Developing a Climate Modelling Framework to Investigate the Climate Impacts of Historical Australian Land Cover Changes

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Abstract: A major obstacle to investigating the climate response that results from land cover change is the need to isolate the effects of land cover from the effects exerted by natural climate variability and other anthropogenic sources. To overcome the inherent complexity of the real world climate system, a climate modelling framework is required where climate simulation experiments can modify specific parameters to investigate the effect of a single forcing. To investigate the climate impacts of historical Australian land cover changes, this project is developing a modelling framework using the CSIRO Mark 3 Atmospheric General Circulation Model (AGCM). This paper details the development of the CSIRO AGCM framework and the realistic inclusion of global current and potential natural land cover distributions.

Keywords: Land Cover Change; Climate Change; General Circulation Modelling; Land Surface Models

1. INTRODUCTION

Significant changes in Australian climate were recorded during the 20th century both at continental and regional scales. These changes are the result of both natural and anthropogenic climate forcing, occurring over various temporal and spatial scales [McKeon et al., 1998; Hennessy et al., 1999; Nicholls et al., 1999].

The major focus of Australian climate change research has been the climate impacts of varying sea surface temperature, increased greenhouse gas concentrations, and atmospheric pollutants. Much less attention has been placed on the climatic impacts resulting from local, regional and continental scale land cover changes.

The local impacts of land cover change on the surface energy balance, moisture budgets, and atmospheric boundary layer processes are well documented [Pielke et al., 1998; Betts et al., 1996]. The manner in which these local changes scale up to affect atmospheric conditions at regional and continental scale is less understood.

The relationships that exist between land cover change and climate have major implications for Australian landscapes. Landscape modification for agriculture, grazing and other economic purposes has resulted in clearing of approximately half of the woody vegetation of the intensive land use area of Australia. This process is ongoing with current land clearing rates still in excess of 300,000 ha per year [Barson et al., 2000; DNR, 2000].

A major obstacle to investigating the climate response resulting from land cover change is the need to isolate the effects of land cover from those exerted by natural climate variability and other anthropogenic sources. To overcome the inherent complexity of the real world climate system, a climate modelling framework is required where climate simulation experiments can vary specific parameters in a systematic manner, to investigate the effect of a single forcing.

This project is developing a modelling framework using the CSIRO Mark 3 Atmospheric General Circulation Model (AGCM). Differences in climate that result from changes in land cover can be identified by comparing modelled Australian climate with current land cover distribution against the climate modelled with land cover prior to historical modification. From the modelled climate differences, potential climatic impacts of Australian land cover can be identified.

2. INFLUENCES OF LAND COVER ON CLIMATE

During the 20th Century meteorologists described the dynamics of the atmosphere using physical and mathematical models derived from observations made with radiosondes, aircraft and satellites. The theoretical models described a complex dynamic climate system with interacting components of atmosphere, land, ocean, ice and biosphere. In this climate system, the amount and type of land cover present at the land surface impacts the dynamics of energy, moisture, and momentum exchange between the land surface, the near earth atmosphere, and the underlying substrate.

International studies show that changes in vegetation have direct impacts on: the surface reflectivity (albedo) of solar radiation; the sensible and latent heat division caused by altered evapotransporation; the effective precipitation reaching the soil from interception and subsequent evaporation; and, the aerodynamic mixing of the near earth atmosphere resulting from changed surface roughness [Pielke et al., 1998; Foley et al., 1998; Sellers et al., 1986].

The changes in surface conditions have impacts on the fluxes of energy and moisture from the land surface to the atmospheric boundary layer (ABL). The changes in these fluxes have impact the sensible heat, moisture and atmospheric stability of the ABL. The impact on the ABL is realised through changes in free and forced convection, mesoscale circulations, cumulus formation, and precipitation [Raupach and Finnigan, 1995; Baidya Roy and Avissar, 2000; Arnfield, 1998]. The direct and flow on impacts of land cover change on the atmosphere are shown in figure 1.

3. CSIRO ATMOSPHERIC GENERAL CIRCULATION MODEL

The CSIRO Mark 3 Atmospheric General Circulation Model is a spectral, global atmospheric simulation model developed by the CSIRO Atmospheric Research (CAR).

