Spatial trends in synoptic rainfall in southern Australia

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[1] This work assesses spatial and temporal changes in rainfall in southern Australia over the period 1990–2009. Rainfall is assessed by season and according to the synoptic system generating the rainfall. Rainfall decreases over the period across much of the southwest, with the most significant decrease occurring around 2000. These changes are associated with frontal and cutoff systems. Frontal systems dominate the timing and changes of rainfall in western Tasmania. In the southeast, the timing and magnitude of rainfall changes are more closely associated with cutoff systems and show consistent decreases in the early 1990s. The largest reductions in rainfall in the southeast are in the Alpine region and are due to cutoffs and fronts and exhibit seasonal and spatial variations consistent with the climatologies of these systems. **Citation:** Risbey, J. S., M. J. Pook, and P. C. McIntosh (2013), Spatial trends in synoptic rainfall in southern Australia, *Geophys. Res. Lett.*, *40*, 3781–3785, doi:10.1002/grl.50739.

1. Introduction

[2] Rainfall exhibits substantial variability in space and time. In the Australian region, rainfall is characterized by large interannual and multidecadal variability and shows different trends in different regions of the continent [*Nicholls et al.*, 1997; *Gallant et al.*, 2007]. Variation in rainfall with space across Australia is created by differences in underlying topography, differences in proximity to oceans, and due to the fact that the continent spans different climate zones and is exposed to different mixes of synoptic systems in the different zones [*Risbey et al.*, 2009a]. Variation in rainfall with time is associated with the passage of synoptic systems and the drivers of their variability from year to year in the atmosphere-ocean system [*Risbey et al.*, 2009b].

[3] Since synoptic systems control much of the variability in space and time of rainfall, it is pertinent to examine the contributions of synoptic systems to the underlying spatial rainfall trends across the continent. Since different synoptic types respond to different large scale drivers, the examination of synoptic contributions helps establish the broader causes of rainfall trends [*Risbey et al.*, 2013]. This paper provides an assessment of synoptic system contributions to recent spatial rainfall changes across southern Australia, focusing on a time period encompassing the recent drought.

[4] There is no single metric that captures long period variations in rainfall. Some series may exhibit near linear trends for some decades and then reverse. Other series may undergo a step change or sequence of step changes. We examine both linear trends and step changes here to reveal different aspects of the longer period behavior. The trends provide an overall assessment of change and the steps provide an indication of when changes occurred. We address whether these metrics are spatially coherent and where they differ for different synoptic systems.

2. Data and Methods

[5] The synoptic database for this analysis is a manual identification of the synoptic system producing rain for all rain days in the southwest of Australia [*Pook et al.*, 2012], southeast of Australia excluding Tasmania [*Pook et al.*, 2006], and Tasmania [*Pook et al.*, 2010] in the months April–October between 1985 and 2009. Daily synoptic classifications were only available for these months, but they span much of the rainfall season in most parts of southern Australia [*Stern et al.*, 2000]. Tasmania has a synoptic classification separate from the rest of the southeast, because it has significant topography at higher latitude and a distinct climate.

[6] The regions used to identify the synoptic systems are shown in Figure 1. For each of the synoptic regions, we have attributed rain in the portions of the continent likely to be influenced by the synoptic systems transiting that region, hereafter designated southwest, southeast, and Tasmania, respectively. The rainfall regions are shown in Figure 2 and are slightly offset from the synoptic boxes in the downstream direction to allow for the typical movement of systems during the 24 h analysis period.

[7] The classification of synoptic systems uses the mean sea level pressure field, the 500 hPa height field, and the 1000–500 hPa thickness field from the NCEP/NCAR reanalysis [*Kalnay et al.*, 1996]. The main synoptic systems of interest in this study are frontal systems and cutoff low systems [*Pook et al.*, 2006]. That study also identifies persistent stream flow conditions as a synoptic type, but they are mostly important in the near coastal zone in the southeast and are not discussed here.

[8] Rainfall across the continent is assessed using the Australian Water Availability Project (AWAP) data [*Raupach et al.*, 2009; *Jones et al.*, 2009]. The rainfall data on the $0.05° \times 0.05°$ grid was smoothed to a $0.5° \times 0.5°$ grid for analysis since the extra resolution is not needed here.

[9] Changes in rainfall are assessed for each of the seasons April, May, June (AMJ); June, July, August (JJA), and August, September, October (ASO). The seasons overlap to maintain 3 month seasons in the April–October period in which synoptic classifications were available.

