Modeling Impacts of Vegetation Cover Change on Regional Climate

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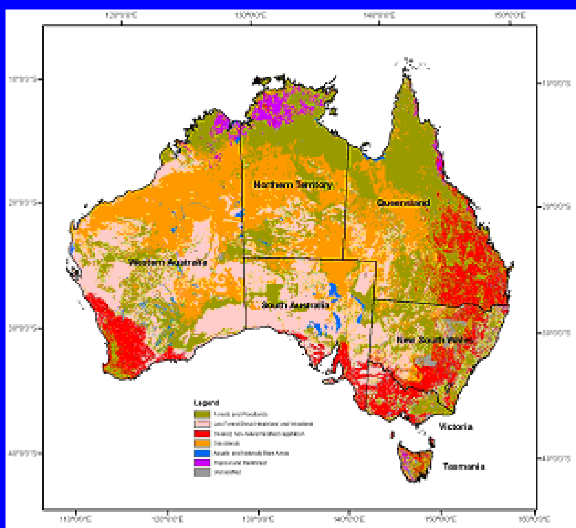

Executive summary

Extensive areas of native vegetation in Queensland and other states have been cleared for agriculture, improved pastures and urban development.

However, the potential impact of land clearing on Australia's climate has been largely ignored in current climate change projections and policies.

In this study, we addressed the question - *is Australia's regional climate sensitive to land cover change*?

We conducted simulation experiments using the CSIRO MARK 3 climate model to compare the effects on regional climate based on differences between pre-European and 1990 vegetation cover. The two experiments aimed to reproduce the Australian climate for the period 1951-2003, with the only difference being the conversion of land cover from native vegetation to pastures and crops.

Consistent with actual climate trends since the 1950s, simulated annual and seasonal surface temperatures showed statistically significant warming for eastern Australia (0.4-2°C) and southwest Western Australia (0.4-0.8°C), being most pronounced in summer.

Mean summer rainfall showed a decrease of 4-12% in eastern Australia and 4-8% in southwest Western Australia which coincided with regions where the most extensive land clearing has occurred.

Further, the study found an increase in temperatures on average by 2°C, especially in southern Queensland and New South Wales, for the recent 2002/2003 drought.

The findings suggest that the large scale clearance of native vegetation is amplifying the adverse impacts associated with El Niño drought periods, which together with rainfall deficiency, is having a strong impact on Australia's already stressed natural resources and agriculture.

Implications for Policy: We suggest that policy needs to recognise that climate change is a two-way process, and that broad scale clearing of native vegetation cover has a strong influence on climate in addition to greenhouse gases. Protecting and restoring Australia's native vegetation therefore needs to be a critical policy and management consideration in mitigating the effects of climate change.

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MODELING THE IMPACT OF ANTHROPOGENIC LAND COVER CHANGE ON AUSTRALIA'S REGIONAL CLIMATE

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Abstract

The Australian landscape has been transformed extensively since European settlement. However, the potential impact of historical land cover change (LCC) on regional climate has been a secondary consideration in the climate change projections. In this study, we analyzed data from a pair of ensembles (10 members each) for the period 1951-2003 to quantify changes in regional climate by comparing results from pre-European and modern-day land cover characteristics. The results of the sensitivity simulations showed the following:**:** a statistically significant warming of the surface temperature, especially for summer in eastern Australia (0.4-2°C) and southwest Western Australia (0.4-0.8°C); a statistically significant decrease in summer rainfall in southeast Australia; and increased surface temperature in eastern regions during the 2002/2003 El Niño drought event. The simulated magnitude and pattern of change indicates that LCC has potentially been an important contributing factor to the observed changes in regional climate of Australia.

1.0 Introduction

There is a growing body of scientific evidence that anthropogenic land cover change (LCC) is having a significant effect on global and regional climate [*Zhao et al*., 2001]. LCC affects the energy balance directly by changing surface albedo and indirectly by influencing the utilization of solar radiation for evaporation, transpiration and transport of sensible, latent and ground heat fluxes [*Pielke et al*., 2002; *National Research Council*, 2005], or by non-linear feedbacks through changes in soil moisture and surface hydrology [*Rial et al*., 2004]. Recent modelling studies for the Amazon Basin have shown that the extensive deforestation has reduced regional moisture cycling and deep convection in the atmosphere with circulation teleconnections to mid and higher latitudes [*Roy and*

Avissar, 2002; *Werth and Avissar*, 2002]. *Los et al.,* (2006) also reported a positive feedback between deforestation and changes in precipitation in the Sahel, leading to a 20-40% reduction in annual rainfall and hence increased aridity.