The model simulates a range of physical processes including radiation, cloud formation and precipitation, to incorporate full diurnal and annual cycles. Atmospheric processes are developed in the model through forward in time integration of equations of motion, using prognostic variables of surface pressure, surface

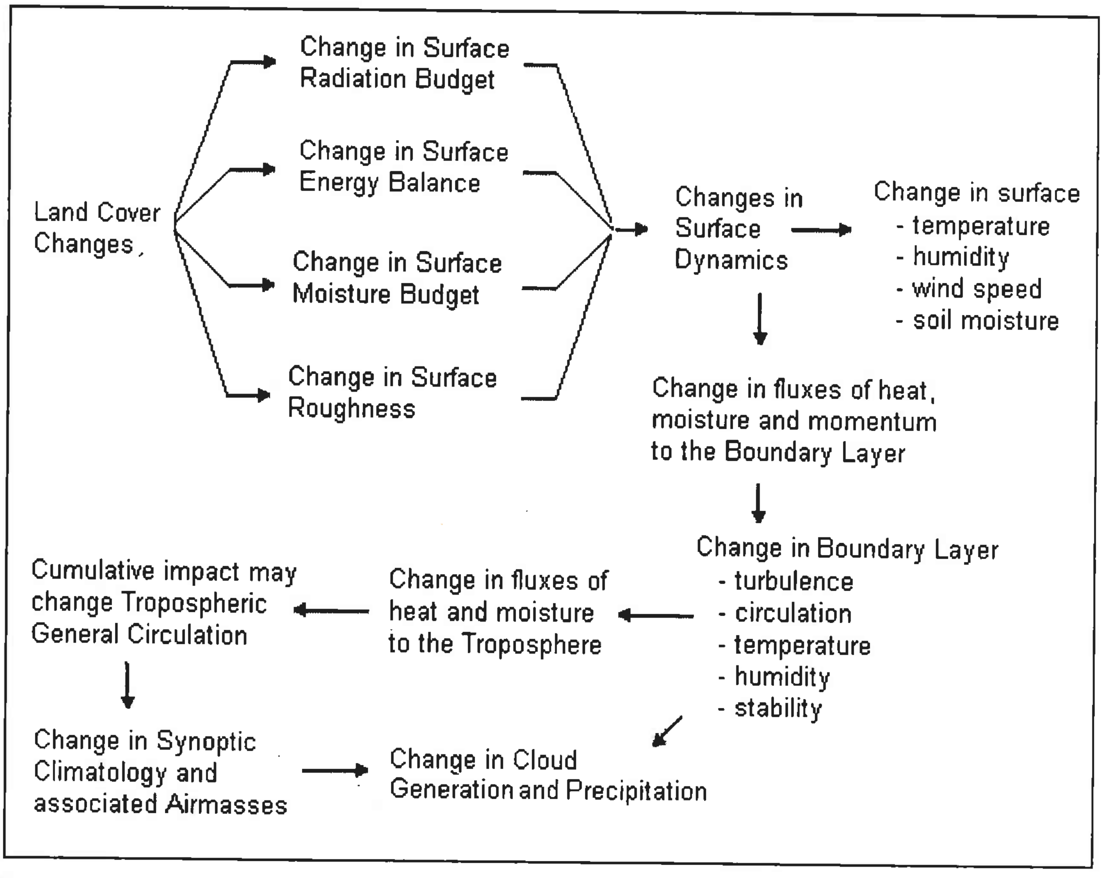

Figure 1. Conceptual model of the direct and flow on impacts of land cover changes on the atmosphere.

pressure weighted divergence, vorticity, temperature and moisture [McGregor et al., 1993].

The model incorporates the influences of oceans and the cryosphere through prescribed sea surface temperatures and sea ice distributions. A dynamic land surface is incorporated through the soil-canopy scheme implemented by Kowalczyk et al., [1994].

The soil-canopy scheme incorporates similar features to the land surface models of Deardorff, [1978], and Noilhan and Planton, [1989]. The land surface is represented by a single vegetation layer, over three soil layers. Fractional vegetation coverage is simulated by division of each grid cell into components of full vegetation and bare soil. The proportions of the division represent the vegetation fraction.

The soil-canopy scheme allows for the inclusion of soil thermal and moisture properties, surface albedo, surface roughness length, canopy resistance to transpiration, runoff, deep soil percolation, and snow accumulation and melting [Kowalczyk et al., 1994]. The vegetation and soil distributions of the soil-canopy scheme draw from the global Simple Biosphere Model (SiB) description of Dorman and Sellers, [1989] in terms of classification and parameterisation.

The horizontal resolution of the model is approximately 1.8 degrees. This is specified as a T63 resolution model grid. The vertical structure of the model consists of 9 atmospheric levels. The levels are determined by the sigma method of atmospheric pressure relative to surface pressure.

4. LAND COVER CHANGE MAPPING

To incorporate anthropogenic land cover changes into the modelling framework, consistent global land cover is required for current and prior to human disturbance distributions. An additional requirement for the land cover distribution is the need to describe land cover in the categorical classifications of the AGCM.