[10] Step changes in rainfall are assessed by determining the most significant year to year change in the gridded rainfall series using a standard t test for difference of means [*Press et al.*, 2007]. A condition is imposed that steps must

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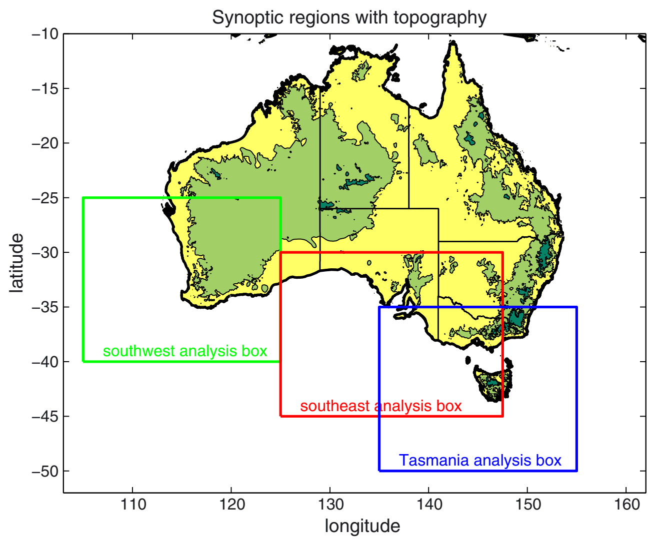

Figure 1. Map of Australia showing the three synoptic analysis regions used and the underlying topography. The southern Alps are highlighted by the dark green shading in the southeast corner of the mainland.

contain at least 10% of the total years on each side of a step. In each of the figures shown here, most grid points for all seasons and synoptic rainfall types yield step changes significant at the 95% level. For the linear trend analyses, the trends are only significant at this level in the Alpine region of the southeast and parts of the southwest.

3. Rainfall Climatology

[11] The spatial distribution of rainfall in southern Australia for the April–October period of synoptic analysis is shown in Figure 2a and shows maxima in the southwest corner of Western Australia, the Alpine region of southeastern Australia, and the west of Tasmania. The contributions to the total rainfall from frontal systems and cutoff systems are shown in Figures 2b and 2c, respectively. Fronts provide the main source of rainfall for the maximum in the far southwest and western Tasmania, whereas cutoff systems tend to dominate fronts in the southeast (excepting the Bonney coast). Together, fronts and cutoffs account for about 80% of the rainfall across the regions shown during the April–October period.

4. Rainfall Variability and Change

[12] There is no unambiguous point in time to assess rainfall trends because the variation in rainfall across these regions is so large over multidecadal time scales, and any trend analysis reflects the period chosen. The southern half of Australia experienced a prolonged drought in the period from the mid-1990s to 2009 [*Watkins and Trewin*, 2007; *Gallant et al.*, 2007; *Murphy and Timbal*, 2008; *Timbal*, 2009; *Risbey et al.*, 2013] and is the subject of the trend analysis here. The drought was more exceptional in the southeast than the southwest, though the latter region has a longer running rainfall deficit extending since the mid-1970s [*Gallant et al.*, 2007].

[13] In regard to the 1996–2009 drought period, one can ask whether the rainfall decreases uniformly in 1996 across southern Australia, and whether the decrease occurs at similar or different times for different synoptic system types. One way to gauge this is to assess the time at which the most significant step in rainfall occurs in the period 1985–2009 prior to and including the drought. This is the period for which we have synoptic classifications and provides a decade prior to the start of the drought to allow earlier steps to be identified as well as those occurring during the drought. The results of this analysis are shown in Figure 3. Here the year in which the significant step occurs is color coded and is shown for separate seasons and for the total rain series and the front and cutoff rain series.

[14] For the AMJ season (Figure 3, top row), the total rain series (Figure 3, top left) shows a step around 2000 for much of the southwest, with a step around 1990 along the southern coast. In the southeast, the step is mostly in the early 1990s. The overall pattern and timing of steps in total rain in the southeast is well-reflected in the timing of steps in cutoff rain (Figure 3, top right), whereas in the southwest, the total rain step pattern and timing has elements of both frontal rain (top middle) and cutoff rain.

[15] For JJA (Figure 3, center row), the timing of steps in total rain (Figure 3, center left) is similar to the AMJ period. For the southeast again, the timing and pattern of steps in total rain is better reflected by cutoff rainfall (Figure 3, center right) than frontal rainfall (Figure 3, center middle).

