18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Water Balance in the Murray-Darling Basin and the recent drought as modelled with WRF

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Abstract: The Weather Research and Forecasting (WRF) modelling system is developed as 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, Oklahoma University, and the Federal Aviation Administration (FAA) in the USA as well as the wider research community. The version used in this study is the Advanced Research WRF (ARW) maintained at NCAR.

WRF was run over the Murray-Darling Basin (MDB) from 1985 through 2007. 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 that covers the whole MDB. Both nests used 30 vertical levels spaced closer together in the planetary boundary layer.

The simulation is evaluated against gridded surface temperature and precipitation observations created as part of the Australian Water Availability Project (AWAP). The WRF simulation is found to reproduce the climate of the MDB reasonably well. WRF was able to improve on the climate produced by the NCEP/NCAR reanalysis which provided the boundary conditions for the WRF simulation. Investigation of the time series of precipitation and soil moisture anomalies show that WRF is able to capture the recent drought in the MDB. While the overall time series captured the drought well the spatial patterns associated with the anomalies produced by WRF differed from those found in the AWAP dataset. Further work will investigate the reasons for these spatial differences as well as WRFs performance at shorter time scales.

Keywords: *regional climate model, water balance, drought*

1. INTRODUCTION

South-eastern Australia contains most of the population and agricultural production for the nation. It contains the largest mountain range 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 South-east Australia is both important and difficult. A high resolution Regional Climate Model (RCM) simulation has been performed that will be used to address various climate related issues for the region. Initial evaluation of this simulation is presented here.

2. REGIONAL CLIMATE MODEL

WRF was run over the Murray-Darling Basin (MDB) from November 1984 through 2007. The first two months of the simulation are considered spin-up and are not used in the subsequent analysis. 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 that covers the whole MDB (see Figure 1). Both nests used 30 vertical levels spaced closer together in the planetary boundary layer.

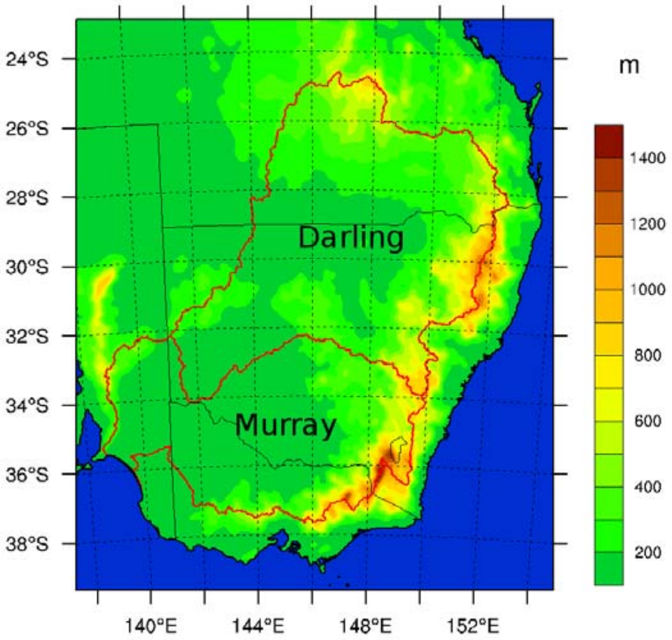

Figure 1: Regional Climate Model terrain (10km resolution).

3. OBSERVATIONS

Observations used for evaluation come from the gridded dataset prepared as part of the Australian Water Availability Project (AWAP). Details of creation of this dataset can be found in Raupach et al. (2008a & b). This dataset includes precipitation, maximum and minimum temperature, and vapour pressure surfaces obtained by interpolating surface station measurements. Solar radiation is derived from satellite measurements. Various surface hydrology parameters, such as soil moisture and runoff, are obtained using the WaterDyn hydrology model driven by the AWAP meteorological variables. Seasonal precipitation and mean temperature derived from the AWAP dataset for the period of interest is shown in Figure 2. The temperature increases from the high country in the South-east of the basin toward the north-west. The Murray basin has a precipitation maxima in winter and spring, while the Darling basin has a summer maxima.

