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Long-term variability of the leading seasonal modes of rainfall in south-eastern Australia

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ABSTRACT

Knowledge of temporal and spatial variability of climate and rainfall can improve agriculture production and can help to manage risks caused by climate variability. Available high-quality monthly rainfall data from the Australian Bureau of Meteorology for 1907–2011 was used to investigate the leading seasonal mode of the long-term rainfall variability over south-eastern and eastern Australia. Spatio-temporal variations of seasonal rainfall and their connection to oceanic-atmospheric predictors were analysed. The links between the first two Principal Components of rainfall of each season with lagged Southern Oscillation Index (SOI), Indian Ocean Dipole (IOD) and Southern Annular Mode (SAM) were season-dependent. The relationship between these climatic indices changed within both inter-seasonal and decadal time scales. Spring and winter rainfalls were continuously positively correlated with lagged (SOI). However, summer rainfall variations indicated negative correlations with lagged SOI which increase from 1970. The correlations between lagged SOI and autumn variations were weak and change to a stronger relationship from 1990. Correlations between lagged (IOD) which varied across all seasons have recently been increasing. Variations in rainfall across all seasons were highly correlated with Southern Annular Mode (SAM) with different signs. Overall, the relationship between predictors and seasonal rainfall has changed after 1970. The results of running correlations between leading modes of seasonal rainfall and lagged SOI, SAM, and IOD indices indicates non-stationary in these links. The relationships of climatic indices and leading modes of seasonal rainfall changed since 1970, with stronger evidence in case of IOD. Recent changes in the relationships between climatic indices and rainfall need to be considered in climate prediction systems. The results of this study suggests that improvement in statistical regional rainfall forecast system with fixed climatic indices for each season and region is achievable by using suitable seasonal and regional climatic indices.

1. Introduction

Agricultural production and the population of Australia are both concentrated in the south-eastern part of the country. Rainfall over south-eastern Australia, and indeed over most of the continent, is highly variable spatially and across time scales ranging from daily to decadal. Rainfall and temperature regimes have a significant impact on agriculture decision points both in time and space (Nelson et al., 2010). Fine resolution climate information can be incorporated into farm business decisions and help to manage climate related risks (Hammer et al., 2001).

Seasonal rainfall patterns over Australia and related atmospheric circulation have been the topic of many studies (Drosdowsky and Chambers, 2001; Kirono et al., 2010; Murphy and Timbal, 2008; Nicholls, 2010; Risbey et al., 2009; Wang and Hendon, 2007). The link between rainfall variability of eastern and south-eastern Australia and oceanic atmospheric variations is highly seasonal and regional specific (Drosdowsky and Chambers, 2001; Evans et al., 2009; Kirono et al., 2010; Murphy and Timbal, 2008; Schepen et al., 2012). In particular, the El Niño–Southern Oscillation (ENSO) is indicated as the major driver of inter annual and decadal climate variability of Australia (Evans and Allan, 1992; Kirono et al., 2010; Robertson et al., 2013; Wang and Hendon, 2007). Temperatures in the tropical Indian Ocean also have an influence on eastern and south-eastern Australia's rainfall, particularly for winter rainfall (Cai et al., 2009; Nicholls, 1989; Verdon and Franks, 2005b; Verdon and Franks, 2006). The Indian Ocean Dipole (IOD) was found to be particularly important in the June-October period, which spans the wet seasons (spring-winter) over south-eastern Australia (Ashok et al., 2003; Risbey et al., 2009). The Southern Annular mode (SAM) (Hendon et al., 2007) is further considered as an extratropical source of variability that is mostly

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confined to the southwest and southeast of the continent (Risbey et al., 2009). The Madden–Julian Oscillation (MJO) (Wheeler and Hendon, 2004; Wheeler et al., 2009), which is linked to the ENSO, can influence rainfall in several areas of the continent in different seasons. The MJO's impact appears to be strongest in its effect on monsoon rains in the north of Australia (Risbey et al., 2009).

Different active times of Indian and Pacific Oceans, and interaction between ENSO and Indian Ocean events, result in complex relationships between these oceanic – atmospheric phenomena and Australian rainfall (Cai et al., 2013; Meyers et al., 2007). At decadal timescales, Australia and particularly its south-eastern regions have a high level of rainfall variability. The drivers for this are still not totally clear, although some of the variability is linked with variations in relative frequency of El Niño and La Niña events on decadal timescales. Interdecadal variability is particularly high across eastern Australia (Kiem and Franks, 2004; Kiem et al., 2003; Verdon et al., 2004).

Statistical seasonal forecast systems for Australia based on SSTs variations over the Pacific and Indian Oceans have been used at the Australian Bureau of Meteorology (Alves et al., 2003; Drosdowsky and Chambers, 2001; Stone et al., 1996). More recent Australian Bureau of Meteorology dynamical forecasts are determined by statistically calibrating rainfall from the Predictive Ocean Atmosphere Model (POAMA) (Hudson et al., 2011; Schepen et al., 2012). Using the strengths of the statistical and dynamical models is suggested to maximize the spatial and seasonal accuracy of seasonal rainfall forecasts (Schepen et al., 2012). The interaction between ENSO and Indian Ocean events, extreme events related mostly to the Indian Ocean events, and changes in the frequencies of IOD events were suggested to explain the recent unexpected changes in Australian rainfall and failed forecasts (Cai et al., 2009, 2013; Ummenhofer et al., 2009). However, further analysis is required to investigate the stability of the link between climate indices and seasonal rainfall variations of south-eastern and eastern Australia as predictors used in the Australian statistical seasonal rainfall forecast systems (Schepen et al., 2012; Drosdowsky and Chambers, 2001; Gergis et al., 2012; Kirono et al., 2010).