[16] For ASO (Figure 3, bottom row), the pattern of steps in total rainfall (Figure 3, bottom left) switches to a more uniform step around 1990 in the southwest and a step around 2000 in the southeast. The pattern and timing of steps in total rainfall in ASO is better matched by frontal rain in the southwest and cutoff rain in the southeast.

[17] In Tasmania, the timing and direction of steps in total rainfall most closely follows frontal rainfall in the west of the state and cutoff rainfall in the east of the state. This is consistent with the relative shares of rainfall by these synoptic types evident in Figure 2 for the two sides of the state.

[18] The direction of steps in the regions favors decreases (steps to drier conditions) over increases (wetter steps) for the analysis period. The main exceptions to this are the increase steps in frontal rainfall for the southwest corner of the southwest region and for western Tasmania.

5. Rainfall Trends

[19] Most of the steps in rainfall considered in the previous section are decreases in rainfall and are associated with the mid-1990s to 2009 drought. The association with the drought is also evident in the years of the steps—typically the early 1990s or around 2000 depending on location and season. In order to capture the trend in rainfall across the steps, we assess the linear trend in rainfall for the period 1990–2009 in Figure 4.

[20] The linear trend for total rainfall is shown in Figure 4 (left column) for the AMJ, JJA, and ASO seasons. There are clear regional differences in the magnitude of the trend. However, the broad pattern shows drying in the southwest (except for the south coast) and drying in the southeast (except for some northern areas). In each season the southwest trend pattern of total rainfall is a closer match to the trend pattern for fronts (Figure 4, middle column), while the southeast (excepting Tasmania) is more closely matched by the cutoff trend pattern (Figure 4, right column).

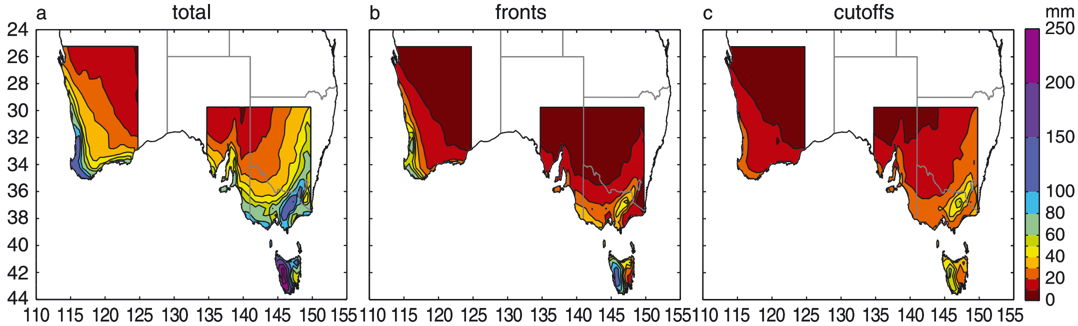

Figure 2. April–October average rainfall (mm) over years 1985–2009 for (a) total rainfall from all systems, (b) rain from frontal systems only, and (c) rain from cutoff systems only.

[21] The drying trend in the southeast is a maximum over the areas of topography in the southern Alps and western Tasmania (except for ASO in western Tasmania). In each season the drying trend over the southern Alps is contributed to by a drop in both frontal and cutoff rainfall. The fronts contribute more to the Alps reduction than cutoffs in JJA (when the westerlies are closest to the equator), but less than cutoffs in the shoulder seasons. Further, the negative frontal trend tends to decrease rainfall on the western slope of the Alps, while the negative cutoff trend decreases rainfall on the north and east slopes of the Alps, consistent with typical flow in these systems. Frontal rainfall in the Alps favors orographic ascent in westerly streams, whereas cutoff systems generate significant rainfall in warm, moist upglide from the northeast [*McIntosh et al.*, 2007]. The changes in rainfall in the mountains of western Tasmania (decrease in

