International Congress on Environmental Modelling and Software

4th International Congress on Environmental Modelling and Software - Barcelona, Catalonia, Spain - July 2008

Jul 1st, 12:00 AM

Runoff projection sensitivity to rainfall scenario methodology

Freddie S. Mpelasoka

F. H. S. Chiew

iEMSs 2008: International Congress on Environmental Modelling and Software
Integrating Sciences and Information Technology for Environmental Assessment and Decision Making
4th Biennial Meeting of iEMSs, http://www.iemss.org/iemss2008/index.php?n=Main.Proceedings
M. Sànchez-Marrè, J. Béjar, J. Comas, A. Rizzoli and G. Guariso (Eds.)
International Environmental Modelling and Software Society (iEMSs), 2008

Runoff projection sensitivity to rainfall scenario methodology

Freddie S. Mpelasoka and Francis H. S. Chiew

CSIRO Land and Water, Black Mountain, Canberra, Australia

(Freddie.Mpelasoka@csiro.au)

Abstract: Runoff characteristics are inextricably linked with climate, particularly the spatial and temporal patterns of precipitation and evapotranspiration. The need for demonstrably objective climate change scenarios consistent with what is realistic under global warming predicted conditions is increasingly growing. Global climate models (GCMs) are the best tools available for simulating global and regional climate for predicting future climate. However, GCMs provide information at a resolution that is too coarse to give results that can be directly used in hydrological studies.

This paper quantifies three simple methods of rainfall scenarios construction informed by GCMs for their potential use in providing desirable future rainfall scenarios for modelling runoff projections. Runoff simulations from daily rainfall time series obtained using three simple methods (*constant scaling*, *daily scaling* and *daily translation*) to transform GCM outputs to catchment-scale rainfall over South-East Australia for 1981-2000 and 2046-2065 periods are used. In the *constant scaling* and *daily scaling* methods, the historical observed daily rainfall is scaled by the changes indicated by the GCM. In the *constant scaling* method, the entire daily rainfall series (in seasons) is scaled by the same factor. In *daily scaling*, the different daily rainfall amounts are scaled differently. In *daily translation*, a relationship between GCM simulation of the present rainfall and the observed catchment-scale rainfall is established, and used to convert the future GCM daily rainfall time series to catchment-scale rainfall series.

In summary, the *constant scaling* method can be used in most applications to transform climate outputs from GCMs to drive hydrological models. However, where more detailed analyses of runoff distribution is required, the *daily scaling* and *daily translation* methods are potentially better, particularly if the GCMs used have skill in modelling extreme rainfall and daily rainfall series.

Keywords: Runoff projections; climate change; scenario construction; rainfall

1. Introduction

Water shortage is a recurrent phenomenon of climate variability in Australia and has significant environmental and socio-economic impacts. For example, the drought of 2002-2003 cost Australia A$10 (US$7.6) billion (Adams *et al*. 2002), about 70,000 jobs were lost and had significant impacts on tourism which currently contributes to 4.5% of Australian Gross Domestic Product (Allen 2005). Water restrictions are becoming almost permanent features in many regions and cities of Australia in response to water shortages. This emphasises Australia's vulnerability to climate variability and limitations of adaptive capacity (Mpelasoka et *al*. 2007).

Most of the current projections from GCMs show a general decrease of mean rainfall over Australia coupled with increase in temperature (Suppiah et *al*. 2007). Changes in spatial and temporal patterns of climate variables will undoubtedly impact on regional hydrological processes. In particular, changes in rainfall will be amplified as an impact on runoff (Chiew, 2006). This will have significant implications on water resources, due to changes in both mean rainfall and increases in variability and extreme events. GCMs are the best tools available for simulating global and regional climate for future climate. However, GCMs provide information at a resolution that is too coarse to give results that can be used directly in hydrological modelling (Mpelasoka *et al* 2001; Mearns and Hulme, 2001).