This study explores the temporal variability of the relationship between reasonable lags (up to six months) of climate indices and the main variations of seasonal rainfall across south-eastern and eastern Australia. Special emphasis is made on the seasonal differences in rainfall variability. The aims of this study are: 1) to provide an overall overview and summary of spatio-temporal seasonal rainfall variations from interannual to inter – decadal for south-eastern and eastern Australia; 2) to reconfirm the main mechanism of seasonal rainfall variations over southern and south-eastern Australia rainfall; 3) to check the stability of links between seasonal rainfall and different lags of major oceanic-atmospheric predictors (SAM, IOD and SOI) over more than 100 years data.

1.1. *Data and area of study*

The dataset in this study consists of 137 Australian Bureau of Meteorology (BoM) high-quality rainfall stations across south eastern and eastern Australia over 1879–2011 (Fig. 1) (Lavery et al., 1997). Seasons in this study are the standard calendar Australian seasons, defined as: December–January–February (DJF) for summer, March–April–May (MAM) for autumn, June–July–August (JJA) for winter, and September–October–November (SON) for spring. Missing data were dealt with following two rules: First, times with missing values at more than 30% of stations were omitted from the dataset. This resulted in the elimination of data before 1907. Secondly, the rest of missing values were replaced by the mean of the four closest stations in terms of geographical distance. This leads a

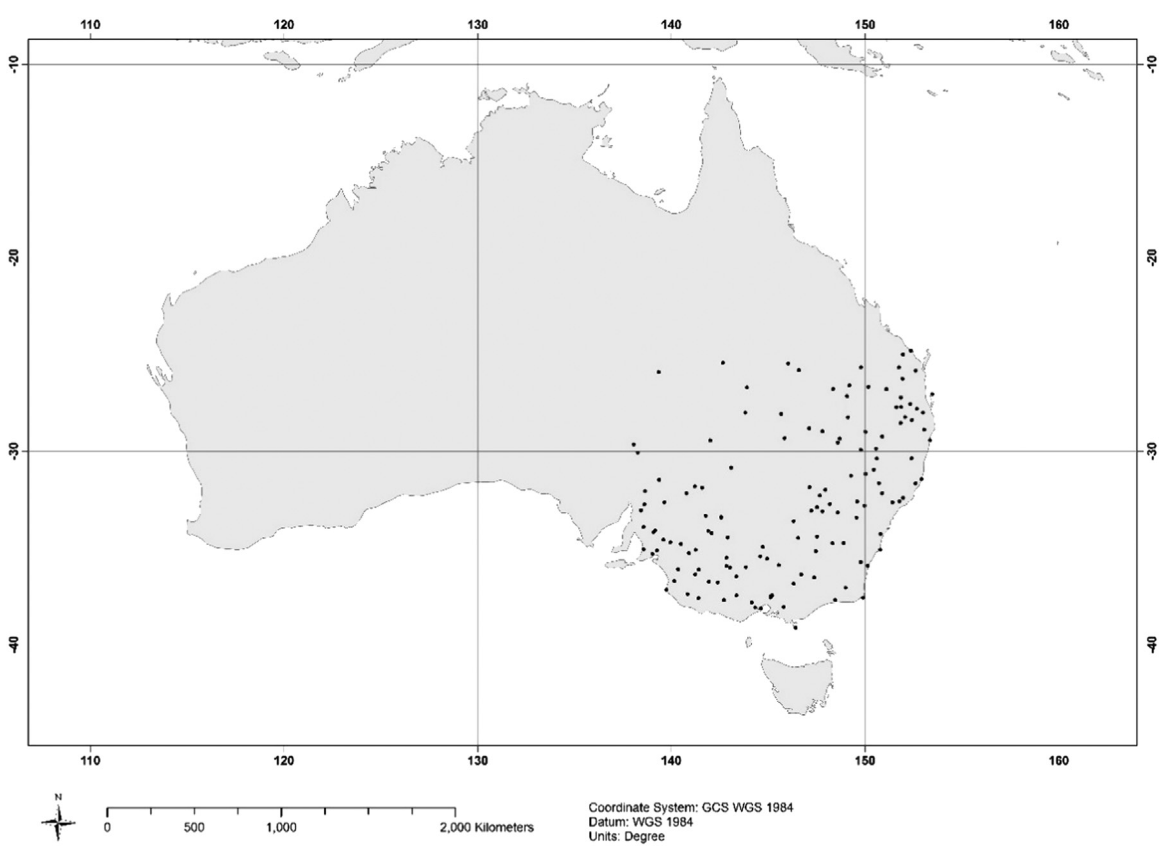

Fig. 1. Location map indicating high quality stations used in this study.