions, including North America (Gajewski et al., 2000; Williams et al., 2000; Viau and Gajewski, 2009), Europe (Cheddadi et al., 1997; Davis et al., 2003; Jost et al., 2005), Georgia (Connor and Kvavadze, 2008), Eurasia (Tarasov et al., 1999; Wu et al., 2007), Africa (Peyron et al., 2000; Peyron et al., 2006; Wu et al., 2007), China (Guiot et al., 2008) and New Zealand (Wilmshurst et al., 2007).

Many pollen-based reconstructions are based on some form of modern-analogue technique, in which modern relationships between pollen assemblages and climate variables are applied to palaeo-assemblages to infer past climate states. Similarity between assemblages is measured using the squared chord distance (SCD) (Overpeck

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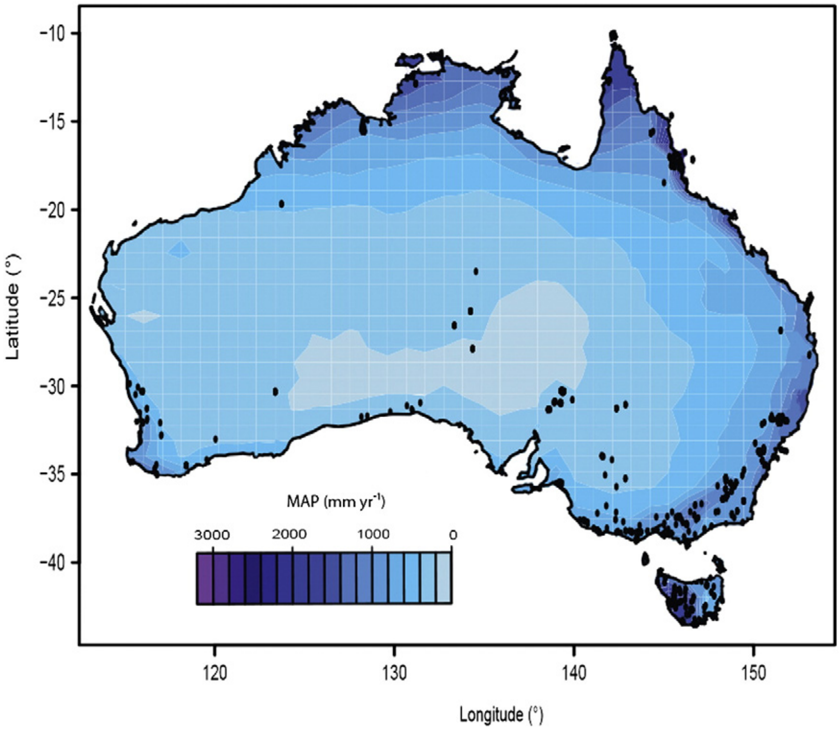

Fig. 1. Distribution of sites with pollen samples with ages <500 yr. BP (1450 to 2014 CE), used in the analyses. The sites are plotted on a map showing mean annual precipitation (MAP), to emphasise the relative paucity of sites from the arid interior of the continent.

et al., 1985), with modern analogues that pass a defined threshold being used to infer the climate of the palaeo-assemblage. However, there are a number of other analytical decisions that also need to be made to make modern-analogue reconstructions (for a review, see e.g. Simpson, 2012). The first is the choice of technique for selecting the appropriate analogues through cross-validation: jackknife leave-one-out (Efron and Efron, 1982) or bootstrapping (Freedman, 1981). The jackknife leave-one-out technique takes one assemblage at a time and compares it to all the others to see which matches most closely. Bootstrapping compares an assemblage to a subset of randomly selected assemblages and repeats the comparisons a predetermined number of times. The second decision is the optimal number of analogues to minimise the

Table 1

Performance statistics for reconstructions performed using two different analogue selection techniques, jackknife leave-one-out (leave-one-out) and bootstrapping (bootstrap), where the number of analogues was selected automatically to produce the lowest possible root mean square error of prediction (RMSEP). The climate variables are mean temperature of the coldest month (MTCO, °C), mean temperature of the warmest month (MTWA, °C), mean annual temperature (MAT, °C), growing degree days above a baseline of 5 °C (GDD5), mean annual precipitation (MAP, mm yr.$^{-1}$) and the Cramer–Prentice plant-available moisture index (α). The reconstructions made using the two different selection techniques are not significantly different from one another (95% confidence limit) nor are they significantly different (95% confidence limit) from the appropriate observed values.

Variable	Mean			RMSEP		r^2		Analogues	
	Observed	Leave-one-out	Bootstrap	Leave-one-out	Bootstrap	Leave-one-out	Bootstrap	Leave-one-out	Bootstrap
MTCO	10.2	10.1	10.1	1.7	2.0	0.93	0.94	2	1
MTWA	21.3	21.3	21.3	1.4	1.7	0.94	0.94	2	1
MAT	15.9	15.8	15.8	1.5	1.8	0.94	0.94	2	1
GDD5	4002	3987	3980	532	642	0.94	0.94	2	1
MAP	1122	1120	1120	209	240	0.92	0.93	2	2
α	0.71	0.72	0.72	0.07	0.08	0.94	0.95	2	2

Table 2

Performance statistics for reconstructions performed using a different pre-selected number of analogues, using the bootstrapping technique of analogue selection. The climate variables are mean temperature of the coldest month (MTCO, °C), mean temperature of the warmest month (MTWA, °C), mean annual temperature (MAT, °C), growing degree days above a baseline of 5 °C (GDD5), mean annual precipitation (MAP, mm yr.$^{-1}$) and the Cramer–Prentice plant-available moisture index (α). Results where the reconstructions made using the different numbers of analogues are significantly different from one another (95% confidence limit) are shown in italics; results where the reconstructions differ significantly (95% confidence limit) from the appropriate observed values are shown in bold; results where the reconstructions made using either 5 or 10 analogues different from the results obtained by automatic selection of the number of analogues, as shown in Table 1, are marked with an asterisk (*).

Variable	Mean			RMSEP		r^2	
	Observed	10 analogues	5 analogues	10 analogues	5 analogues	10 analogues	5 analogues
MTCO	10.2	**9.9***	**10.1**	2.5	2.3	0.88	0.91
MTWA	21.3	21.1	21.3	2.1	1.9	0.88	0.91
MAT	15.9	**15.6***	15.8	2.3	2.0	0.88	0.91
GDD5	4002	**3916***	3978	791	706	0.88	0.92
MAP	1122	**1120**	1122	269	248	0.88	0.91
α	0.71	***0.72***	*0.72*	0.10	0.09	0.90	0.93