Various approaches have been employed to develop climate change scenarios at different scales. For example, dynamic and statistical downscaling techniques, ranging from the simple to the complex, are frequently used to transform large-scale GCM outputs to catchment-scale climate variables. Statistical downscaling techniques relate large synoptic-scale atmospheric predictors to catchment scale rainfall (Charles *et al*., 2004; Mpelasoka *et al*., 2001). However, the choice of appropriate atmospheric predictors and the calibration of statistical downscaling models are fairly laborious and subject to expert judgement. Dynamic downscaling techniques, by nesting high resolution limited area models within a GCM, account for processes that are not resolved by the GCM (Nunez and McGregor, 2007; Lorenz and Jacob, 2007). While this approach is conceptually consistent with the GCM representation of the climate system dynamics, they suffer from several limitations, including high computing costs. Also, the success of a dynamic model strongly depends on its horizontal resolution and the computational expenses often limit the sample sizes.

Simpler empirical approaches such as pattern scaling and translation methods offer a more immediate solution (Kidson and Thompson, 1998). Because they are simple to use, they can be applied to outputs from a number of runs of different GCMs, therefore taking into account the large uncertainties associated with global warming and local climate change projections. However, there is need for these methods to also account for changes in extremes and sequence of events, as it is evident that changes will not be restricted to the mean state of the climate but also in the higher order moments (Mearns *et al*., 1996; IPCC-TGCIA, 1999).

This paper compares runoff results from a rainfall-runoff model driven with future climate inputs obtained using three simple methods for transforming rainfall from several GCM transient experiments: *constant-scaling*, *daily-scaling* and *daily-translation*. We demonstrate that the *constant scaling* method can be used in most applications to transform climate outputs from GCMs to drive hydrological models. However, where more detailed analyses of runoff distribution is required, the *daily scaling* and *daily translation* methods are potentially better, particularly if the GCMs used have skill in modelling extreme rainfall and daily rainfall series.

2. Data and Methods

2.1 Historical climate data and modelling of historical runoff

Daily runoff is modelled using a lumped conceptual daily rainfall-runoff model, SIMHYD, for 0.25^o x 0.25^o grid cells across South Eastern Australia (SEA). The SIMHYD model has been used successfully for various applications across Australia. The structure of SIMHYD and the algorithms describing the processes modelled by SIMHYD are shown in Figure 1. The seven parameters in SIMHYD have been calibrated against observed streamflow data for 331 catchments across Australia by Chiew *et al*. (2002). For this study, runoff for each 0.25^o x 0.25^o grid cell is modelled using optimised parameter values from the geographically closest 'calibration catchment'.

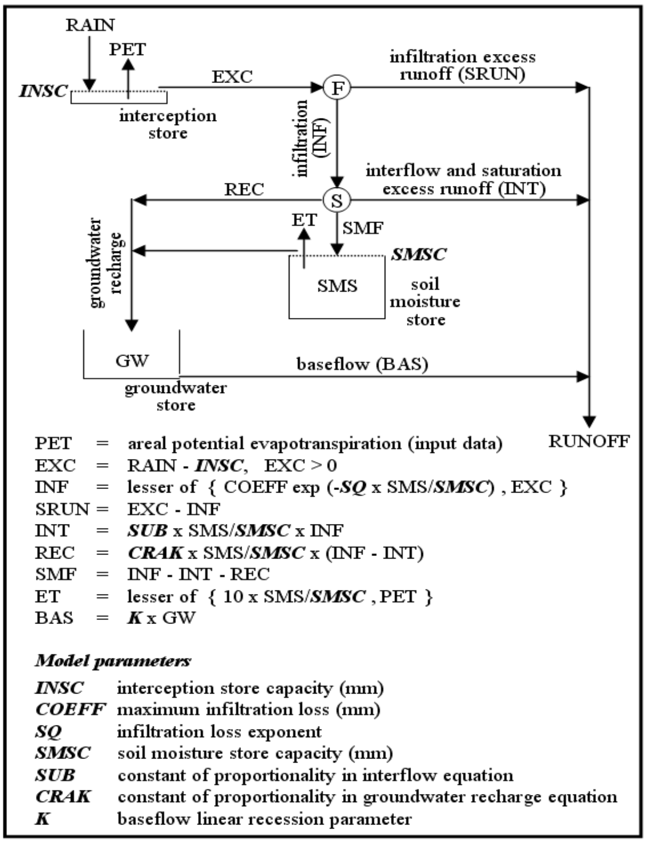

Figure 1: Structure of the SIMHYD model.

