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South-east Australia's drought: Numerical modelling and land-atmosphere feedback

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Abstract South-eastern Australia covers approximately 14% of Australia land mass, and is very important for Australia's community and economy. In this work, the Weather Research and Forecasting (WRF) regional model was run to simulate the severe drought that happened and then (partially) recovered in this region from 2000 through 2008. The model used the following physics schemes: WRF Single Moment 5-class microphysics scheme; the Rapid Radiative Transfer Model (RRTM) longwave radiation scheme; the Dudhia shortwave radiation scheme; Monin-Obukhov surface layer similarity; Noah land-surface scheme; the Yonsei University boundary layer scheme and the Kain-Fritsch cumulus physics scheme. The model simulation uses boundary conditions from the NCEP/NCAR reanalysis with an outer 50km resolution nest and an inner 10km 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, emphasizing changes in the large scale circulation as a primary cause. Differences in the surface conditions do however provide local influence on the intensity and severity of drought.

Keywords Murray-Darling basin; albedo; vegetation fraction; drought; land-atmosphere interaction

INTRODUCTION

The exchange of moisture and heat between the earth's surface and the atmosphere affects both the dynamics and the thermodynamics of the climate system [*Guillevic et al.*, 2002]. These interactions have been the focus of much recent inquiry into questions ranging from the maintenance of extreme drought or flood conditions, to the influence of deforestation on rainfall, to responses to increases in atmospheric concentrations of greenhouse gases[*Findell and Eltahir*, 2003].

The Murray Darling Basin (MDB) located in south-eastern Australia, covering approximately 14% of the Australian land mass and producing one third of Australia's food supply, is Australia's most important agricultural region (Fig. 1). Three quarters of Australia's irrigated crops and pastures are grown in the Basin. However, the water resources of the MDB have been threatened by consistent droughts since 1997. The averaged annual rainfall between 1997 and 2006 was about 16% lower than the climatology value across the whole MDB, which led to the reduction in runoff by 39%. The 7-year averaged rainfall for the period between October 2001 and September 2008 is close to the lowest since 1900[*Potter et al.*, 2010]. This makes the investigation of climate change and water resources over the MDB, including all hydrological and climate components, more important.

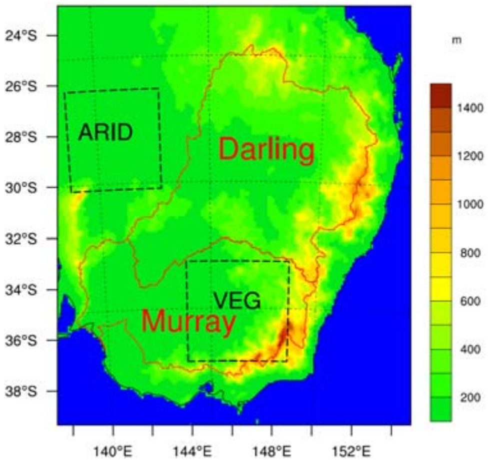

Fig.1 Topography of the Murray Darling Basin from Regional climate model terrain (10 km resolution domain)

REGIONAL CLIMATE MODEL

The WRF model is a widely used numerical model developed under a collaborative partnership between the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA).

The WRF version 3.1.1 was run in this study by using the following physics schemes: WRF Single Moment 5-class microphysics scheme; the Rapid Radiative Transfer Model (RRTM) longwave radiation scheme; the Dudhia shortwave radiation scheme; Monin-Obukhov surface layer similarity; Noah land-surface scheme; the Yonsei University boundary layer scheme; and the Kain-Fritsch cumulus physics scheme.
The model simulation uses 6 hourly 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 southeastern Australia (Fig. 1). Both nests used 30 vertical

levels spaced closer together in the planetary boundary layer. The deep soil temperature was allowed to vary slowly with a 150 day lagged averaging period, while the atmospheric CO_2 concentration changed monthly following measurements taken at Baring Head, New Zealand[*Evans and McCabe*, 2010].

