Impact of dynamic albedo and vegetation fraction on the simulation of drought in southeast Australia using a regional climate model

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Abstract The Weather Research and Forecasting (WRF) regional model was run from 2000 to 2009 over southeast Australia. During this period the region entered into and later (partially) recovered, from a severe drought. The model used the following physics schemes: WRF Single Moment 5-class microphysics scheme; Rapid Radiative Transfer Model (RRTM) longwave radiation scheme; Dudhia shortwave radiation scheme; Monin-Obukhov surface layer similarity; Noah land-surface scheme; Yonsei University boundary layer scheme and Kain-Fritsch cumulus physics scheme. The model simulation uses boundary conditions from the NCEP/NCAR reanalysis with an outer 50 km resolution nest and an inner 10 km resolution nest. Both nests used 30 vertical levels spaced closer together in the planetary boundary layer. WRF was run in control mode with the default climatological surface albedo and vegetation fraction datasets, as well as with these datasets prescribed using satellite data. Comparison of these simulations demonstrates the importance of capturing the dynamic nature of these fields as the climate moves into (and then out of) a persistent multi-year drought. Both simulations capture the drought reasonably well, emphasising changes in the large scale circulation as a primary cause. Differences in the surface conditions do however provide regional differences in the drought severity and speed of recovery.

Key words Murray-Darling Basin; albedo; vegetation cover; drought

INTRODUCTION

The southeast (SE) of Australia (Fig. 1) contains most of the nation's population. The Murray-Darling Basin contains the largest mountain range in Australia and is significantly impacted by events in the Pacific, Indian and Southern Ocean. Due to these factors, understanding of the current and future climate of the southeast of Australia is both important and difficult. A high resolution Regional Climate Model (RCM) simulation has been performed and used to investigate the role played by land surface feedbacks on the evolution of drought in the region. Much of the region experienced an extended drought from 2002 until 2007.

REGIONAL CLIMATE MODEL

The Weather Research and Forecast (WRF) model is developed and maintained at the National Center for Atmospheric Research in the USA. WRF was run over SE Australia from 2000 to 2008. The model used the following physics schemes: WRF Single Moment 5-class microphysics scheme; Rapid Radiative Transfer Model longwave radiation scheme; Dudhia shortwave radiation scheme; Monin-Obukhov surface layer similarity; Noah land-surface scheme; Yonsei University boundary layer scheme and Kain-Fritsch cumulus physics scheme. The model simulation uses boundary conditions from the NCEP/NCAR reanalysis project (NNRP) with an outer 50 km resolution nest and an inner 10 km resolution nest that covers SE Australia (see Fig. 1). Both nests used 30 vertical levels. Data from the NNRP are on a 2.5° grid. WRF has been evaluated extensively over SE Australia and found to perform well (Evans & McCabe, 2010).

Four simulations have been performed. The first uses the standard WRF albedo and vegetation cover datasets and is referred to as the control simulation (CTL). The second used satellite derived albedo (ALB) but CTL vegetation fraction. The third uses satellite based vegetation fraction (VEG) but CTL albedo. The last uses satellite based albedo and vegetation fraction (BOTH).