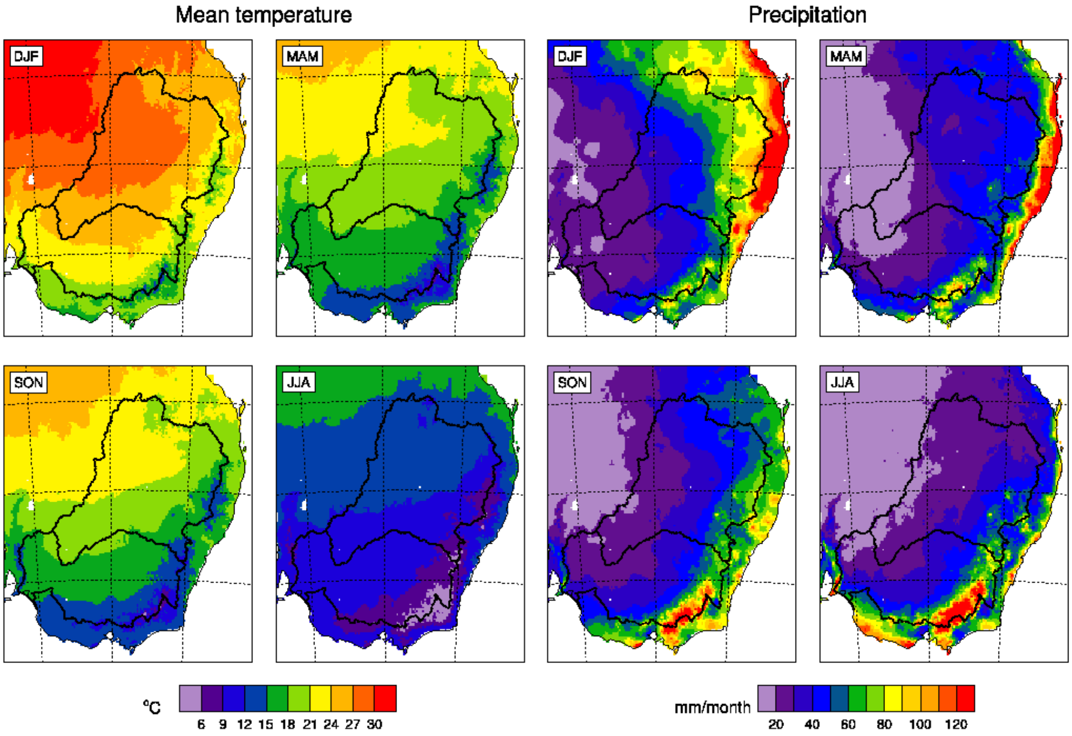

Figure 2: AWAP Seasonal temperature and precipitation.

4. STATISTICAL MEASURES

Many different statistical measures have been used previously to test the performance of climate models quantitatively. Willmott*, et al.* (1985) and Legates and McCabe (1999) provide an analyses of the suitability of several of these measures as well as suggesting some of their own. In this paper the model performance is evaluated against observations using several statistics including the bias

$$Bias = \bar{M} - \bar{O} \quad (1)$$

where $\bar{M}$ is the mean of the modeled values and $\bar{O}$ is the mean of the AWAP observations. The Root Mean Square Error (RMSE) is given by

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(O_i - M_i\right)^2} \quad (2)$$

where N is the number of observed, O, and modeled, M, values being compared. Here N is the number of WRF grid cells in the domain. Climatological values are used in calculating RMSE.

In order to quantitatively evaluate the spatial agreement between model and observations, Walsh and McGregor (1997) define the pattern correlation (3), ρ_p, between observed and simulated fields simply as the correlation of a series of data points from the observed field with corresponding values from the modeled field at a fixed time, in this study monthly means are used.

$$\rho_p = \frac{\sum\left(O_i - \bar{O}\right)\left(M_i - \bar{M}\right)}{\sqrt{\sum\left(O_i - \bar{O}\right)^2}\sqrt{\sum\left(M_i - \bar{M}\right)^2}} \quad (3)$$

The anomaly correlation, ρ_a, is similar to the pattern correlation except that fields are replaced by anomalies from climatology. The anomaly correlation provides a more rigorous test of whether the model can capture the spatial pattern of interannual variations. Here the sums are calculated over the number of WRF grid cells within the domain.