Daily rainfall and areal potential evapotranspiration (APET) are required to run SIMHYD. The observed climate series for 1981-2000 are obtained from the 'SILO Data Drill' of the Queensland Department of Natural Resources and Water (Jeffrey *et al*., 2001). Areal PET (APET) is calculated from the SILO climate surface using Morton's wet environment evapotranspiration algorithms (Morton, 1983). The 1981-2000 daily rainfall and APET series are used to drive SIMHYD to estimate daily runoff for 1981-2000.

2.2 Future climate and modelling of future runoff

To obtain the future climate series, daily simulations from three GCMs for 1981-2000 and for 2046-2065 for the mid-range IPCC A1B global warming scenario are used. The three GCMs used are *cccma* (Climate Modelling and Analysis Centre, Canada, 3.8^o x 3.8^o horizontal resolution, 31 levels), *mk3* (CSIRO, Australia, 1.9^o x 1.9^o horizontal resolution, 18 levels) and *gfdl* (Geophysical Fluid Dynamics Lab, USA, 2.5^o x 2.0^o horizontal resolution, 24 levels). The simulations were obtained from the World Climate Research Program (WCRP) Coupled Model Intercomparison Project (CMIP3) (https://esg.llnl.gov:8443/index.jsp).

Since GCM simulations of current climate generally validate well against observations at seasonal to annual temporal scales, we applied the three methods of scenario-construction to seasonal changes. In the *constant scaling* method, the mean rainfall and APET simulated by the GCM for 2046-2065 and for 1981-2000 are compared to determine the change in the mean rainfall and APET. The ratios of mean rainfall and APET between 2046-2065 and 1981-2000 are then used to scale the historical 1981-2000 daily rainfall and APET series to obtain the 2046-2065 rainfall and APET series to drive SIMHYD. Each of the four seasons are considered separately (i.e., a different constant scaling factor is used for each season).

In the *daily scaling* method, the daily rainfalls from the GCM for 2046-2065 and for 1981-2000 are ranked from highest to lowest, and changes at the different ranks/percentiles are determined. The percentage change to each rainfall rank/percentile is then used to scale the observed 1981-2000 daily rainfall (i.e., different rainfall amounts are scaled differently) to obtain the 2046-2065 rainfall series to drive SIMHYD. Again, each of the four seasons is considered separately. The 2046-2065 daily rainfall series obtained is then rescaled such that the mean rainfall for each season is the same as that in the *constant scaling* method. Common to ‘scaling’ approaches is the assumption that the relative pattern of change is scale invariant, that is, a relative pattern of change calculated at the GCM grid-scale can be applied at any point within a GCM grid-box.

The *daily translation* approach is based on the comparison of the GCM cell simulations for the 20^{th} century to observed data over the same period on finer grid (at different rainfall percentiles), to establish a model ‘biases-correction scheme’ against the catchment scale climate variable of interest. The 1981-2000 daily rainfall distribution from the GCM is compared with the 1981-2000 observed rainfall at each 0.25^o grid cell to relate the GCM daily rainfall to 0.25^o grid cell daily rainfall at the different rainfall ranks/percentiles. This relationship is then used to translate the 2046-2065 daily rainfall series simulated by the GCM, to 0.25^o grid cell daily rainfall series. The 2046-2065 daily rainfall series are also rescaled such that the mean rainfall for each season is the same as that in the *constant scaling* method.