Like the Sahel, the Australian landscape is an extremely fragile system that responds quickly to low amplitude climate perturbations. Australia has a naturally highly variable climate strongly influenced by the ENSO cycle, which has a pronounced impact on temperature and rainfall extremes in eastern Australia [*Nicholls et al.*, 1997]. The impact of the major persisting drought in eastern Australia and the Murray-Darling Basin (Australia's most productive agricultural region) is now stimulating much public debate on the natural mode of climate variability and appropriate land and water use policies. However, the effect of LCC on the Australian climate has been a secondary consideration for climate change projections, despite the clearing of over 1.2 million km^2 or ~13% of the continent since European settlement. The regions of greatest LCC are southeast Australia (New South Wales, Victoria and South Australia, cleared 1800-mid 1900s), southwest Western Australia (1920-1980s), and more recently inland Queensland [*AUSLIG*, 1990; *Barson et al.*, 2000]. *Nair et al.,* [2007], using satellite observational data, showed that replacement of half the native vegetation by croplands in southwest Western Australia resulted in a decrease of 7 Wm^{-2} in radiative forcing. They argue that general circulation models tend to underestimate the radiative forcing of LCC by a factor of two.

Human-induced climate forcings (e.g., increasing levels of CO_2) are already affecting Australia's climate over and above the high natural variability [*Nicholls*, 2006]. During the past century, Australian temperatures have warmed by ~1.0 $^{\circ}$C with the warming most pronounced in eastern Australia since 1950. At the same time, the rainfall has increased in northwest Australia and decreased in central and southeast Queensland, southwest Western Australia and southeast Australia, with the trends being more enhanced during the last 50 years. Some studies have explicitly considered the impact of LCC on Australia's regional climate [*Narisma and Pitman*, 2003, 2004; *Pitman et al.*, 2004; *Lawrence*, 2004]. These studies have suggested that some of the observed changes in temperature and rainfall over eastern and southwest Australia can be attributed to human-induced LCC. However, the approach used in past studies has some important limitations, including the coarse spatial scale and classification of land cover data, choice of model domain, and the use of single simulations rather than ensembles, which can strongly influence the accuracy of model outcomes. The question then is - *is Australia's regional climate sensitive to land cover change*?

We addressed this question using simulations of a 10 member ensemble each for the period 1949-2003 to quantify changes in Australian regional climate resulting from anthropogenic LCC from pre-European to the modern day (1990) conditions. The experimental design used the CSIRO Mark 3 atmospheric GCM [*Gordon et al*., 2002], the latest satellite image based vegetation parameter maps and high-spatial resolution (10 km) soil characteristics. As a result, this study gives a reliable estimate of the sensitivity of the Australian regional climate to historical anthropogenic LCC.

2.0 Methodology

2.1. Global and Australian land surface parameters

The original land surface parameters of the CSIRO Mark 3 atmospheric GCM, developed from the global land surface climatology of *Dorman and Sellers* [1989], were unable to reliably represent the fine-scale heterogeneity of the modified Australian land cover relative to its pre-European distribution due to their coarse spatial resolution. For this reason, we used more recent global land surface data with relatively fine spatial resolution, covering longer, more representative time periods, than were used in generating the land surface parameters of *Dorman and Sellers* [1989].

The mapping of Australian LCC was derived from the structural and floristic vegetation maps of Australian vegetation, captured in 1985 [*AUSLIG*, 1990], and simplified to modern-day and pre-European land cover maps in the land cover classes according to *Graetz et al.* [1995]. This mapping was updated using LAI mapping derived from Pathfinder AVHRR satellite imagery for the period 1981 to 2001 at an 8 km spatial footprint [*Lawrence,* 2002, 2004]. The available global and Australian data of vegetation characteristics was translated to the vegetation classification based on the SiB approach used by the CSIRO model [*Sellers et al*., 1996; *Gordon et al*., 2002]. Pre-clearing land surface parameters of vegetation fraction, broadband surface albedo, LAI, surface roughness, and stomatal resistance were generated by extrapolating the modern-day values of remnant native vegetation to the pre-European extents of each land cover class. The extrapolation was performed for the Australian continent at an 8 km spatial resolution and aggregated using the approach of *Shuttleworth* [1991], thereby ensuring the seasonal dynamics captured by the satellite imagery were represented in monthly pre-European parameters [*Lawrence,* 2004].