The global land cover distributions now available from satellite mapping are several orders of magnitude more detailed than the physiognomic classifications of Kulcher, [1983], used by Dorman and Sellers, [1989] to describe SiB vegetation distributions. Recent developments in bioclimatic vegetation distribution modelling have also made estimation of potential natural distributions of vegetation more realistic.

4.1 Current Global Land Cover Distribution

There are a numerous mapping projects that have generated current global land cover data from satellite imagery over the past decade. The spatial scale, mapping methods, temporal extent, and classifications vary between the projects. From the available data this project has selected the International Geosphere Biosphere Program's (IGBP), Data Information System, Global Land Cover Characterisation (DISCover) to represent current land cover distribution.

The DISCover data set is derived from 1 km resolution Pathfinder Advance Very High Resolution Radiometer (AVHRR) satellite imagery for the period April 1992 – March 1993. The interpretation method uses variance in greeness and seasonal Normalised Difference Vegetation Index (NDVI) values to assign vegetation types to a variety of classification types [Defries and Townshend, 1999].

The classifications of interest for this project are the SiB and Olson's Global Ecosystems (OGE) classifications. The DisCover, Version II data set in the SiB classification is shown in figure 2.

4.2 Potential Natural Global Land Cover Distribution

As there is no comprehensive record of the natural distribution of global land cover, estimates of the distribution must be made from existing land cover, expert opinion and bioclimatic modelling.

For this project potential natural vegetation was reconstructed using the methodology of Ramankutty and Foley, [1999]. This method uses current land cover distribution as a baseline with non-natural land cover types replaced with bioclimatically modelled vegetation. This method ensures natural remnant ecosystem distributions are maintained, minimising the abstraction involved in bioclimatic modelling.

To ensure consistency with the current land cover distribution, the DISCover data set was used for the current baseline and the Biome 4 vegetation distribution of Kaplan, [2001] was used for bioclimatically modelled potential natural vegetation.

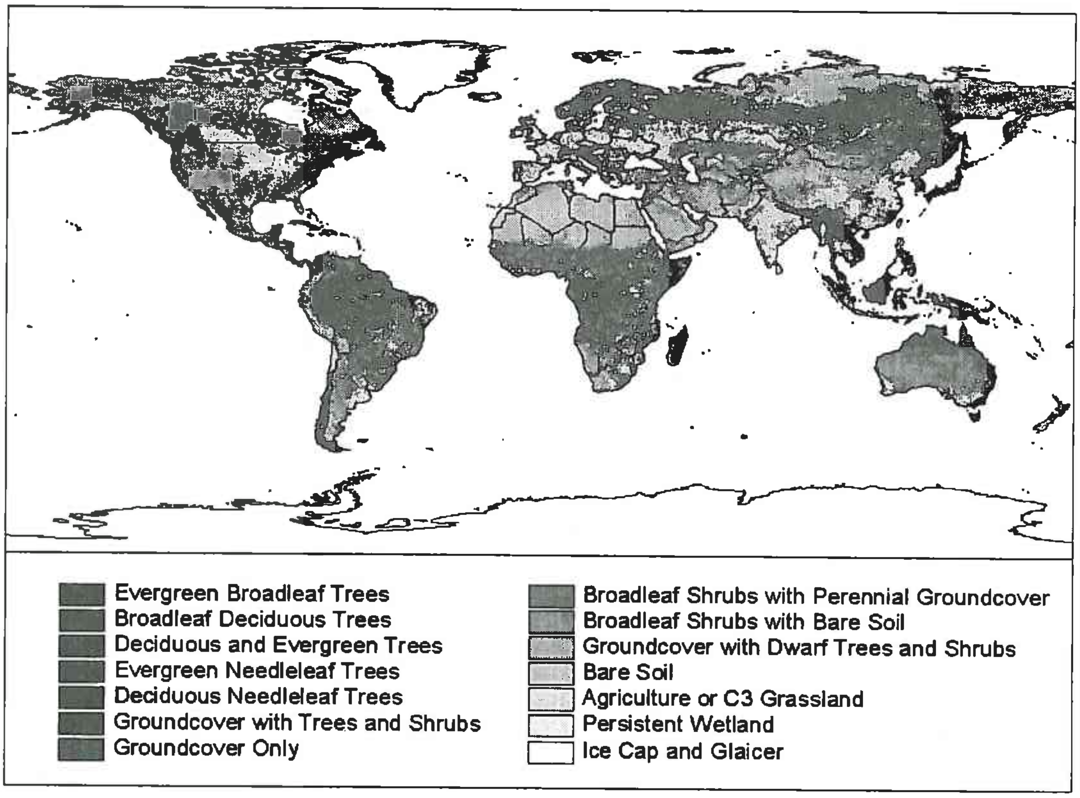

Figure 2. International Geosphere Biosphere Project, Global Land Cover Characterisation for 1992 – 1993 in Simple Biosphere Model classes [Defries and Townshend, 1999].