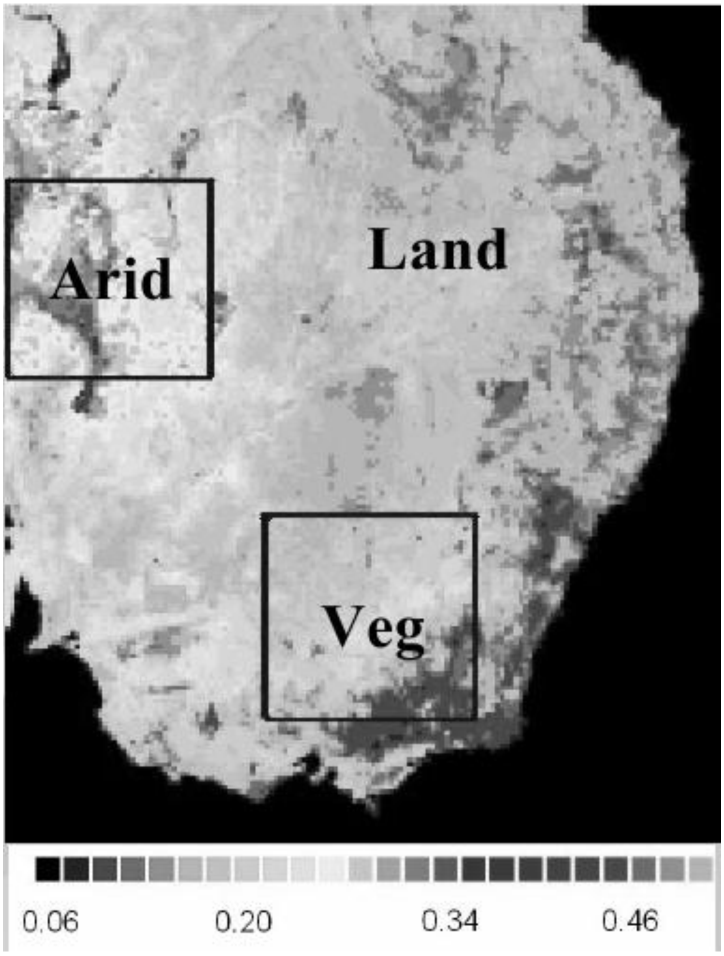

Fig. 1 Fraction of bare ground in southeast Australia. Arid and vegetated regions for further analysis are marked. **[NB this figure will be printed in black and white unless payment is received]**

ALBEDO DATA

Satellite albedo data used to update the WRF lower boundary conditions is produced by the Nadir BRDF-Adjusted Reflectance at 1000 m spatial resolution and with 16 d data composite (MCD43B4.005), which comes from the MODIS Land Mosaics for Australia and can be found at the Water Resources Observation Network (WRON) in Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). The original data used to produce the MODIS Land Products for Australia were supplied by the Land Processes Distributed Active Archive Center (LPDAAC), located at the US Geological Survey (USGS) Earth Resources Observation and Science Center (EROS). Detail of the data can be found in Paget & King (2008).

WRF climatological albedo was derived from a monthly means of clear-sky, surface, broadband, snow-free albedos for overhead sun illumination angle determined using data from a five-year period of April 1985–December 1987 and January 1989–March 1991. Details of the WRF climatological albedo can be found in Csiszar & Gutman (1999).

VEGETATION FRACTION DATA

Satellite vegetation fraction data used to refresh the WRF lower boundary conditions is produced by the Nadir BRDF-Adjusted Reflectance (NBAR) based on the combined Terra-Aqua MODIS data (MCD 43A4.005). It provides 500 m reflectance data adjusted using a bidirectional reflectance distribution function (BRDF) to model the values as if they were taken from nadir view. MODIS NBAR data are 16 d composites in a phased production strategy, produced every 8 d with 16 d of acquisition. Details of the data can be found in Guerschman *et al.* (2009). All vegetation fraction data can be downloaded from the WRON website.

WRF climatological vegetation fraction data was produced by the global 5-year AVHRR NDVI climatology with the same time period as the climatological albedo data. Details of the data can be found in Gutman & Ignatov (1998).

RESULTS AND DISCUSSION

The difference between the control and satellite derived albedo and vegetation fraction can be seen in Fig. 2. The inter-annual variability of the satellite data provides a clear distinction with that of the control data, which are climatological values and do not reflect the changes that occur at the surface throughout the drought.