2.2. Climate model and experimental design

The CSIRO climate model is a fully coupled atmosphere, land surface, sea ice and ocean model. The model horizontal resolution is T63 or ~1.8^{o} grid increment and 18 vertical levels [*Gordon et al*., 2002]. In this study, we used the uncoupled version where ocean and sea ice components were represented by observed seasonally varying sea surface temperatures and sea ice data [*Rayner et al*., 1996]. This experimental set-up followed the design of the Climate of the 20th Century project [*Folland et al*., 2002]. This allowed direct comparisons between the observed and modeled data even for individual El Niño and La Niña events, which are known to strongly influence the Australian climate [*Nicholls*, *2006*].

To evaluate the impacts of historical anthropogenic LCC on the Australian regional climate, we completed two sets of model simulations (ensemble of 10 each) for the period 1949-2003. The only difference between the experiments were prescribed characteristics of land cover parameters for Australian continent: the first experiment set had pre-European land cover characteristics, and the second had modern day land cover characteristics. Outside Australia, the land cover characteristics were set at modern day conditions for both experiments. The first two years of simulations were classed as a "spin up" period and were discarded. We analysed the annual averages and seasonal means for the 1951-2003 period averaged over all model ensembles for selected climate variables. The CSIRO T63 climate model performance is described in the work of *Cai et al.* [2003] and *Watterson and Syktus* [2007]. *Syktus et al.* [2003] found the AMIP-style simulations had good skill in simulating the mean seasonal and inter-annual variability of rainfall in Australia. Statistical significance was assessed using Student's t-test, following *Zwiers and Thiébaux* [1987], with a two-tailed test at 95% confidence level.

3.0 Results

The modeled results of the experiment are presented as the differences between the selected climate variables from the pre-European to the modern-day land cover conditions. These are: 1) the annual averages of surface temperature, rainfall, and near-surface soil moisture; 2) seasonal averages of summer (DJF) surface temperature, winter (JJA) surface temperature, summer average rainfall, winter average rainfall, and summer surface wind speed; and 3) summer surface temperatures for the 2002/2003 El Niño event.

3.1. Regional climate changes

The mean annual changes in surface temperature (Fig. 1) showed a warming of 0.1 – 0.6 $^{\circ}$C in eastern and northeast Australia and in southwest Western Australia, with a cooling of 0.1 – 0.4 $^{\circ}$C over remaining regions. The strongest anomalies of temperature increase coincided with coastal eastern and southwest Australia. These increases were statistically significant. The mean annual rainfall showed a decrease of 4-8% in southeast Australia, an increase of 4-12% over southern and central Australia and a decrease of up to 4% in southwest Western Australia. The rainfall decrease in southeast Australia was statistically significant. The annual average of near-surface soil moisture showed a statistically significant increase in southwest Australia and eastern Australia (Fig. 1).

The summer surface temperature (Fig. 2) showed a warming anomaly of 0.2-2.0 $^{\circ}$C for eastern Australia and 0.5 $^{\circ}$C for southwest Western Australia. The winter temperatures response was smaller and showed a similar pattern to summer, showing a statistically significant cooling over southwest Western Australia, and warming over coastal eastern Australia. Mean summer rainfall showed a decrease of 4-12% in eastern Australia and 4-8% in southwest Western Australia (Fig. 2), which were both statistically significant and coincided with regions with the most extensive LCC. Summer rainfall increased by 1-5% over central Australia and the remaining regions of Western Australia. During winter, the rainfall anomalies were weaker and mostly not statistically significant.

While the patterns of significant surface annual and seasonal surface temperature response showed good correspondence with the location of major areas of land cover modification in both summer and winter seasons, the patterns of significant rainfall changes were less coincident with the prescribed land cover modifications, especially for the winter season. The pattern and magnitude of simulated response of surface temperature and rainfall can be compared with the observed changes, in order to provide an indication of the potential impact of historical anthropogenic LCC on the regional climate of Australia. Direct comparison is difficult because model data is from time-slice sensitivity experiments while the observed seasonal surface temperature and rainfall data is available only for the second part of 20th Century.