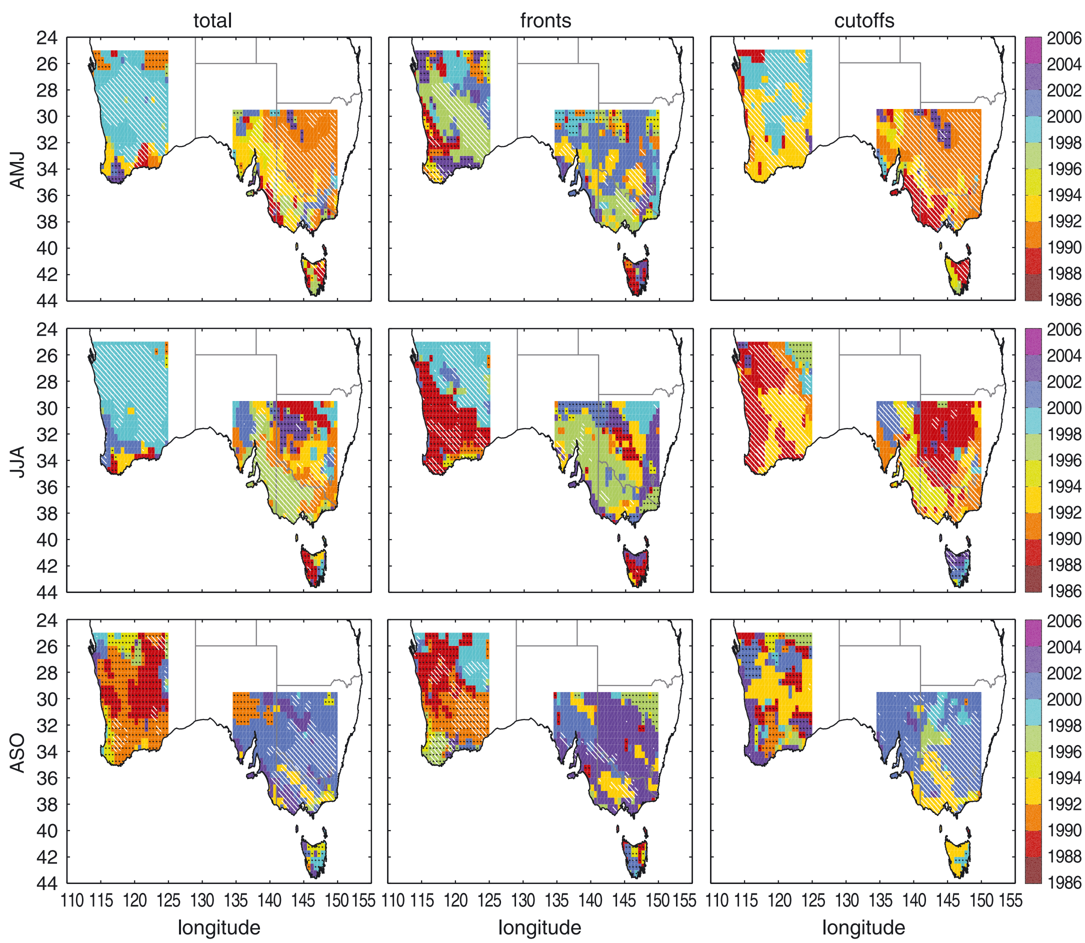

Figure 3. Year in which the most significant step in rainfall series occurs in the period 1985–2009 for (left column) total rainfall from all systems, (middle column) rain from frontal systems only, and (right column) rain from cutoff systems only. The top row is for months AMJ, the middle row for JJA, and the bottom row for ASO. Steps represent decreases unless indicated by the presence of a black dot, which denotes increases. The white hatched areas indicate steps significant at the 95% level.

