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final report

knowledge for managing Australian landscapes

Modelling impacts of vegetation cover change on regional climate

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Project Objectives

1. Refine existing conceptual model of land surface-atmosphere interactions and feedback developed by Lawrence (2004), with a specific focus on regional-scale processes and feedbacks.

2. Model the sensitivity of continental and regional climate to imposed woody and herbaceous land cover characteristics using CSIRO GCM climate models, addressing the following:
   a) Evaluate the impact of pre-European and modern land cover characteristics using an ensemble of 10 simulations each for the period 1949-2005, and the strength of the ENSO impact for the two land cover change scenarios;
   b) Test the sensitivity of the magnitude of land cover change in order to identify threshold changes in regional climate with an emphasis of hydrological cycle;
   c) Evaluate the climate impact of transient historical land cover changes occurring over the past 100 years using National Centre for Atmospheric Research (NCAR) and United Kingdom Meteorological Office data for the Australian region, thereby increasing our confidence in robustness of the sensitivity of model results to historical land cover changes;
   d) Analyse the results of CLIMATE OF 20th CENTURY project, evaluate the relative contribution of different radiative forcings to climate change signal in regional Australia, with a specific emphasis on comparing the relative importance of land cover change; and
   e) Explore the options linking the climate model output with the AussieGRASS simulation system in order to evaluate the impact of land cover change on regional climate characteristics such as pasture growth, runoff, groundcover and sediment load.

3. Review the potential relevance of the outcomes of Objective 2 for natural resource management and policy.

Summary

Global climate change is the major and most urgent global environmental issue. Australia is already experiencing climate change as evidenced by higher temperatures and more frequent and severe droughts. These impacts are compounded by increasing land use pressures on natural resources and native ecosystems.

This study provided new evidence of the interactions, feedbacks and risks of natural climate variability, climate change and land use/land cover change impacting on the Australian continent and how they vary regionally. We reviewed evidence of climate change and underlying processes resulting from interactions between global warming caused by increased concentration of atmospheric greenhouse gases and modification of the land surface. The consequences of ignoring the effect of land use/land cover change on current and future droughts in Australia could have catastrophic consequences for the nation's environment, economy and communities.

The study demonstrates the need for more integrated, long-term and adaptive policies and regional natural resource management strategies that restore the beneficial feedbacks between native vegetation cover and local-regional climate, to help ameliorate the impact of global warming. There is a critical need to reassess national climate change and natural resource management policies to include the interactions and feedbacks between the land surface and regional climate, particularly the role native vegetation plays in ameliorating climate extremes and the severity of droughts.

Report

This report addresses Objectives 1, 2 and 3 collectively. Full details are contained in the papers McAlpine et al. (2009) which reports on Objective 1 and 3, and McAlpine et al. (2007) and Deo et al. (2009) which report on the revised Objective 2. Links to these papers are under Journals at the end of this report..

1. Conceptual Model

In general, land surfaces comprised of trees (woodlands and forests) retain a greater proportion of incoming short- and long-wave radiation than do pastures or crops. Similarly, clearing native forests and woodlands for exotic crops and pastures reduces the amount of moisture available for exchange with the planetary boundary layer, although crops can increase the moisture flux in the growing season.

Actively growing vegetation and moist soils are able to absorb more solar radiation both at the soil surface and at the root zone. Conversely, in dry years, soils tend to have higher albedos and less moisture available for evaporation, which can have a positive feedback yielding a lower rainfall. The proportion of native vegetation, crops, pastures and bare soils in the regional landscape mosaic affects the fraction of precipitation that originates from evaporation and evapotranspiration from within the same region. This process can add up to 20% of the precipitation occurring over a region, while several locations across the biosphere may actually receive up to 40% from recycled precipitation.

2. The Changing Australian Climate

Australian annual mean surface air temperatures have risen by about 0.9 °C since 1910. The first half of the 20th century experienced very little trend in temperature, however since 1950 a warming trend of 0.16 °C per decade has occurred. Southeast Australia has experienced persistent dry conditions and well above average temperatures since the mid 1990s.

There has been an increase in rainfall in the north and north-west of Australia and a widespread decrease in eastern Australia for recent decades. Since the late 1970s, the frequency of El Niño events often associated with eastern Australian droughts has increased, with droughts in southeast Australia characterised by higher temperatures and prolonged heat waves.