Regional changes in the near-surface wind patterns showed a wind speed increase of up to 1 ms^{-1} in all seasons along the eastern seaboard, and of a smaller magnitude over southwest Western Australia (Fig. 1d). A statistically significant strengthening of the summer near-surface winds occurred along the eastern seaboard, and is attributed to reduced surface roughness resulting from replacement of native vegetation with seasonal crops and improved pastures.

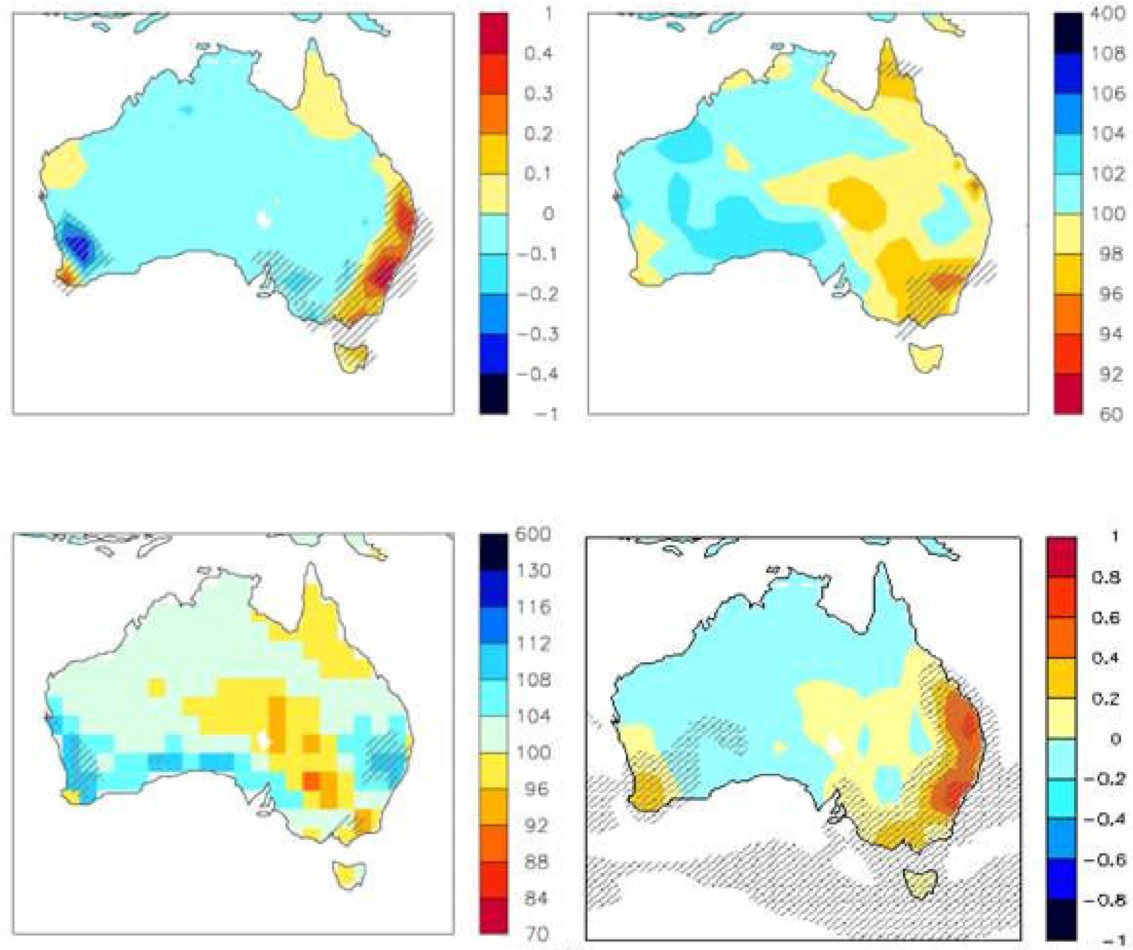

Figure 1: Differences in the ensemble climate averages (1951-2003) between pre-European and modern day conditions: (a) mean annual temperature (°C), (b) mean annual rainfall (% change), (c) mean annual soil moisture (% change); and (d) summer (DJF) surface wind speed at 10 m (m sec^{-1}) during DJF season. The hatched areas are statistically significant at the 95% confidence level.