The same SIMHYD parameter values used for the 1981-2000 modelling are used for the 2046-2065 modelling with future rainfall obtained using the *constant scaling*, *daily scaling* and *daily translation* methods.

3. Results and discussion

3.1 Changes in rainfall and potential evapotranspiration

The three scenario-construction methods produce exactly the same changes in mean rainfall and APET for each of the four seasons due to the common rescaling (2046-2065 relative to 1981-2000). Figure 2 shows changes in annual rainfall derived from the three GCMs by applying *constant scaling*, *daily scaling* and *daily translation* methods.

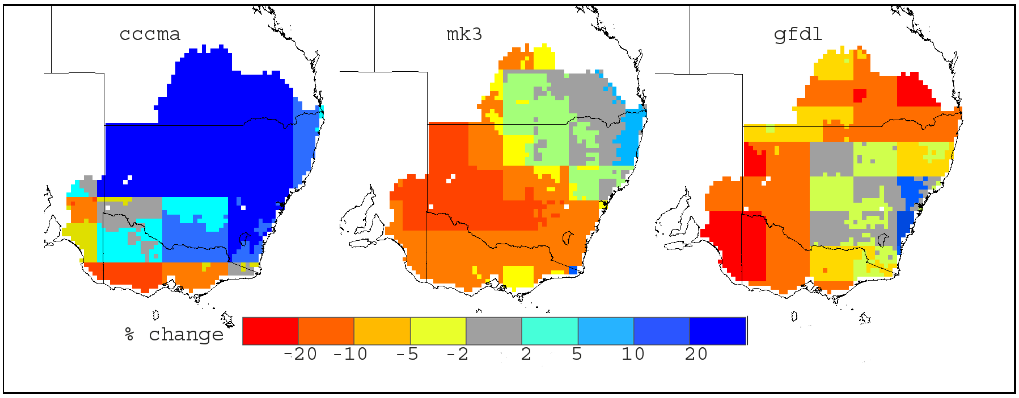

Figure 2: Changes in annual rainfall for 2046-2065 with respect to 1981-2000 derived from *cccma*, *mk3* and *gfdl*.

To interpret the differences in the runoff characteristics between the scenario-construction methods of rainfall, which is the main driver of runoff, only *constant scaling* was used in the construction of APET scenarios.

3.2 **Changes in runoff characteristics**

Figure 3 shows changes in mean annual runoff for 2046-2065 relative to 1981-2000 modelled by the rainfall-runoff model using the *constant scaling*, *daily scaling* and *daily translation* methods to provide future rainfall series as informed by the three GCMs. A comparison of percent of study area with change in mean annual rainfall less than a specified percentage change shows systematic differences between the *constant scaling* and *daily scaling* methods.

The *daily scaling* method shows higher runoff than the *constant scaling* method. This is because the three GCMs generally indicate that the increase in extreme rainfall in a future climate is more than the increase in mean rainfall (or the decrease in extreme rainfall is less than the decrease in mean rainfall). The *daily translation* method considers changes in the future rainfall time series, and runoff results from the *daily translation* method can be significantly different to the *constant scaling* and *daily scaling* methods.

Figure 4 shows an example of the potential use of the proposed simple scenario construction methods in providing objective information on the impacts of climate change in water accounting. A scenario of water availability at Torrumarry Weir, in the Murray-Darling Basin derived from *gfdl* GCM for 19 years (2047-2065) relative to 1982-2000 period show a general decline in water flows. However, occasional relatively high/extreme flows are also exhibited by flows derived using *daily scaling* and *daily translation* rainfall scenario construction methods. The Torrumarry Weir facilitates the division of flows for the main irrigation agriculture area in the Murray-Darling basin. The amount of water supplied for irrigation is a function of demand, but water restrictions are applied when river low flows reach pre-established thresholds. Table 1 shows a summary of the decreases in the projected flows relative to respective monthly means. The *constant scaling* method shows relatively low projections of the number of months under decreased flows compared to *daily scaling* and *daily translation* methods. This can be attributed to the tendency of the *daily scaling* method to suppress the variability of the flow. Potentially such information in the table is useful in decision making on levels of water restrictions over various periods.