The WRF model physics does not predict sea-surface temperature, vegetation fraction, albedo and sea ice. For long simulations, the model reads in these time-varying data and continually updates the lower boundary condition. In this work, WRF was restarted based on the simulations in [*Evans and McCabe*, 2010]from 2000 through 2008, using the WRF default albedo and vegetation fraction data and MODIS data respectively. Hereafter these simulations are referred to as WRF_CTL (with default data), WRF_ALB (with MODIS albedo), WRF_VEG (with MODIS vegetation fraction) and WRF_BOTH (with MODIS albedo and vegetation), respectively. This allowed WRF more than 15 years to "spin-up" the soil moisture states in a coupled environment.

DATA

WRF climatlogical data

The albedo product used in the current WRF model was derived from monthly means of clear-sky, surface, broadband, snow-free albedo for overhead sun illumination angle determined using the data captured by AVHRR from April 1985-December 1987 and January 1989-March 1991. Details of the WRF default albedo can be found in[*Csiszar*, 2009].

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 from [Gutman and Ignatov, 1998].

MODIS data

The MODIS albedo data used in this paper is produced by the Nadir BRDF-Adjusted Reflectance (NBAR) at 1000m spatial resolution and 8-day interval with 16-Day data's composite (MCD43B4.005) from 2000 through 2008, which comes from the MODIS Land Mosaics for Australia in 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 U.S. Geological Survey (USGS) Earth Resources Observation and Science Center (EROS). More details about the data can be found in[Paget and King, 2008].

Satellite vegetation fraction data used to refresh the WRF lower boundary conditions is produced by the NBAR based on MCD43A4.005, which provides 500-meter reflectance data. Detail of the data can be found from [Guerschman et al, 2009]. And all the vegetation fraction data can be downloaded from the WRON website as well.

To match the MODIS products with WRF, both MODIS data were quality controlled then reprojected and resampled temporally and spatially to be consistent with the WRF simulation. The difference between the control and satellite derived albedo and vegetation fraction can be seen in Fig. 2.

To better address albedo changes over the different underlying surfaces, examples of sparsely and densely vegetated areas were selected (Fig. 1), which are referred to as ARID and VEG respectively. Both datasets display similar seasonal cycles in terms of the timing of maximum and minimum values though WRF_CTL displays a larger cycle in the ARID region and a smaller cycle in the VEG region. Being a monthly climatology WRF_CTL has no inter-annual variations. MODIS Albedo displays significant inter-annual variability. In the ARID region there is a clear step increase in albedo after 2002, after which it remains fairly consistent. In the VEG region, albedo increases from 2001 until 2003, decreases in 2004 before increasing again until 2007.

Obviously the vegetation fraction minimums occur in the summer following the precipitation minimums, indicating a clear impact of drought on vegetation density. WRF_CTL shows larger seasonal cycle while MODIS data has more obvious interannual change for both regions especially for VEG region. MODIS data has larger values for ARID region all the time but smaller ones for VEG region in most times which means vegetation degradation happened. In addition, vegetation over the VEG region decreased from 2000 to 2003 with the minimum in 2003 and recovered from late 2003 until reduced again in 2006, then recovered and decreased in 2007 and 2008 respectively.

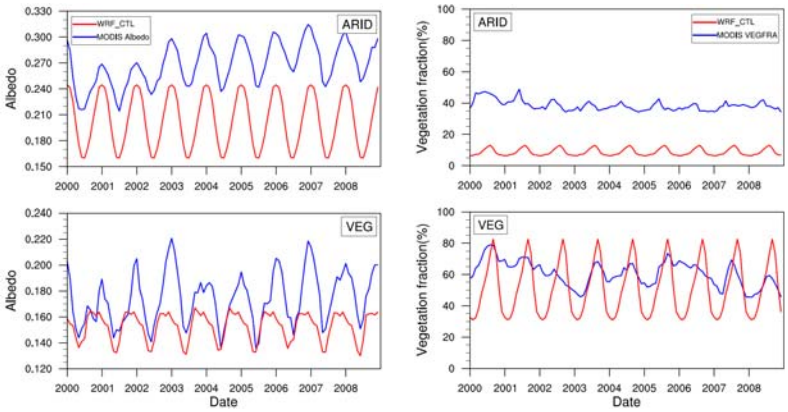

Fig. 2 Default WRF and satellite based albedo and vegetation fraction for the arid and vegetated regions.