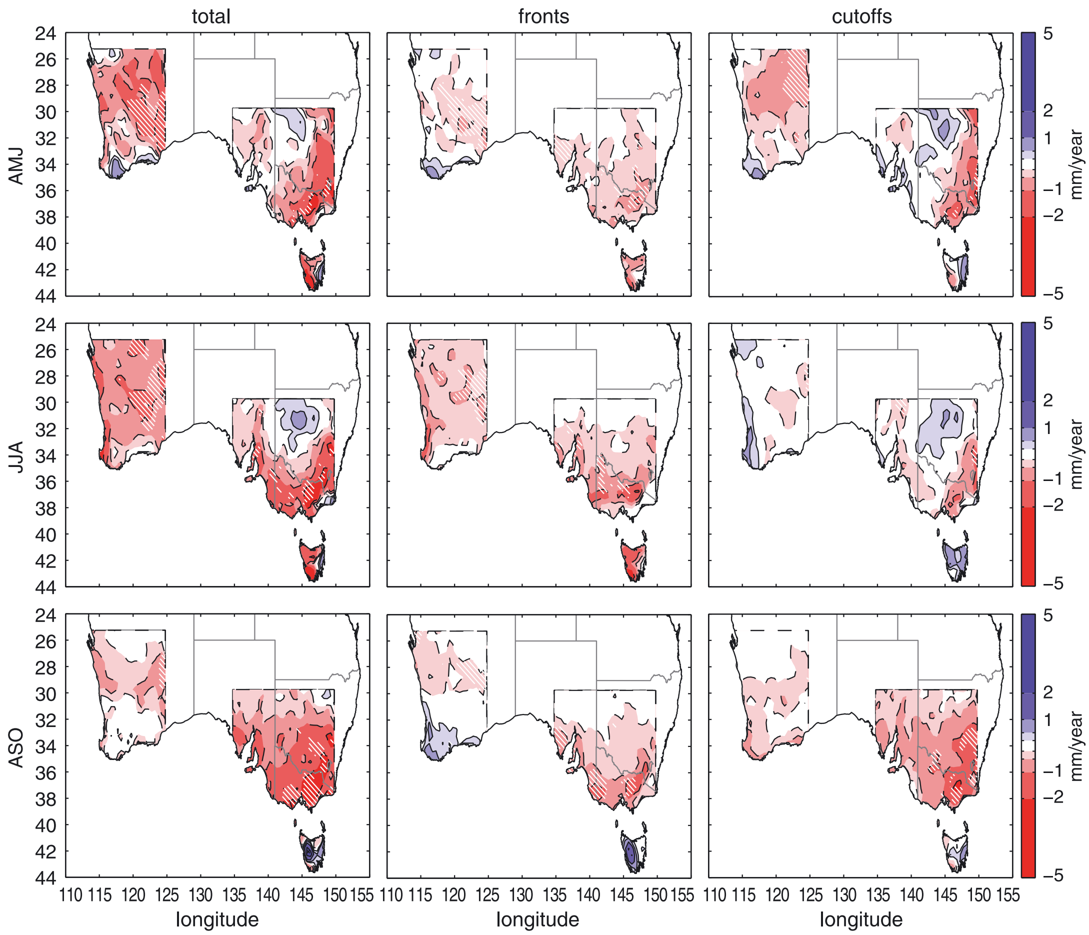

Figure 4. Linear trend (mm/year) in rainfall series over the period 1990–2009 for (left column) total rainfall from all systems, (middle column) rain from frontal systems only, and (right column) rain from cutoff systems only. The top row is for months AMJ, the middle row for JJA, and the bottom row for ASO. Trend areas significant at the 95% level are indicated by white hatching. The innermost contour levels are ±0.2 and 0.5 mm/year.

AMJ, JJA; increase in ASO) are much more closely associated with changes in frontal rainfall than cutoff rainfall as expected.

[22] Note that the southernmost part of the southwest region has weak trends in all seasons. In ASO, there is no trend in total rainfall there, but compensating increases in frontal rainfall (consistent with the step in Figure 3 toward wetter conditions) and decreases in cutoff rainfall.

6. Conclusions

[23] The spatial changes and trends in rainfall in southern Australia over the period since 1985 show broad similarities in subregions (southwest, southeast, western Tasmania), but clear differences from subregion to subregion. The reduction in rainfall in the southwest is most evident from around 2000 in AMJ and JJA. The timing and changes in rainfall there are associated with both frontal and cutoff rainfall.

[24] In the southeast, the reduction in rainfall occurs in the early 1990s for AMJ and JJA, but the most significant step drop is much later for the ASO season. The timing and magnitude of rainfall reductions is more closely associated with cutoffs in the southeast, but fronts also contribute, especially on the western slope of the Alps. In western Tasmania, the changes in rainfall timing and amount reflect mostly changes in frontal rainfall.

[25] The synoptic signature of rainfall can be reasonably well-decomposed from the total rainfall by accounting for the synoptic system responsible for each rainfall event. That in turn highlights the systems that tend to be most important in particular regions. During the April–October period, two synoptic types (fronts and cutoffs) broadly suffice to explain the patterns and timing of rainfall changes across southern Australia.

[26] Explanations of rainfall changes should be consistent with an understanding of which processes drive the dominant synoptic types in a region. Both fronts and cutoffs are associated with baroclinic zones (particularly for development) and the longwave pattern (for steering). However, fronts are typically embedded in a westerly stream and respond to latitudinal (north-south) shifts in baroclinic zones and the westerly stream [*Frederiksen and Frederiksen*, 2007]. By contrast, cutoffs are equatorward of the westerly stream and respond more directly to zonally asymmetric excursions of the stream and shifts in the locations of the longwave troughs and ridges [*Risbey et al.*, 2013]. That implies that a fuller understanding of causes of rainfall changes in southern Australia needs to account for longitudinal as well as latitudinal shifts in the storm tracks.

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