The Australian continent is likely to experience further warming of 0.6-1.5 °C by 2030, increasing to 1.0-5.0 °C by 2070. As may be expected with increased warming, the number of hot days that exceed 35 °C for many locations throughout Australia is projected to increase substantially. Likewise, the number of days below 0 °C is expected to decrease. The projected rainfall changes for eastern Australia show strong rainfall declines of up to 30% when the more reliable climate models are selected and the poorly performing models are discarded.

3. Land Cover Change and Land Use Pressures

Two hundred years of European settlement has transformed the Australian continent. Within the intensive land use zone of southeast and southwest Australia, approximately 50% of native forests and 65% of native woodlands have been cleared or severely modified.

In recent decades, the deforestation of the Australian landscape has been compounded by increased and sustained land use pressures arising from a steadily growing human population, rapid economic growth and rising global demand for Australian commodities, especially mineral and energy exports. There are also pressures on the extensive rangelands, with the sustainable management of rangeland landscapes continued to be outpaced by the need for growth, droughts, personal gain and invasive species.

It is likely therefore that loss of ground cover due to drought and overgrazing will have a similar effect on energy fluxes and convective processes as broad-scale land clearing. A major uncertainty in attributing causes to changes in perennial land cover (trees and shrubs) in agricultural and rangeland landscapes results from the number of interacting factors involved (CO_2, grazing management, frequency of pasture burning and wildfires, and severity of intermittent drought).

4. Evidence of Regional Climatic Impacts of Land Cover Change

4.1 Mean climate

The study has shown that land cover change has produced a significant impact on Australia's regional climate (Figure 1). Changes to Australia's land cover translate into significant changes in land surface parameters, and therefore represents an important additional influence on Australia's climate.

During the summer season in eastern New South Wales and Victoria, the area-averaged changes in surface characteristics showed large decreases in vegetation fraction (19%) and LAI (23%), and a resulting 7% increase in albedo. A corresponding reduction in surface roughness (46%) coincided with a 9% increase in wind speed, while summer surface temperatures exhibited an average warming of ≈0.6 °C. This warming was related to an increase in surface absorption of incoming short-wave radiation by 5.2%. The area-averaged rainfall decreased by 5.2%. The area-averaged energy fluxes showed a reduction in latent heat flux (7.3%) and an increase in sensible heat flux (1.3%).

During the winter season in southwest Western Australia, replacing native woodlands with predominantly winter crops resulted in a modest decrease in vegetation fraction of 5% and LAI of 12%. The stomatal resistance decreased by 15%, surface albedo increased by 14%, while surface roughness decreased by 35%. The strong increase in surface albedo is a combination of vegetation changes and bright sandy soils characteristic of this region. Conversion of native vegetation to winter crops changed the Bowen ratio, as evidenced by a small increase in latent heat flux and a 12% decrease in sensible heat flux, which was opposite to changes in east New South Wales. The surface temperature decreased by 0.14 °C with a small increase in rainfall.

The impact of land cover change in southeast Australia was larger than in southwest Western Australia as evident from changes to surface temperature and precipitation. The simulated rainfall reduction in summer rainfall southern New South Wales extending into Victoria of more than 5% for modern land cover conditions. In southwest Western Australia, multiple factors, in addition to land cover change, appear to be impacting the regional climate.

4.2. Daily Climate Extremes

We found land cover change significantly impacted daily indices of climate extremes and droughts in eastern Australia (Figure1). The results showed: an increase in the number of dry and hot days, a decrease in daily rainfall intensity and wet day rainfall, and an increase in the decile-based drought duration index for modified land cover conditions. These changes were statistically significant, and especially pronounced during strong El Niño events. Therefore it appears that land cover change has exacerbated the natural climate variability, thus resulting in longer-lasting and more severe droughts.

The analysis of daily rainfall intensity showed a spatially coherent decrease of ~15% in central New South Wales and northern Victoria for modern day conditions, and was statistically significant as determined by the bootstrap procedure. This region corresponds to the southern Murray Darling Basin. The index of wet day rainfall showed a statistically significant decrease for modern day conditions (~10-30 mm yr^{-1}) concentrated over southern New South Wales and northern Victoria. The number of dry days showed a statistically significant increase by 3-5 days yr^{-1} over coastal New South Wales, and a weak non-significant increase for inland New South Wales.

