Attachment 2

Indian Ocean Climate Initiative Stage 2:

Unabridged Reports of Phase 1 Theme 2 Activity

July 2003 – Dec 2004

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Contents

Project 2.1 Dynamical Downscaling

Project 2.3 Comparison with Observations

The dynamical downscaling of the large-scale global climate model results will be performed using the CSIRO Conformal Cubic Atmospheric Model (CCAM). This model takes the surface boundary and far-field boundary results from the global model to provide a finer scale simulation of the climate for the region of interest. The change in scale will typically be from approximately 200 km down to 60 km. The comparison will focus on the trends in rainfall, the large-scale circulation, and synoptic events both observed and simulated.

Here we report on the results of analyses conducted with both the relatively coarse scale Mk3 climate model and the relatively fine scale CCAM model as identified under Stream 2.1 and 2.3 objectives. The key issues addressed are summarized by the following questions:

1. How well does dynamical downscaling perform in the current climate?
2. What does dynamical downscaling tell us about the drivers of decadal variability?
3. Is dynamical downscaling feasible within climate change simulations?

Analysis of results from the Mk3 atmospheric model forced by observed sea surface temperatures (SSTs) alone.

Figure 2.1 compares the observed SWWA winter season (May to October) rainfall totals with those simulated in two climate model experiments. The first experiment was designed to investigate whether prescribing observed, monthly sea surface temperatures within a climate model would yield similar fluctuations – both on a year-to-year basis and also over the long-term. The results are referred to in the figure as Mk3 C20C (an acronym for Climate of the 20th Century) and cover the 30-year period 1961 to 2000.

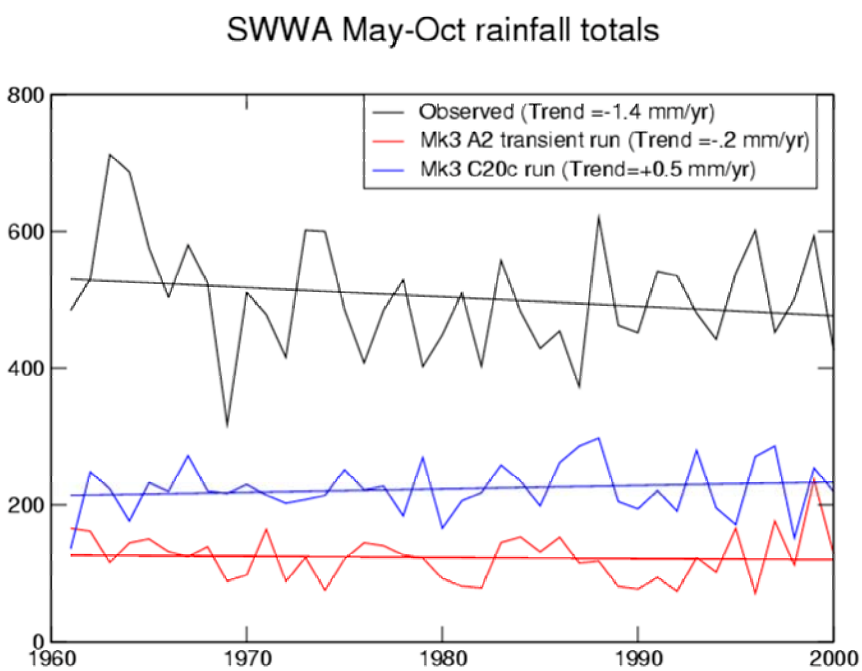

Figure 2.1. SWWA winter season (May to October) rainfall totals – observed (black), simulated by Mk3 when forced by observed SSTs (blue), and simulated by the Mk3 coupled model when forced by transient greenhouse gas concentrations (red).

The three features of the results are:

(1) The model rainfall totals underestimate the observed totals by almost a factor of 2. This is partly a result of the coarse-scale horizontal resolution (approximately 200 km by 200km) employed by the climate model which means that topographic features are not well represented.
(2) Ignoring the rainfall bias, the model does not reproduce the relatively wet and dry years as observed.
(3) The trend in the model results is one of increasing rainfall over time. The rate of increase is +0.5 mm per year compared to the observed decrease of -1.4 mm per year.