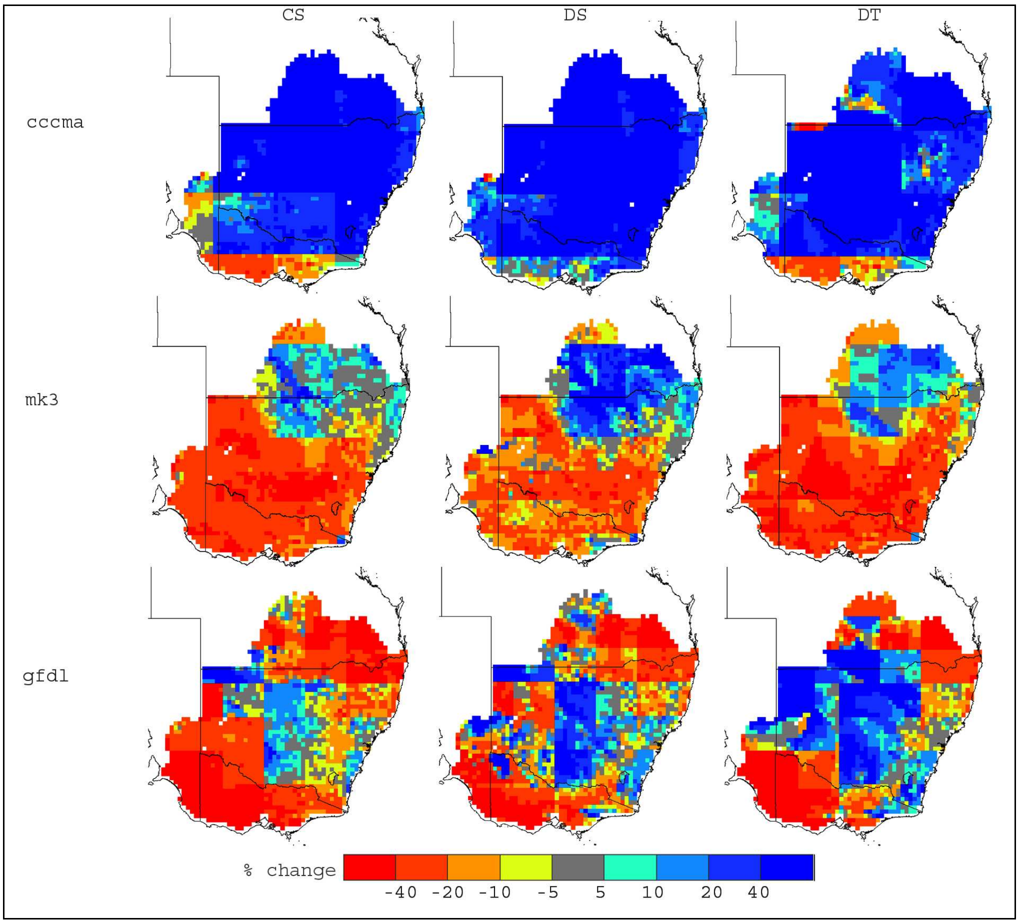

Figure 3: Change in mean annual runoff for 2046-2065, with respect to 1981-2000, derived from *cccma* (row 1), *mk3* (row 2) and *gfdl* (row 3) by using *constant-scaling* (CS), *daily scaling* (DS) and *daily translation* (DT) methods.