5. RESULTS

5.1. Precipitation and temperature

Figure 3 shows the difference in seasonal temperature between the simulations and AWAP observations. The reanalysis (NNRP) fails to capture the topography of the great dividing range and hence overestimates temperatures there while WRF is much better at capturing temperatures in that region. Also note that the NNRP generally underestimates temperatures in the north-east of the domain and this underestimation extends throughout the domain during winter. WRF generally performs better at capturing the temperatures in the north-east though it also contains a winter cold bias in the Murray basin. WRF also overestimates the temperatures through much of the domain, particularly toward the north-west in Spring and Summer. This overestimation is inherited partially from the NNRP boundary conditions but WRF has increased the warm bias in these seasons compared to NNRP. These results are reflected in Table 1 where it can be seen that on an annual basis WRF overestimates temperatures in the Murray basin by 0.24K while NNRP underestimates them by 0.29K. While WRF produces only marginal improvements in pattern and anomaly correlation over NNRP it has a significantly better root mean square error (RMSE). So while WRF is able to capture the spatial temperature distribution better than NNRP, the changes in this pattern through time are only marginally closer to that found in the AWAP observations compared to NNRP. Table 2 shows a similar situation in the Darling basin though both simulation show larger biases than in the Murray basin. In the Darling basin it can also be seen that WRF produces larger improvements in the pattern and anomaly correlations suggesting it is better at capturing the time evolution of the temperature pattern here.

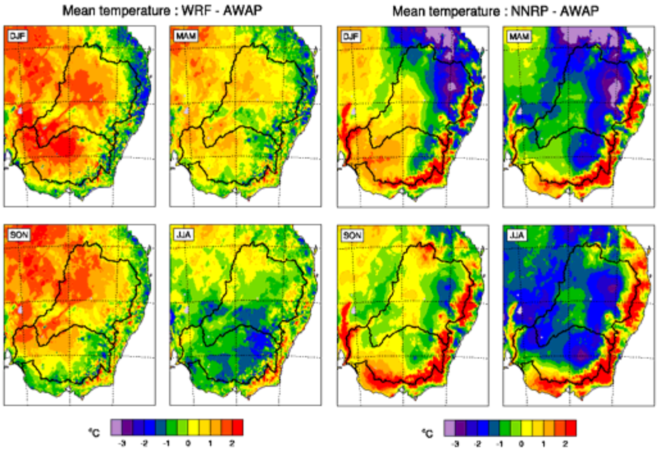

Figure 3: Difference in seasonal temperature (model - AWAP).

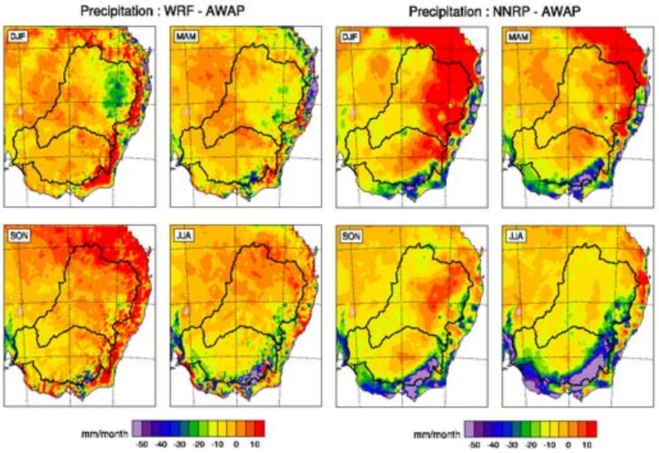

Figure 4: Difference in seasonal precipitation (model - AWAP).

Figure 4 shows the seasonal precipitation differences between the simulations and the AWAP observations. It can be seen that NNRP significantly underestimates the precipitation in the high country in the south-east in all seasons while WRF produces a much better estimate of precipitation in this area, though still containing a winter underestimate. NNRP also tends to overestimate in the north-east during Summer and Autumn. WRF demonstrates a better performance in this situation however it tends to overestimate in this area during Spring. Table 1 shows that WRF produces improvements over NNRP in all statistics in the Murray basin. That is, the precipitation distribution produced by WRF significantly enhances that produced by it's driving model (NNRP). In the Darling basin (Table 2) the situation is less clear with mixed statistics over all. This may imply that local features such as topography are less important in the production of precipitation in the Darling basin compared to the Murray.

Table 1: Murray River basin monthly statistics compared to AWAP.

	Temperature (K)		Precipitation (mm)	
	WRF	NNRP	WRF	NNRP
Bias	0.24	-0.29	-5.93	-13.31
RMSE	0.68	1.23	9.97	20.64
Pattern Correlation	0.87	0.84	0.76	0.65
Anomaly Correlation	0.26	0.25	0.43	0.31

Table 2: Darling River basin monthly statistics compared to AWAP.