The increase in the number of dry days and decrease in wet day rainfall has direct consequences for the duration of droughts in the region, which showed a statistically significant increase by 0.25-0.5 months yr^{-1} in central New South Wales and northern Victoria for modern land cover conditions. The largest changes in extremes of surface temperature increase and rainfall decrease, indicating that land cover change may be reinforcing El Niño-related droughts in eastern Australia.

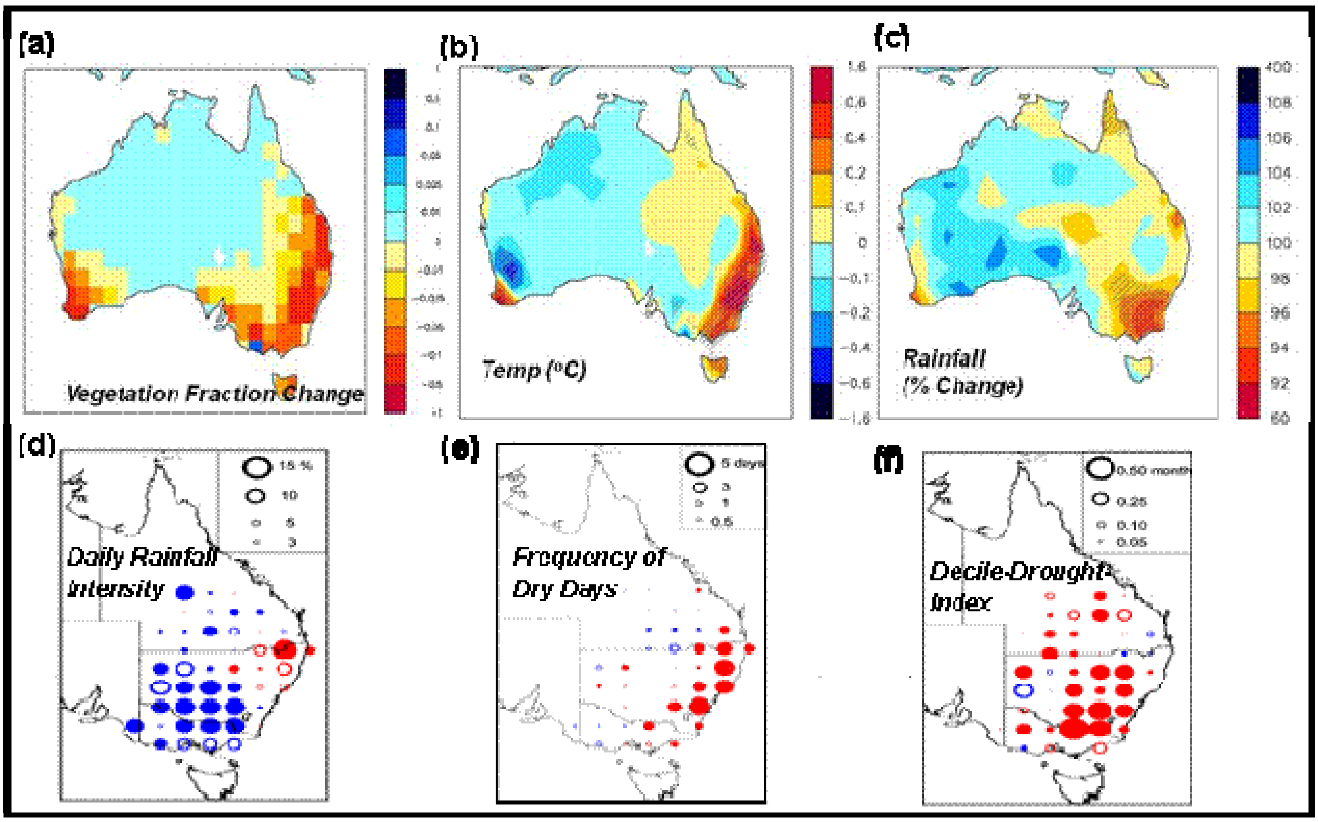

Figure 1: The changes in (a) vegetation fraction used in the CSIRO model, (b) annual mean surface temperature (°C), (c) annual mean rainfall (%), (d) daily rainfall intensity (%), (e) frequency of dry days (days yr^{-1}), and (f) rainfall-decile-based drought index (months yr^{-1}) for the period 1951-2003, Changes are for modern day vegetation cover compared to pre-European vegetation. For (b-c), the hatches show areas that are statistically significant, and for (d-f), black (closed) circles show increase and are statistically significant, white (open) circles are not statistically significant at α = 0.01 (Modified from: McAlpine et al. 2007; Deo et al. 2009).