RESULTS AND DISCUSSION

Results from the simulations comparing with the observations are shown in Fig. 3. All simulations can catch the main trend of air temperature and precipitation. The applications of the MODIS satellite data clearly improve the simulation for air temperature, while they simulate the precipitation slightly worse than WRF_CTL except WRF_VEG. But all simulations can catch the severe drought happened in 2002 and 2006, which means the main trend of temperature and precipitation depends on the large scale circulations. So, the difference between the simulations and WRF_CTL will be used to analysis the influence of land-atmosphere interaction due to the change of albedo and vegetation density on local climate.

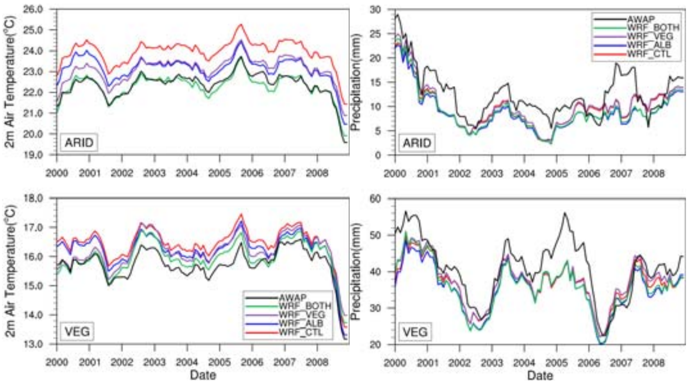

Fig. 3 Simulations for 2m air temperature and precipitation for the two simulations and observations (12 months running average)

Fig.4 shows the time series of difference for air temperature and precipitation between the new simulations and control. Results show that both MODIS satellite data lead to lower air temperature, especially WRF_BOTH. WRF_ALB and WRF_BOTH cause to less precipitation while WRF_VEG enhances precipitation slightly. In addition, the peaks of the precipitation reduction in WRF_ALB and WRF_BOTH simulations happened in 2002, 2006 and early 2008, which means the increased albedo result in the intensity of the severe drought. At the same time, enhanced vegetation slightly releases the drought.

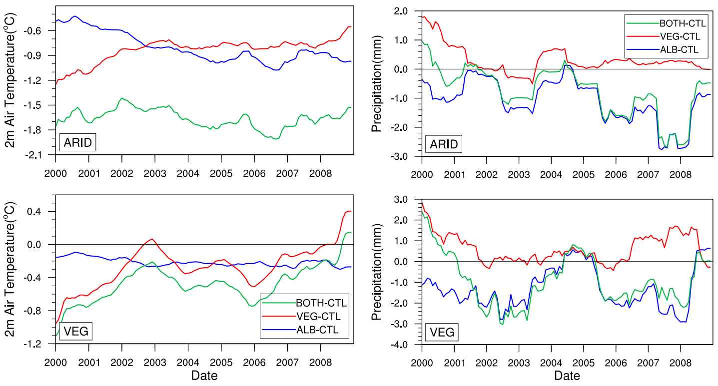

Fig.4 12-month running average of difference for air temperature and precipitation

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.

The impact on various components of the surface energy balance is shown in Fig. 5. The change in albedo has the largest effect on the net radiation. In the ARID region these changes are reflected almost completely in the change in sensible heat, while in the VEG region 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 though 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 region while both contribute tot he overall change seen in the VEG region.