3.2. Impact on 2002/03 drought conditions

The 2002/2003 El Niño event had pronounced impact on southeastern Australia, with the severe drought resulting in large reduction of primary production. The modeled results (Fig. 3a) showed that, for the modern day land cover conditions, the summer surface temperature was warmer by 0.75-2.0°C in a band stretching from eastern Australia to Central Australia. The observed drought experienced abnormally high surface temperature (Fig. 3b) and a low rainfall [*Nicholls*, 2006]. Our results demonstrate that regional perturbation of woody native vegetation cover can magnify the impact of natural mode of inter-annual climate variability, such as the ENSO, which is known to have a strong impact on seasonal climate conditions in eastern Australia.

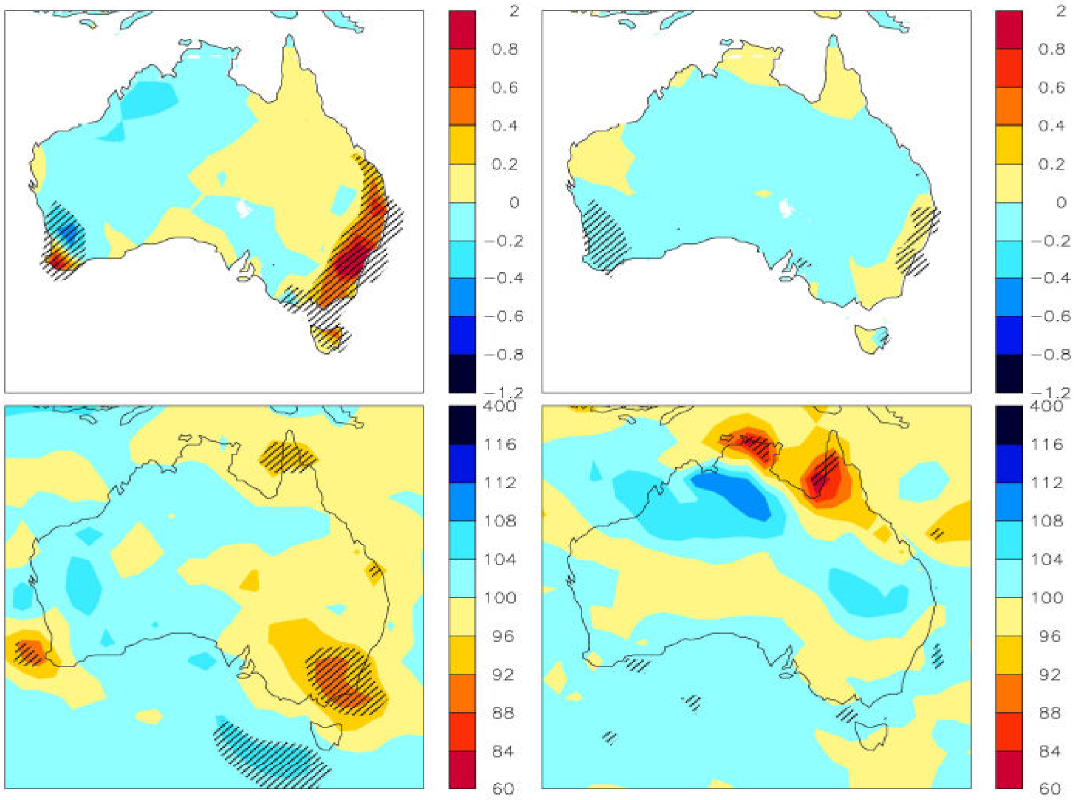

Figure 2: Difference in the ensemble seasonal climate averages (1951-2003) between pre-European and modern conditions for: (a) summer (DJF) surface temperature (°C), (b) winter (JJA) surface temperature (°C); (c) summer (DJF) mean rainfall (% change); and (d) winter (JJA) mean rainfall (% change). The hatched areas are statistically significant at the 95% confidence level.