4.3 Droughts

The daily maximum surface temperature and rainfall data during November-March (summer) for the 1982/83 and 2002/03 El Niño events showed a statistically significant increase in the number of hot and dry days in eastern Australia. The number of hot days increased over New South Wales, Victoria and Queensland, with the largest increase of up to six days in inland New South Wales and Queensland for the 1982/83 event. However, during the 2002/03 event, there was an increase of up to 18 days concentrated in northern New South Wales and southern Queensland. The number of dry days increased over most of eastern Australia for both events; however, for the 1982/83 event, the increase was much larger and concentrated in Victoria, northern New South Wales and inland Queensland.

While the magnitude of increase in the number of dry days was the largest during 1982/83 event, the magnitude of increase in the number of hot days was the largest during the 2002/03 event due to different characteristics of any two given El Niño events. These results show that daily indices of climate extremes are enhanced for modified vegetation conditions, and are much larger during the El Niño conditions as compared to the average response analysed for the 1951-2003 period.

In eastern Australia, both 1982/83 and 2002/03 El Niño events had a strong impact on surface temperatures, with anomalies of 2-2.5 °C; however the 2002/03 El Niño had a less severe impact on rainfall. The model results show the number of dry days during both events was sensitive to land cover change and corresponded with spatial patterns in the observed rainfall anomaly. Similarly, the number of hot days was sensitive to land cover change, and corresponded with observed surface temperature anomalies. This spatial correspondence was especially pronounced during the 2002/03 El Niño event, and implies that native vegetation can act as a moderator of extreme climatic conditions associated with strong El Niño events.

5. Comparison with CO_2

The project has completed analysis of daily data from six member ensembles using CSIRO Mk3.6 coupled climate model which was run for 1871-2100 period using historical and future (SRES A2) emission scenarios. Using daily model output we have computed comprehensive list of climate extremes using BoM Extreme Climate indices:

(http://www.bom.gov.au/silo/products/cli_chg/extremes_info.shtml)

A subset of selected indices such as number of hot days, number of dry days and rainfall intensity were computed over Australian continent for a selected historical and future 30-years long periods, for example 1871-1900, 1901-1930, 1971-2000, 2016-2045, 2036-2065 and 2061-2090. The changes between base period (1971-2000) period and the late part of 19th Century, early part of 20th Century and the three periods in the future were computed.

The results of this analysis were used to compare the magnitude of change in a selected climate change extremes forced by the greenhouse gases and the land cover change in Australia. Results indicate the effect of CO_2 on the number of hot days >35 °C was stronger than land cover change by the end of the 21st Century, but that land cover has an important effect on rainfall and droughts.

6. Risks

The risks of ignoring the role of land surface feedbacks in current and future droughts are potentially catastrophic for Australia's environment, economy and communities. Climate changes due to increased anthropogenic greenhouse gases coupled with land surface feedbacks appears to be amplifying the natural climate variability and has the potential to tip Australia's climate, especially in southeast Australia, into a new regime of more extensive, frequent and severe droughts. The combined effect of transient increases in greenhouse gases and pressures from land use/land cover change may already be contributing to more severe droughts for eastern and southern Australia, and is an ominous sign for the increased incidence and severity of projected future droughts.

A transition to a hotter and more drought prone climate represents a major risk for Australia, particularly if changes are beyond the capacity of environmental and production systems to recover or adapt. The Murray-Darling Basin is already at risk of environmental collapse due to the combined stressors of land use intensification and climate changes. Declining inflows due to persisting drought conditions are triggering conflict between human and environmental uses of water. A 1 °C rise in temperatures would reduce river inflows by ~15% of their present levels. Even more alarming, a warming of 2 °C would reduce inflows by up to 30%, further exacerbating the effect of predicted rainfall decline.

7. Implications for NRM and Climate Change Policy

Reducing greenhouse gas emissions is essential but not sufficient as a climate change mitigation strategy. Anticipatory policies need to be explored and tested aiming at reduction in land use pressures and restoration of native vegetation cover in order to try to avoid likelihood of irreversible climate change. Potential mitigation and adaptation options include:

i) tighter legislative controls on the clearing of native vegetation, including regrowth native vegetation in previously cleared sub-tropical landscapes;
ii) expanded investment in ecological restoration based on the strategic integration of native vegetation with production systems in the highly modified agricultural landscapes;
iii) an evaluation of the long-term viability of marginal cropping and grazing lands and their vulnerability to soil and vegetation degradation; and
iv) adaptive management of stocking rates according to climate conditions.

