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Palaeohydrology in climatological context: Developing the case for use of remote predictors in Australian streamflow reconstructions

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ABSTRACT

The dry continent of Australia experiences frequent periods of devastating regional drought, making high quality palaeohydrological reconstructions essential for water resource management and planning. In other parts of the world tree-rings form a core component of such reconstructions. Yet for much of Australia, annually resolved palaeohydrological reconstructions derived from tree-rings have proven elusive. The island state of Tasmania in the far south is an important exception, with over 50 tree-ring chronologies available. Coupled ocean-atmosphere processes that drive precipitation across mainland Australia also influence Tasmanian precipitation. Here, we provide a basic analysis of how geographic relationships between important drivers of seasonal Tasmanian streamflow and potential streamflow predictors such as tree-ring chronologies may extend the spatial applicability of Tasmania's tree-ring predictors beyond the local context. We find clear geographically and seasonally defined patterns in Tasmanian streamflow that are reflected in the relationships between individual Tasmanian tree-ring chronologies and their relationships with streamflows. We find strong evidence that quality Tasmanian summer (DJF) streamflow reconstructions based on tree-rings are possible. Evidence also suggests that streamflow reconstructions for other seasons are also likely to be possible, especially as additional chronologies based on wood properties such as tracheid radial diameter, microfibril angle, density and cell wall thickness become available. Based on the relationships between streamflows and tree-ring chronologies, and between streamflows and major precipitation drivers across Australia, we conclude that Tasmanian tree-ring chronologies are likely to prove useful as predictors for seasonal streamflow reconstructions, particularly in eastern Australia. Successful streamflow reconstructions for a much broader portion of Australia than currently available will be invaluable for future water resource management and planning.

1. Introduction

Australia is a continent subject to recurring droughts, floods and fires (Fox-Hughes, Harris, Lee, Grose, & Bindoff, 2014; Hasson, Mills, Timbal, & Walsh, 2009; Ummenhofer et al. 2009, 2011; Verdon-Kidd & Kiem, 2009) and has experienced an increasing frequency of extreme events over recent decades (Alexander & Arblaster, 2009; Christidis, Stott, Karoly, & Ciavarella, 2013; Suppiah & Hennessey, 1998). As a consequence, the need to understand water resource dynamics has become increasingly urgent. Naturally high interannual variability in precipitation (Poff, Olden, Pepin, & Bledsoe, 2006; Puckridge, Sheldon, Walker, & Boulton, 1998) coupled with increasing temperatures and decreasing precipitation (Allan & Haylock, 1993; Lewis & Karoly, 2013; Murphy & Timbal, 2008; Timbal & Drosdowsky, 2012; Trewin & Vermont, 2010) over recent decades, has accentuated the need for high-quality projections of Australian hydroclimate for the mid-late 21st century.

Streamflow is a critical target for modelling future water availability in the landscape because it provides a spatially integrated measure of catchment level water availability and is a key determinant of ecosystem health. Ideally, streamflow projections would be based on long historical time series. However, of the streamflow

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records included in the Australian Bureau of Meteorology's reference dataset (available at www.bom.gov.au), 41% of records are less than 40 years in length and none exceed 61 years. Short records make it difficult to assess decadal and multi-decadal hydroclimatic variability. Extending these short hydrological records is essential for improving water availability projections and in order to better manage Australia's hydrological systems and the ecosystems and organisms that rely upon them (Cullen & Grierson, 2009; Isdale, Stewart, Tickle, & Lough, 1998; Kotwicki & Allan, 1998; Peel, Chiew, Western, & McMahon, 2000). Palaeohydrological reconstructions based on tree-rings have been extensively used in other parts of the world to extend records back hundreds, or even thousands, of years (e.g., Cook et al. 2013; Davi, Jacoby, Curtis, & Baatarbileg, 2006; D'Arrigo, Abram, Ummenhofer, Palmer, & Mudelsee, 2011; Devineni, Lall, Pederson, & Cook, 2013; Ferrero, Villalba, Membiela, Hidalgo, & Luckman, 2015; Lara, Villalba, & Urrutia, 2008; Meko, Therrell, Baisan, & Hughes, 2001; Stahle, Fye, & Therrell, 2003; Stockton & Jacoby, 1976; Woodhouse, Gray, & Meko, 2006). These reconstructions indicate significant hydrological variability over millennial time scales, including the occurrence of regional scale 'mega-droughts' (Stahle, Fye, Cook, & Griffin, 2007; Woodhouse & Overpeck, 1998). To date, however, relatively few highly resolved (annual or better) Australian palaeohydrological reconstructions have been produced and those that exist are concentrated in two locations: the far north (D'Arrigo, Baker, Palmer, & Anchukaitis, 2008; Isdale et al. 1998; Lough, 2007, 2011) and the southeast (Allen et al. 2015; Gallant & Gergis, 2011; Gergis et al. 2011). Cullen and Grierson (2009) autumn-winter precipitation reconstruction is the only tree-ring reconstruction for southwestern Western Australia so far. This geographic bias is largely due to the general lack of high-resolution precipitation or streamflow proxies across much of the continent.