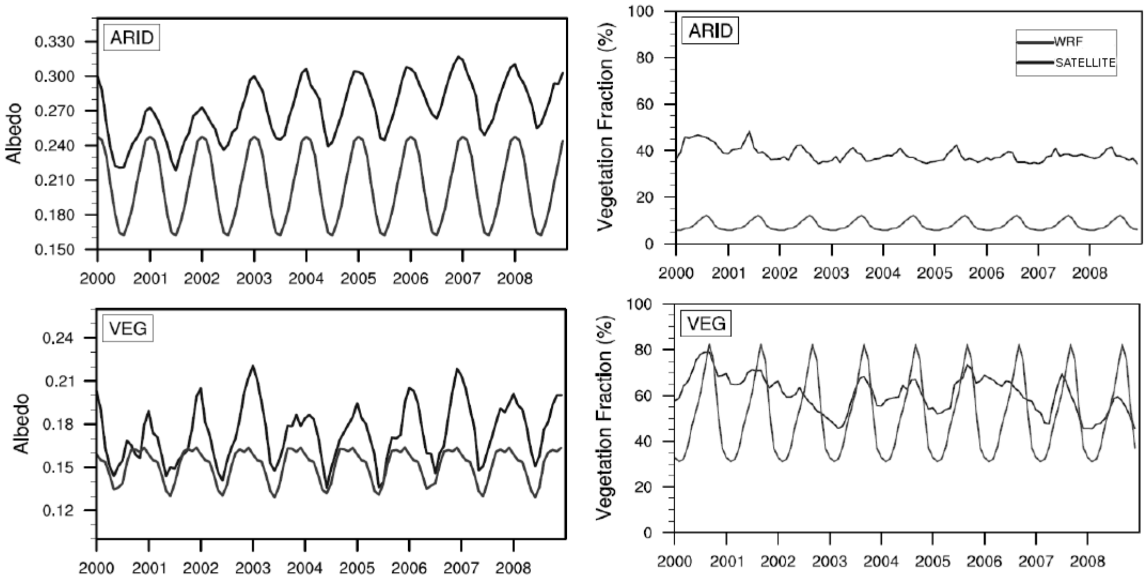

Fig. 2 Default WRF and satellite based albedo and vegetation fraction for the arid and vegetated regions.

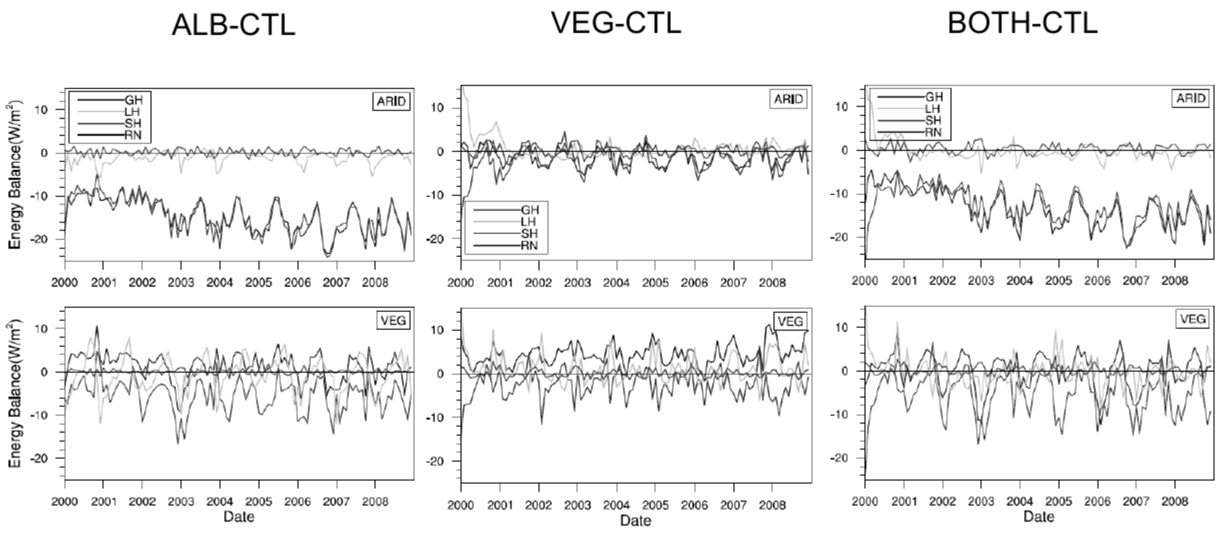

Fig. 3 The difference in energy balance components.

The introduction of satellite based albedo improved the simulation of surface temperature compared to the control simulation while having relatively little effect on the precipitation. Similarly the VEG and BOTH simulations provided successively better estimates of the surface temperature while producing relatively minor changes in the precipitation statistics.

The impact on various components of the surface energy balance is shown in Fig. 3. The change in albedo has the largest effect on the net radiation. In the arid zone these changes are reflected almost completely in the change in sensible heat, while in the vegetation zone the change in net radiation affects both the sensible and latent heat in a more complicated manner. A similar situation is achieved when changing the vegetation fraction, although a clear decline in latent heating can be seen in the early years. The simulation that changes both the albedo and vegetation fraction shows that the albedo affect dominates in the arid zone, while both contribute to the overall change seen in the vegetated region.

Examining the transition from the relatively wet year of 2000 into the extreme drought year of 2002 shows that the introduction of satellite albedo causes a more rapid decrease in the precipitation, hastening the onset of the drought. Introducing the vegetation fraction change alone tended to slow the decrease in precipitation; however, the combination of the two produced the most rapid decrease in the precipitation and caused the peak of the precipitation deficit to occur earlier than in the CTL simulation.

These early results suggest a significant role for the land surface feedbacks in the timing and eventual intensity of this drought. These impacts are currently undergoing further analysis.

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