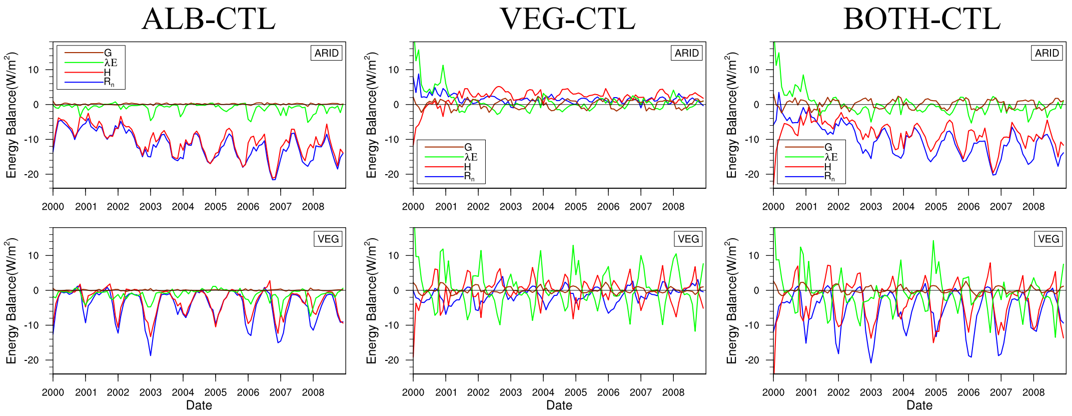

Fig.5 monthly average difference in energy components

The impact on precipitation in different seasons is shown in Fig. 6. Albedo reduces precipitation while vegetation increases it the most in late SON and DJF. The change in albedo hasn't large effect on precipitation in JJA and early SON. In MAM, albedo decreases the precipitation while vegetation density increases the precipitation. Totally, the combination of changed albedo and vegetation fraction reduces air temperature and precipitation in MDB.

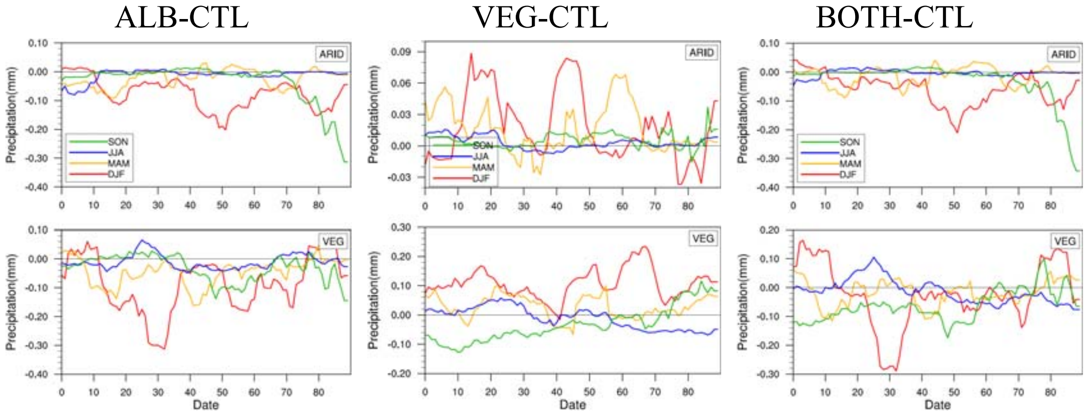

Fig. 6 Daily average of precipitation in different seasons
(Dec, Jan, Feb – DJF; March, Apr, May – MAM; Jun, Jul, Aug – JJA; Sep, Oct, Nov – SON)

CONCLUSIONS

In this work, the dynamic MODIS albedo and vegetation fraction data were used to update the boundary conditions of the advanced research WRF model, to simulate the drought happened in the Murray Darling basin and study the influence of the satellite data introduction on the occurred drought. The primary results are as follows:

Analysis shows that 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.

The introduction of MODIS albedo reduces the precipitation and enhances the drought while the vegetation fraction releases the drought slightly. The combination of the two satellite data produces the most rapid decrease in the precipitation and caused the peak of the precipitation deficit to occur earlier than in the CTL simulation. And the influences of land-atmosphere interaction on precipitation are different in different seasons, mostly focusing on DJF while might be negligible in JJA.

These early results suggest a significant role for the land surface feedbacks in the timing and eventual intensity of this drought.

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