	Temperature (K)		Precipitation (mm)	
	WRF	NNRP	WRF	NNRP
Bias	0.47	-0.63	-3.32	-3.07
RMSE	0.73	1.16	5.26	7.05

Pattern Correlation	0.86	0.8	0.66	0.72
Anomaly Correlation	0.31	0.23	0.43	0.42

5.2. Recent drought

The precipitation anomaly time series for the two basins (12 month running average) can be seen in Figure 5. The recent drought can be clearly seen with an extended period of negative anomalies extending from 2002 through to the present in both basins and in both the AWAP observations and the WRF simulation. Similar low rainfall years occurred in 1991 and 1994 in both basins, and 1997 in the Murray basin only. In each case WRF agrees quite well with the AWAP data in terms of producing below average rainfall. It is worth noting that the rainfall produced in the Murray basin for the recent drought is reproduced well by WRF but in the Darling basin WRF predicts a consistently larger negative rainfall anomaly after the initial drop in 2002.

AWAP produced both gridded datasets of meteorological observations (temperature, precipitation etc) based on station observations and using a water balance model WaterDyn, it produced gridded datasets of various components of the surface water and energy balance. In this case WaterDyn is forced using the AWAP meteorological data but the state of the land surface does not influence the local meteorology at all. WRF uses the Noah Land surface model to simulate the surface water and energy cycles. In this case the land surface is fully coupled with the atmosphere and hence feedbacks between the land surface and atmosphere are included. Figure 6 displays the soil moisture anomalies in the root zone simulated by each model. The actual depth of the soil layer used in WaterDyn various according to soil types. The mean soil depth in the Murray basin is 90cm, while in the Darling basin it is 99cm. The Noah soil moisture is always from the top metre of soil. Figure 6 shows that despite having almost identical precipitation anomalies in the Murray basin, WaterDyn produces a larger soil moisture anomaly compared to WRF. In the Darling basin the soil moisture anomalies simulated by the two models are almost identical despite WRF having a larger precipitation anomaly.

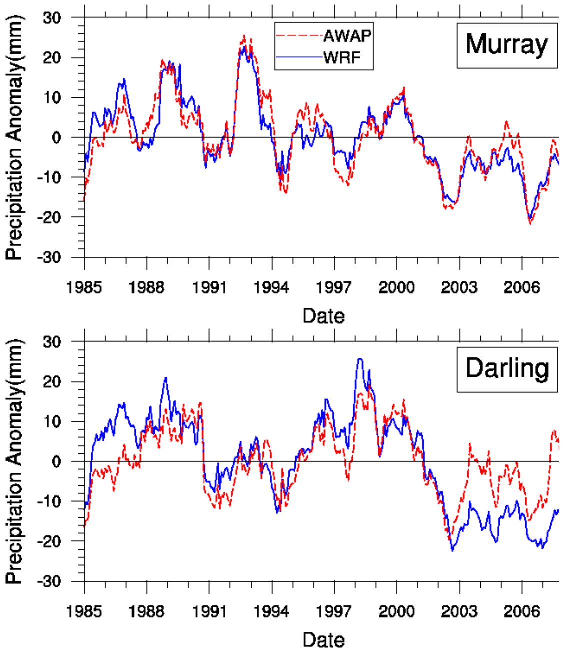

Figure 5: Precipitation anomaly time series (12 month running average) for the Murray and Darling basins.

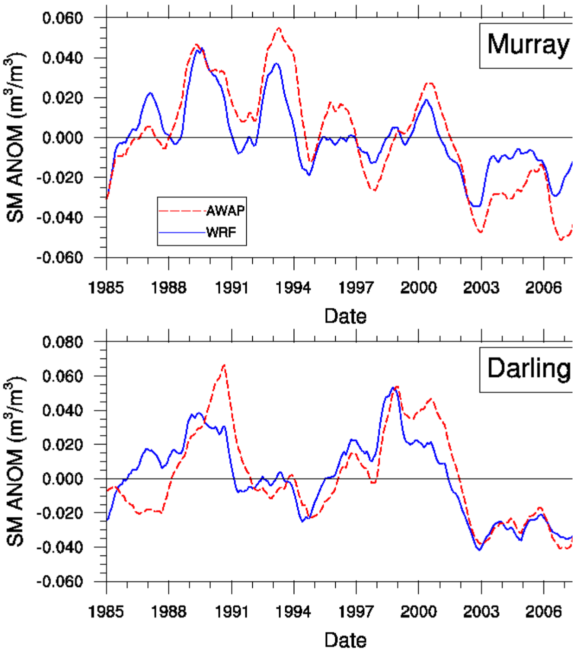

Figure 6: Soil moisture anomaly time series (12 month running average) for the Murray and Darling basins.