Based on the opportunistic growth habits of many of Australia's woody plants (Heinrich & Allen 2012), it has not thus far been possible to develop annually dated hydrological reconstructions based on tree-rings for much of the continent. Recently, however, Ho, Verdon-Kidd, Kiem, and Drysdale (2014) have indicated that the use of remote proxies in palaeohydrological reconstructions for some regions may be plausible. Through an evaluation of relationships between rainfall in the Murray Darling Basin (MDB) area and rainfall in areas remote from that region, Ho et al. (2014) identified key locations from which palaeo-proxies may be useful for future reconstructions of annual streamflows in some MDB subcatchments. They also noted some of the dominant ocean-atmosphere processes driving rainfall over both the target and remote regions. Ho et al.'s (2014) study was based on annual data, but geographic signatures in the relationships between specific ocean-atmosphere processes affecting SEA precipitation are highly seasonal (Risbey, Pook, McIntosh, Wheeler, & Hendon, 2009). Therefore, a logical extension of Ho et al.'s (2014) study would be to target seasons (not necessarily limited to traditional seasons) for which palaeo-proxies reflect local hydroclimate and there are also significant dynamic relationships between precipitation/streamflow in the local and target regions (e.g. see Pezza, Simmonds, & Renwick, 2007; Risbey, Pook, McIntosh, Wheeler, et al., 2009; Ummenhofer et al. 2009; Verdon, Wyatt, Kiem, & Franks, 2004). Given the lack of locally available and highly resolved proxies for many regions in Australia, this work would provide an important conduit for the development of palaeohydrological reconstructions in new areas or for specific seasons. Clearly articulated links between local and remote hydroclimate also provides an underlying rationale for inclusion of remote proxies in a specific reconstruction.

To date, the vast majority of long and annually resolved Australian tree-ring records originate from Tasmania in southeastern Australia. While many of the tree-ring sites are located in western Tasmania, there are also some records from the east (Fig. 1). The dominant drivers of seasonal precipitation across Tasmania differ by subregion (see below) and previous work demonstrates clear links between ocean-atmosphere processes and precipitation (Risbey, Pook, McIntosh, Wheeler, et al., 2009). Generally shallow soils and relatively few diversions of many of Tasmania's rivers mean that Tasmania's streamflow is highly correlated with precipitation across individual catchments (Robertson et al. 2010; Figure S1). In this study, we consider the possibility of using Tasmanian tree-ring chronologies as remote predictors in palaeohydrological reconstructions for other parts of Australia. However, in contrast to Ho et al.'s (2014) study which began with analysis of relationships between precipitation over one catchment and precipitation in remote catchments, we begin with an examination of interrelationships amongst catchment flows across the spatially limited Tasmanian domain, and how flows in these different catchments relate to important drivers of precipitation over the region. We then assess relationships between the Tasmanian tree-ring records (≥200 years in length) and Tasmanian streamflow to determine whether there are strong geographical and seasonal relationships that are associated with known regional precipitation drivers. Such a localised analysis of relationships should precede attempts to include the chronologies as predictors for palaeohydrological reconstructions in remote catchments. We then discuss how these tree-ring – streamflow relationships, in the context of dominant ocean-atmosphere processes, may be useful for the development of much-needed palaeohydrological reconstructions elsewhere in Australia. The study is particularly timely as the Past Global Changes (PAGES) 2 K effort turns its attention to hydroclimate reconstructions.

2. Materials and methods

2.1. The study area

Although Tasmania comprises only a small part of Australia (Fig. 1), the rugged mountainous west of the state casts a strong rainshadow effect over the generally lower elevation east. Western Tasmania typically receives 2000–3000 mm precipitation annually, while eastern Tasmania receives 500–600 mm (see www.bom.gov.au). In the west, the cool season is demonstrably wetter than the warm season and there is a pronounced seasonal cycle in precipitation that is much less apparent in eastern Tasmania (Shepherd, 1995).

The importance of large scale ocean-atmosphere processes such as El-Niño –Southern Oscillation (ENSO), the Southern Annular Mode (SAM), the Interdecadal Pacific Oscillation (IPO), the Indian Ocean Dipole (IOD) and atmospheric blocking over Australia is well known (Hendon, Thompson, & Wheeler, 2007; Ho et al. 2014; Kiem & Verdon-Kidd, 2009; Kuhnel, McMahon, Finlayson, & Haines, 1990; McMahon & Finlayson, 2003; Meneghini, Simmonds, & Smith, 2007 Meyers, Macintosh, Pigot, & Pook, 2007; Murphy & Timbal, 2008; Peel, McMahon, & Finlayson, 2002; Pezza et al. 2007; Piechota, Chiew, Dracup, & McMahon, 1998; Pook, McIntosh, & Myers, 2006; Pook, Risbey, & Mcintosh, 2010; Power, Casey, Folland, Colman, & Mehta, 1999; Risbey, Pook, McIntosh, Wheeler, et al., 2009, Risbey, Pook, McIntosh, Ummenhofer, & Meyers, 2009; Timbal & Drosdowsky, 2012; Ummenhofer et al. 2009; Vance, van Ommen, Curran, Plummer, & Moy, 2013; Verdon et al. 2004). Despite the small size of Tasmania, there are clear seasonal and regional differences in the impact of these systems on precipitation across both Tasmania and the broader Australian region (Grose et al. 2010; Risbey, Pook, McIntosh, Wheeler, et al., 2009). The following is a brief description of the