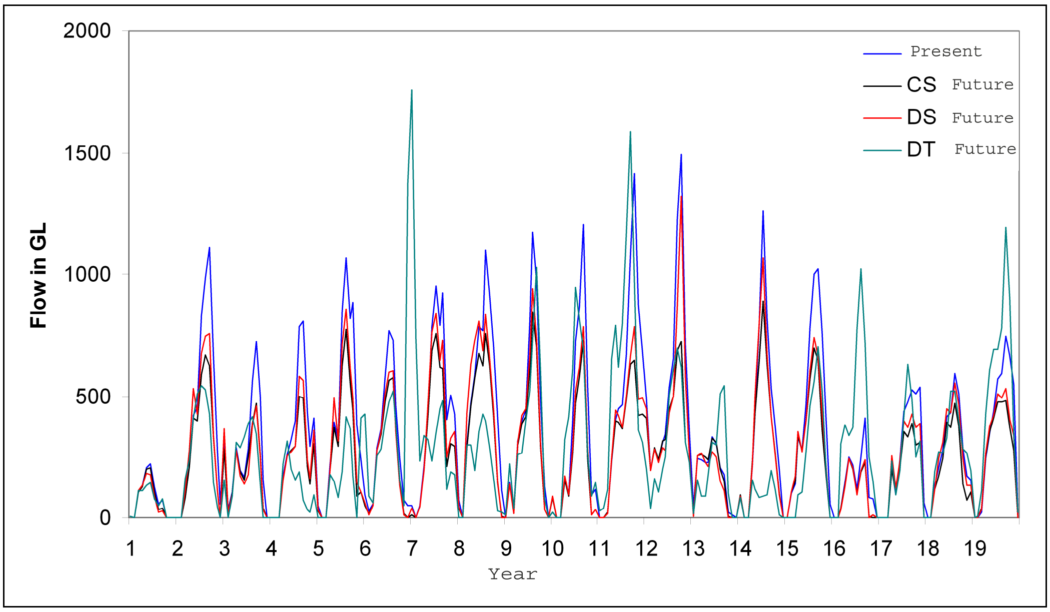

Figure 4: Monthly flows of the Murray-Darling River at Torrumbary Weir for 1982-2000 (present) and projected flows for 2047-2065 (future) derived from *gfdl* GCM rainfall scenarios using *constant-scaling* (CS), *daily scaling* (DS) and *daily translation* (DT) methods.

Table 1: Total number of months under projected changes in monthly flows at Torrambarry Weir in the Murray-Darling Bain for the 2047-2065 period relative to 1982-2000.

Change (%)	Number of months showing change		
	CS	DS	DT
-50	18	26	24
-25	30	38	38
-10	41	51	44

4. Conclusions

The *constant-scaling* method is currently used in almost all hydrological impact modelling studies due to its simplicity. However, the *daily scaling* method is likely to be a better method because it considers different changes to different rainfall amounts. This can be particularly important because many GCMs indicate that the extreme rainfall in a future climate is likely to increase by more than the increase in mean rainfall or decrease by less than the decrease in mean rainfall. As high rainfall events generate significant runoff, the runoff estimated from the *daily scaling* method will be higher than that estimated by the *constant-scaling* method. However, the difference between the *constant-scaling* and *daily scaling* modelling results is small compared to the differences between the three GCMs.

The *daily translation* method considers changes in the future rainfall time series, and runoff results from the *daily translation* method can be significantly different to the *constant-scaling* and *daily scaling* methods. As the *daily translation* method uses the future rainfall series modelled by the GCM and translates it to catchment scale rainfall, the *daily translation* method potentially exhibits the dynamics of the climate system associated with global climate change as simulated by the GCM.

The *constant-scaling* method is useful because it is simple and can be used with results from many GCMs and global warming scenarios to take into account the large uncertainties associated with climate change projections. The GCM simulation of mean climate is also considerably better than its ability to simulate extreme climate and daily series. However, the *daily scaling* method is conceptually better than the *constant-scaling* method if GCMs have skill in modelling extreme rainfall. Likewise, the *daily translation* method is conceptually better than the *constant-scaling* and *daily scaling* methods if GCMs have skill in modelling daily rainfall series and if the rainfall at GCM grid cell can be meaningfully translated to catchment scale rainfall.