The Biome 4 potential vegetation data set was translated from the plant functional type biomes used in the bioclimatic model to OGE classes compatible with the DISCover data set. The OGE classification was used to maximise the ecosystem diversity in the translated Biome 4 potential natural vegetation distribution. The OGE classification is also directly translatable to the SiB classification using a simple OGE/SiB equivalence table provided by the U.S. Geological Survey.

The translation process was based on the dominance of DISCover remnant natural ecosystems found within each bioclimatically modelled biome. This was done on a continent by continent basis to maximise the OGE and plant functional type equivalence.

The dominant ecosystem that agreed with the modelled plant functional type biome was used to build an equivalency table for the continent. Using this relationship the Biome 4 data set was translated for each continent and then recompiled to make a global Biome 4 distribution in OGE classification.

The translated Biome 4 data set was used to replace non-natural OGE ecosystems from the DISCover data set with potential natural vegetation. This produced a global potential natural land cover distribution in the OGE classification.

5. LAND COVER CHANGE SURFACE PARAMETERS

To incorporate land cover change in the CSIRO AGCM, the characteristics of both land cover distributions need to be described for the soil-canopy scheme. The scheme describes the characteristic of land cover through five parameter files:

- SiB Vegetation type;
- Fraction of vegetation coverage;
- Monthly surface albedo;
- Minimum monthly values for resistance to canopy transpiration;
- Monthly surface roughness length.

The specification of land cover types can be directly taken from the global land cover distributions in SiB classification. The remaining data must be obtained from other sources. For the project, the extensive land surface observational data compiled through the International Satellite Land Surface Climatology Project (ISLSCP) was used for this data.

The first data release of the ISLSCP project provides vegetation fraction, and monthly surface albedo, percentage green leaf area, and leaf area index at 1 degree grid resolution for the 1987 – 1988 period. The project also provides time invariant properties for SiB vegetation classes to be used with the data.

Using the SiB derivation methods described in Sellers et al., [1995], with the ISLSCP data, the parameter files are generated as follows:

- Vegetation Type is generated directly from land cover distribution;
- Fractional vegetation cover is generated directly from the ISLSCP vegetation fraction data;
- Monthly surface albedo is generated directly from ISLSCP monthly albedo data;
- Monthly values for resistance to canopy transpiration are calculated using vegetation type, the time invariant minimum leaf resistance for the vegetation type, the leaf area index, and the percentage green leaf area;
- Monthly surface roughness length is calculated using vegetation type, the time invariant relationship between leaf area index and surface roughness of the vegetation type, and the leaf area index.

To use the 1 km resolution land cover distributions in conjunction with the ISLSCP data, the land cover data sets were resampled to the 1 degree grid resolution. Resampling was done based on the dominant land cover type for each cell by area.

Generating parameter files for use with the potential natural land cover distribution required analysing the current land cover parameter files on a latitudinal and monthly basis. This developed a profile for each parameter value based on vegetation type, latitude and month.

The parameters generated for the current land cover distribution were used with the potential natural land cover distribution. Where vegetation types were the same the parameters were assigned as they were in the current land cover. Where vegetation type was different the parameters were assigned from the latitude and monthly average value for the vegetation type. This produced two sets of land surface parameters representing the potential natural and current land cover distributions.

The AGCM requires parameter files as averaged values at the T63 resolution of the model. To perform this last step, the 1 degree parameter files were resampled to the T63 resolution using a fortran program supplied by the CSIRO DAR.

6. AUSTRALIAN LAND COVER CHANGE CLIMATE EXPERIMENTS

To investigate the continental scale climate impacts of historical Australian land cover changes, AGCM modelling experiments will be performed under various land cover distributions:

- Global current land cover;
- Australian potential natural vegetation and remaining global land cover in current distribution;
- Global potential natural vegetation.

The climate for each land cover scenario will be simulated over a 30 year period using prescribed sea surface temperatures and sea ice distributions for 1970 to 2000. Comparison of the model climate variables over the Australian continent, will identify differences between the models.

7. CONCLUSIONS

An investigative climate modelling framework has been developed using the CSIRO AGCM with realistic representations of global current and potential natural land cover. Land cover distributions are from the best available global vegetation mapping and bioclimatic vegetation modelling, and land cover parameters have generated using realistic satellite observations.

The framework has been tested and will be used in the next phase of the project to investigate the climate impacts of historical Australian land cover change.

8. ACKNOWLEDGEMENTS

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