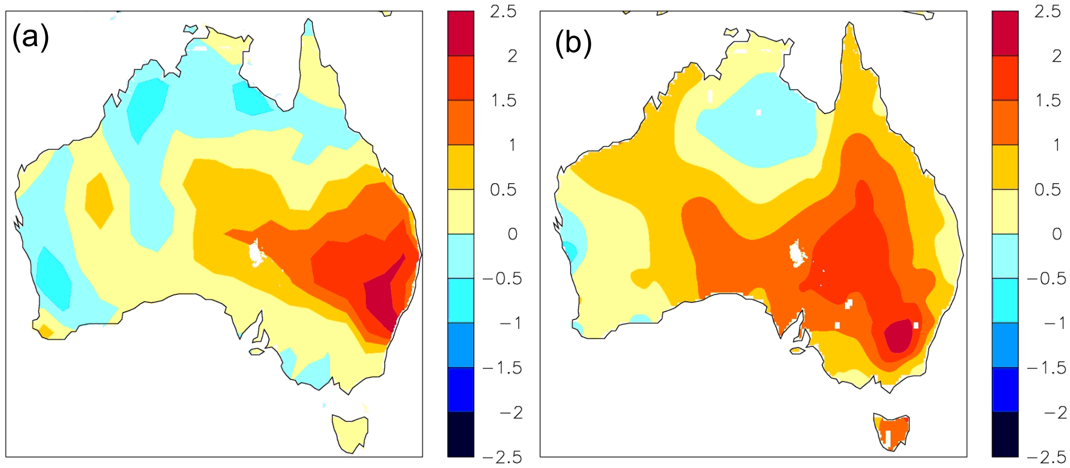

Figure 3: The anomaly of the summer (DJF) surface temperature (°C) during the 2002/2003 El Niño drought: (a) model simulated difference between pre-European and modern day conditions; and (b) the observed difference from the long term mean (1951-2003).

4.0. Discussion

The observed historical changes in Australia's regional climate result from a complex interaction of various factors, producing radiative forcing of different magnitudes. Trying to attribute historical changes in mean and seasonal surface temperature and rainfall using a single radiative forcing such as greenhouse gases is simplistic and needs to be re-evaluated, as advocated by *Pielke* [2005]. Our study indicates that LCC is an important climate forcing which potentially compounds changes in radiative forcing due to elevated atmospheric greenhouse gases. Although our experiment was a sensitivity study exploring the potential impact of historical LCC on Australian regional climate, there are numerous other forcings which potentially could have contributed to observed changes in Australian temperature and rainfall. We are therefore cautious of attributing the observed climate changes to the impact of LCC. However, there is some correspondence between the observed and simulated magnitude and pattern of change, which strongly suggests the importance of LCC as a contributing factor to the observed changes in Australia's regional climate.

A comparison of pre-European and modern day land surface parameters shows a strong decrease in the vegetation fraction, LAI and surface roughness over eastern and southwest Australia, and an increase in albedo for all regions of LCC. The direct changes in surface roughness by changing woody vegetation cover causes an increase in the strength of surface winds by reducing aerodynamic drag [*Lawrence*, 2004], while a change in stomatal resistance modifies surface evaporation rates, latent and sensible heat fluxes and planetary boundary layer properties [*Sellers*, 1992]. The impact of decreased surface roughness, which was strongest along the coast of New South Wales and southwest Western Australia, is an increase in surface wind strength and sensible heat fluxes, resulting in a subsequent change in the Bowen ratio. The increase in the near-surface wind amplified the shift from moist northeast tropical air to cooler and drier southeast flow from the Tasman Sea, resulting in the decreased precipitation.

The simulated warmer and drier conditions in eastern Australia are cumulatively impacting on surface and sub-soil moisture, and likely to be affecting vertical moisture transport processes, changing the partitioning of available water between runoff and evaporation. This has important, largely unrecognized consequences for agricultural production and already stressed land and water resources. Further, the simulated increase in temperatures in the sensitivity experiments, especially in southern Queensland and New South Wales, for the recent 2002/2003 drought, is consistent with the observed trend of recent droughts being warmer than previous droughts (1982, 1994) with a similar low rainfall [*Nicholls*, 2006].

5. 0. Summary

The findings of our sensitivity experiment indicate that replacing the native woody vegetation with crops and grazing in southwest Western Australia and eastern Australia has resulted in significant changes in regional climate, with a shift to warmer and drier conditions, especially in southeast Australia, the nation's major agricultural region. The simulated changes in Australia's regional climate suggest that LCC is likely a contributing factor to the observed trends in surface temperature and rainfall at the regional scale. While formal attribution studies are required, the outcomes raise important questions about the impact of LCC of Australia's regional climate, and highlight a strong feedback effect between LCC and the severity of recent droughts impacting on Australia's already stressed natural resources and agriculture.

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