The second experiment referred to here is a transient climate change experiment in which a coupled ocean-atmosphere model has been forced only by increasing amounts of atmospheric greenhouse gases (acronym Mk3 A2). The difference with the first experiment is that rather than relying on prescribed SSTs, in this case the SSTs are calculated as a response by the oceanic component of the coupled model. In this case the climatological rainfall is less because the coupled model climatology differs from the first experiment. There is no correspondence between the wet and dry years and none is expected since the model is only forced by the increasing greenhouse gas concentrations. However, over a period within this experiment when the greenhouse gas concentrations could be regarded as similar to those in the real world, the simulated rainfall totals do decrease over time. The rate of decrease is only -0.2 mm per year (c.f. -1.4 mm per year observed) and represents a trend within the model which continues through to the middle of the century. This could be interpreted as evidence that the decline in SSWA rainfall over recent decades is partly related to enhanced greenhouse gases, but this needs to be tempered by the fact that the simulated circulation changes that accompany these decreases do not agree with the observed changes (IOCI2002).

These results suggest several possibilities:

1. The Mk3 Atmospheric model alone is not appropriate for simulating SWWA rainfall.
2. The SSTs used to drive the first experiment are incorrect
3. SSTs are not the prime drivers of SWWA winter rainfall fluctuations and we have not accounted for the relevant factors
4. Using prescribed SSTs (especially average monthly mean values) to force an atmospheric model may not be entirely appropriate if there are important coupled mechanisms that can operate at short time scales.

The first of these options has been addressed by looking at the results from a very different climate model – CCAM which is suitable for high resolution regional scale studies. Here, the model has a resolution of 60 km over all of Australia. Beyond the Australian region, the resolution becomes progressively coarser such that the bulk of the computational load refers to the region of interest and minimal computations are required for the most distant regions on the other side of the globe. Away from the region of interest, the wind fields (above 800 meters) are nudged towards observed winds on a daily basis. The observed winds are those taken from the NCEP reanalysis product. Figure 2.2a and Figure **2.2**b refer to two different experimental configurations. In the first, wind nudging takes place at all the far-field grid points. Within a region closer to Australia, this nudging takes place on a much weaker basis and, over the Australian region, no nudging takes place at all and the resultant winds are purely those calculated by the model. This configuration is designed to allow some information from afar to be propagated into the region of interest, otherwise the local circulation represents a response to the imposed SSTs. In the second configuration, the upper level winds are nudged uniformly across the entire grid. In this case the local circulation over Australia is dominated by the observed winds and the effect of the SSTs is minimal.