Integrated climate change mitigation/amelioration and landscape restoration strategies need to be urgently developed and tested. Successful implementation could lead to increased ability of the Australian landscape to buffer against climate extremes driven by increased concentrations of greenhouse gases. Such strategies could provide win-win situations for farmers where increased native woody vegetation on farms would result in greenhouse gas sequestration (including $ for green carbon credits) and restoration of the beneficial feedbacks between the land surface and Australia's regional climate.

Linkages with other research

The project has direct input into the forthcoming 5th Assessment report of the IPCC, through international collaborations with Dr Peter Lawrence and colleagues at National Centre for Atmospheric Research (Boulder Colorado).

The project also has developed strong linkages with Dr Greg McKeon's LWA Fellowship *Impact of Climate Change on Grazing Systems*. This includes two joint publications with Dr McKeon.

Impacts delivered through the project

- More informed, coherent vegetation cover management strategies, policies, land use planning and implementation of strategies that mitigate against negative impacts on regional climate; and
- Reduced conflict over vegetation cover impacts and responsibilities.
- Greater capacity to mitigate the impacts of land degradation resulting from drought and increased aridity under various total vegetation cover management options; and
- Increased capacity to maximise soil moisture retention, cropping returns, risk management and long term economic and environmental sustainability.
- Help strengthen the capacity of government investment in regional Planning and NRM management initiatives (Caring for our Country, Australia's Farming Future) to deal with the sustainable management of vegetation cover in a changing regional climate.

Target Audience	**Type of engagement**	**Method / Activity**	**Engagement & Impact**
Scientists in climate modelling and natural resource management	Indirect, moderate engagement target, sharing 1st results through regular international journal publications	Four refereed publications in international journals, plus refereed conference proceedings and oral conference presentations in Australia and internationally.	Papers circulated to key researchers in the related fields. McAlpine et al. (2007) already cited seven times in scientific literature including L. Hughes (2008) Climate Change in Lindenmayer et al. Ten Commitments: Reshaping The Lucky Country's Environment. Research reported in New Scientist and Nature
Regional NRM bodies and Community interest	Articles in Indirect, low engagement information to local media – newspaper and radio	Multiple media hits including ABC Regional Radio, ABC News Online, Science Daily and Science Alert. Feature articles in Canberra Times. Briefing to Queensland regional NRM bodies and presentation at Veg Futures conference Toowoomba 2008	LWA have been actively involved in these activities including the Veg Futures conference.
LWA	Project administration and evaluation	Reporting milestones (as specified), include pictures, media coverage, grey publications and contacts list for client database	We have worked closely with Dr Stuart Pearson LWA in project reporting and media coverage.
Policy		We have conducted policy briefings to Commonwealth Government Departments including the Murray Darling Basin Authority, Department of Agriculture, Fisheries and Forestry and have briefed Australian Government Prime Minister & Cabinet staff. Dr McAlpine has also appeared as a witness to the Commonwealth Joint Committee (Treaties) on the review of the Kyoto protocol and mentioned in Parliamentary debates in relation to the Victorian bushfires.	LWA have been actively involved in and informed of these policy communications and impacts.
Media		Extensive media coverage	

Measuring the Impacts

Prior to this study, there was no evidence of the impact of vegetation on climate and no evidence that retention or restoration of vegetation could deliver value to mitigate climate variability, extremes or change. The project has provided the best available scientific evidence for revegetation to achieve more liveable Australian landscapes. It justifies ongoing management of the Australian vegetation as an important contribution to regional climate. It is highly significant for Australia because it coupled the widely-used CSIRO climate models (those used for IPCC 3rd and 4th Assessment Reports) with a landscape scale model of land-surface-atmospheric interactions. This is the scale of management and the scale at which scientific information about climate change has been lacking.

Project Legacy

The excellence of the science and the successful communication of it enable people to see the impact of broad-scale land clearing on climate extremes and drought severity and duration. The opportunities for landscape scale revegetation to mitigate global climate change are also being realised. This makes the research both scientifically and politically powerful.

The widespread policy and media interest demonstrates that this research, through its fundamental contribution to raising vegetation-land surface interactions into the climate change mitigation discussion ensures a better outcome for Australia's environment and future. This has global implications to the way native vegetation is valued. We are already seeing the influence of this science in Australian Government policy and it has been positioned to influence global thinking.