In summary, the constant scaling method can be used in most applications to transform climate outputs from GCMs to drive hydrological models. However, where more detailed analyses of runoff distribution is required, the daily scaling and daily translation methods are potentially better, particularly if the GCM used have skill in modelling extreme rainfall and daily rainfall series.

ACKNOWLEDGEMENTS

This work was funded by the South Eastern Australian Climate Initiative (SEACI). The authors would like to thank Harvey Davies for his support in developing Tcl/NAP software tools used extensively in this study, Mainuddin Mohammed for water accounting analysis and Steve Charles for reviewing the manuscript.

REFERENCES

Adams, P.D., Horridge M., Masden J.R. and Wittwer G., Drought, regions and the Australian economy between 2001-02 and 2004-05, *Australian Bulletin of Labour*, 28, 233-249, 2002.

Allen Consulting Group, Climate Change Risk and Vulnerability: Promoting an Efficient Adaptation Response in Australia, *The Allen Consulting Group*, 159 pp, 2005.

Charles SP, Bates BC, Smith, IN & Hughes JP, Statistical downscaling of daily precipitation from observed and modelled atmospheric fields, *Hydrological Processes*, 18, 1373-1394, 2004.

Chiew FHS, Estimation of rainfall elasticity of streamflow in Australia, *Hydrological Sciences Journal*, 51, 613-625, 2006.

Chiew, F.H.S., Peel, M.C. and Western, A.W.., Application and testing of the simple rainfall-runoff model SIMHYD, In: Mathematical Models of Small Watershed Hydrology and Applications Editors: V.P. Singh and D.K. Frevert, *Water Resources Publication, Littleton*, Colorado, USA, pp. 335-367, 2002.

IPCC-TGCIA, Guidelines on the use of scenario data for climate impact and adaptation assessment. Version 1. Prepared by Carter, T.R., Hulme, M. and Lal, M., Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, 69pp, 1999.

https://esg.llnl.gov:8443/index.jsp, World Climate Research Program (WCRP) Data. Last cited, 19 February,2008.

Jeffrey, S.J., Carter, J.O., Moodie, K.M and Beswick, A.R, Using spatial interpolation to construct a comprehensive archive of Australian climate data", *Environmental Modelling and Software*, Vol **16/4**, pp 309-330, 2001.

Kidson J W, Thompson CS., A comparison of statistical and model-based downscaling techniques for estimating local climate variations. *Journal of Climate* **11**: 735–753, 1998.

Lorenz P. and Jacob D., The link between regional and global climate -applications of the two-way nested GCM-RCM system. *Second International Conference on Earth System Modelling (ICESM) Abstracts*, Vol. 1, ICESM2007-A-00139, 2007.

Mearns, L.O., Rosenzweig, C. and Goldberg, R., The effect of changes in daily and interannual climatic variability on CERES-wheat: A sensitivity study. *Climatic Change* 32, pp. 257–292, 1996.

Morton, F. I., Operational estimates of areal evapotranspiration and their significance to the science and practice of hydrology. .*Journal of Hydrology* **66**: 1-76, 1983.

Mpelasoka F.S., Hennessy K., Jones R. and Bates B., Comparison of suitable drought indices for climate change impacts assessment over Australia towards resource management, *International Journal of Climatology*, (www.interscience.wiley.com) DOI: 10.1002/joc.1649, 2007.

Mpelasoka F., Mullan A.B. and Heerdegen R.G., New Zealand climate change information derived by multivariate statistical and artificial neural network approaches. *International Journal of Climatology*, 21, 1415–1433, 2001.

Nunez M. and McGregor J. L., Modelling future water environments of Tasmania, Australia. *Climate Research*, 34, 1-14, 2007.

Suppiah, R., K. J. Hennessy, P. H. Whetton, K. McInnes, I Macadam, J. Bathols, J. Ricketts and C. M. Page, Australian climate change projections derived from simulations performed for the IPCC 4th Assessment Report. *Australian Meteorological Magazine* (In press), 2007.