The spatial distribution of the precipitation and soil moisture anomalies are shown in Figure 7 and Figure 8. The precipitation anomalies are distributed quite differently especially in the Darling basin with WRF having the largest anomalies near the northern and eastern boundary and AWAP having a swath across the basin with the largest anomaly. The transition from precipitation anomaly to soil moisture anomaly is quite different between with WaterDyn generally producing larger soil moisture anomalies for the same precipitation anomaly.

6. DISCUSSION AND CONCLUSIONS

The regional climate model WRF was run for 23 years over the MDB. The climate simulated by WRF was generally an improvement over that produced by the NNRP despite the fact that WRF does not assimilate any observations while NNRP does. WRF was able to reproduce the inter-annual variability reasonably well. This includes capturing the recent severe drought. While the overall magnitudes of precipitation and soil moisture anomalies were captured well the spatial distribution of these anomalies were quite different. Further work will investigate the causes for these spatial differences as well as investigate shorter time-scales from monthly to daily.

ACKNOWLEDGMENTS

This work was carried out as part of the ARC Discovery project DP0772665.

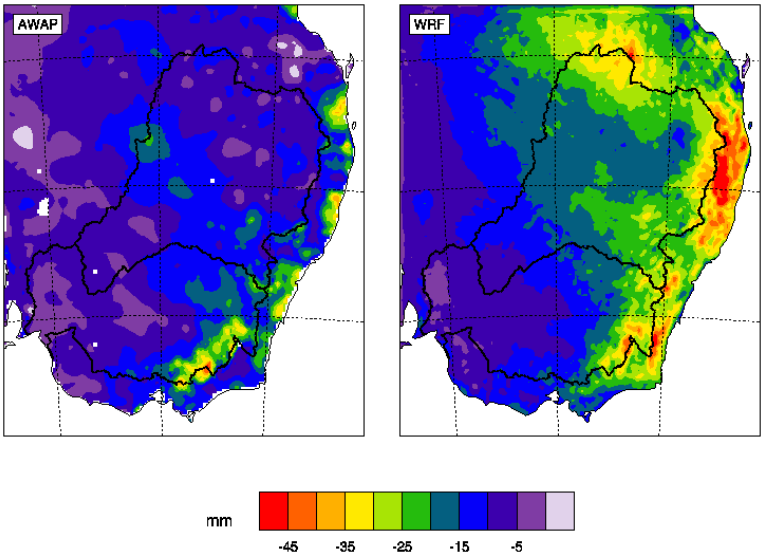

Figure 7: Precipitation anomaly (2002-2006).

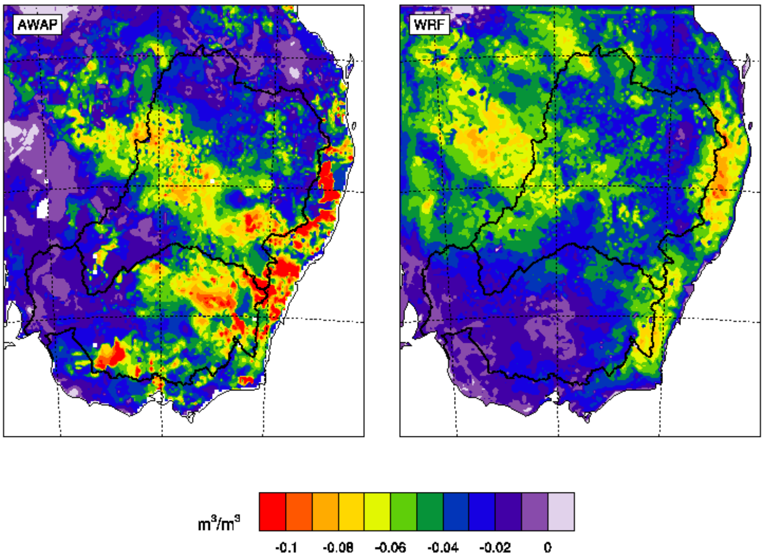

Figure 8: Soil Moisture anomaly (2002-2006)

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