List of Publications and Presentations arising out of the project

Journals

Deo, RC, Syktus, JI, McAlpine, CA, Lawrence, PJ, McGowan, HA & Phinn, SR (2009) Impacts of land cover change on daily climate extremes including droughts in eastern Australia. *Geophysical Research Letters*, doi: 10.1029/2009GL037666. http://www.mssanz.org.au/MODSIM07/papers/10_s61/ImpactOfLand_s61_Syktus_.pdf

McAlpine CA, Syktus J, Deo RC, Lawrence PJ, McGowan HA, Watterson IG, Phinn SR (2007) Modelling the impact of historical land cover change on Australia's regional climate. *Geophysical Research Letters*, 34, L22711, doi: 22710.21029/22007GL031524. http://espace.library.uq.edu.au/view/UQ:136718 (provides abstract and link to publisher)

McAlpine CA, Syktus J, Ryan, JG, Deo RC, McKeon, GM, McGowan HA, Phinn SR (2009) A continent under stress: interactions, feedbacks and risks associated with impact of modified land cover on Australia's climate. *Global Change Biology*, doi: 10.1111/j.1365-2486.2009.01939.x. http://espace.library.uq.edu.au/view/UQ:178647 (provides abstract and link to publisher)

Mahmood R, Pielke RA Sr, Hubbard KG, Niyogi D, Bonan G, Lawrence P, Baker B, McNider R, McAlpine CA, Etter A, et al. Impacts of land use land cover change on climate and future research priorities. *Bulletin American Meteorological Society* (Accepted with Revision)

Conference Proceedings

Deo, RC, Syktus, JI, McAlpine, CA, McGowan, HA & Phinn, SR (2009) The simulated impact of land cover change on climate extremes. In Proc: *International Congress on Modelling and Simulation*. Modelling and Simulation Society of Australia and New Zealand, 13-16 July 2009.

Syktus, JI, Deo, RC, McAlpine, CA, McGowan, HA & Phinn, SR (2007) Impact of land cover change on regional climate and El Niño in Australia. In Proc: Oxley, L. and Kulasiri, D. (eds) MODSIM

2007 *International Congress on Modelling and Simulation*. Modelling and Simulation Society of Australia and New Zealand, December 2007, ISBN: 978-0-9758400-4-7, pp 611-618.

Deo, RC, McAlpine, CA, Syktus, JI, McGowan, HA & Phinn, SR (2007) On Australian heat waves: Time series analysis of extreme temperature events in Australia, 1950 – 2005. In Proc: Oxley, L. and Kulasiri, D. (eds) MODSIM 2007 *International Congress on Modelling and Simulation*. Modelling and Simulation Society of Australia and New Zealand, December 2007, ISBN: 978-0-9758400-4-7, pp 626-635.

Conference Presentations

McAlpine CA, 2007, *Detecting the Atmospheric Response to the Changing Face of the Earth: A Focus on Human-Caused Regional Climate Forcings, Land-Cover/Land-Use Change, and Data Monitoring*, National Science Foundation funded workshop, Boulder, CO on August 27-29, 2007

McAlpine CA, 2007, Workshop on *natural landscapes: climate change, water conservation and management*, Vegetation Futures 08, Organized by Greening Australia & Land and Water Australia, Albury, 20th–23rd October, 2008

Deo RC, 2007, Presentation at MODSIM 2007 *International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, 10th - 13th December 2007

Syktus JI, 2007, Presentation at MODSIM 2007 *International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, 10th - 13th December 2007

Syktus JI, 2009, Presentation at MODSIM 2007 *International Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, 13th - 16th July 2009

McAlpine CA, *Adapting to Change*, Workshop of Ecological Society of Australia, Perth Convention Centre, Perth Western Australia, 25th - 30th November 2007

Public Lectures

McAlpine CA, 2008, *A Continent under Stress: Interactions, Feedbacks and Risks Associated with Impact of Modified Land Cover on Australia's Climate*, Public Lecture 27th August 2008, The University of Queensland, Brisbane

McAlpine CA & Syktus JI, 2008, *Policy Briefing*, Commonwealth Government Departments, Canberra, July 2008

McAlpine CA, 2009, *Expert Witness*, Joint House of Representatives and Senate Treaties Committee on the Kyoto Protocol, Canberra