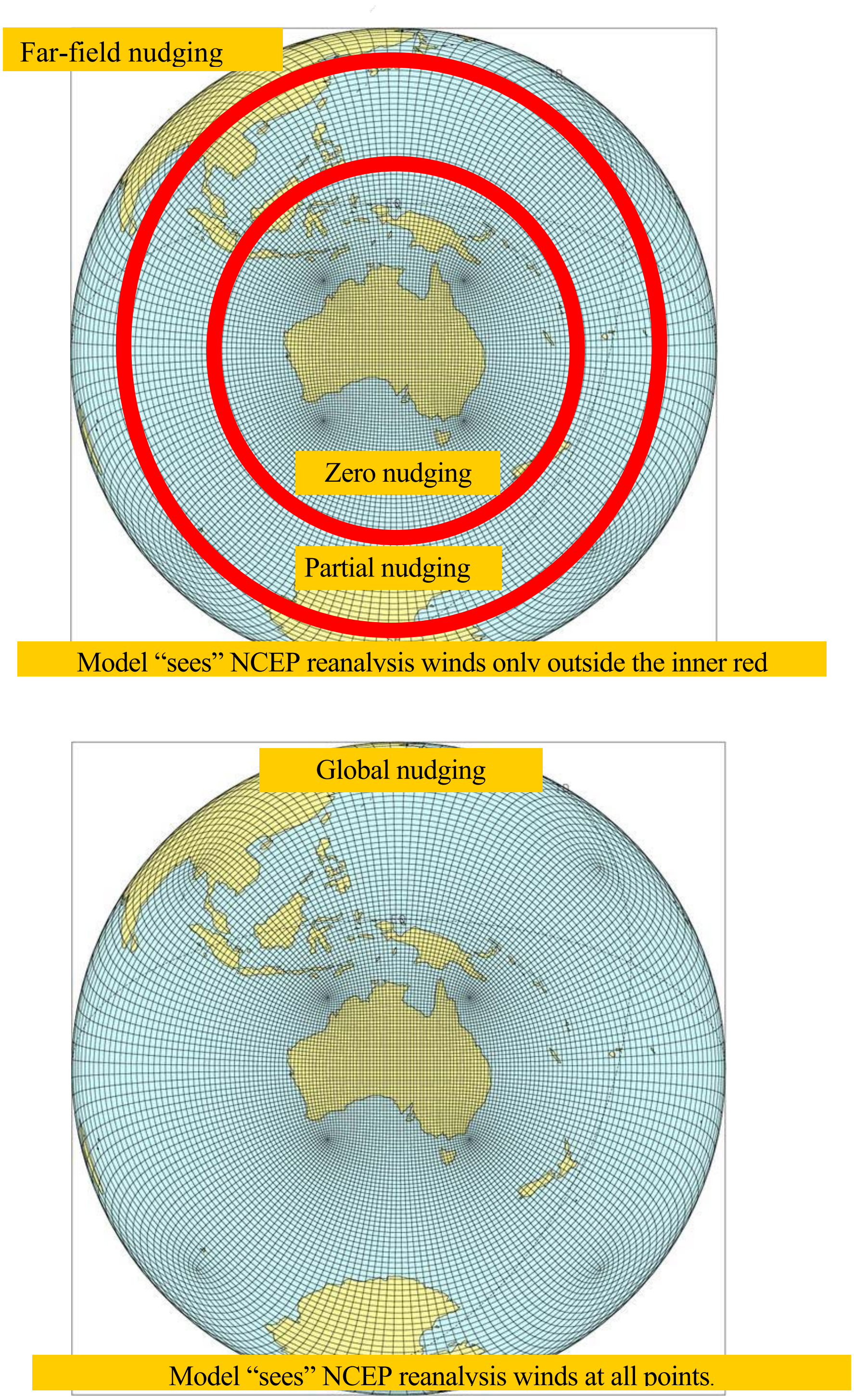

Figure 2.2
(a) far-field nudging of winds
(b) global nudging of winds

The results for rainfall from the first CCAM experiment are compared with both observed values and those derived from the NCEP reanalysis product in Figure 2.3. When forced by observed SSTs, and far-field nudging of the winds, CCAM provides better rainfall climatology than that provided by Mk3. While still representing an underestimate, the rainfall totals are much closer to the observations than those from Mk3. This mainly reflects the higher horizontal resolution employed (60km). While CCAM still underestimates the actual totals, this is associated with the fact that the climatological mean sea level pressure field over SWWA is somewhat higher than observed. Despite the improvement in the climatological mean rainfall amount, the simulated values over the period 1961 to

1990 do not compare well with the observed values. The correlation between the two time series over this period is only +0.37. By way of comparison, the rainfall totals according to the NCEP reanalysis data over the period 1961 to 2000 are highly correlated (r=+0.78) with the observations. This is not unexpected since the NCEP rainfall values, although model generated, are driven by the observed/analysed atmospheric fields (winds, pressure, temperature, moisture, etc.) on a 6-hourly basis. The fact that they underestimate rainfall is again most likely due to the coarse resolution (250km) of the NCEP grid. What is somewhat unexpected is the fact that the NCEP rainfall values exhibit an increase over time whereas the observations and the CCAM result (while poorly correlated on the interannual time scale) both exhibit decreases over time.

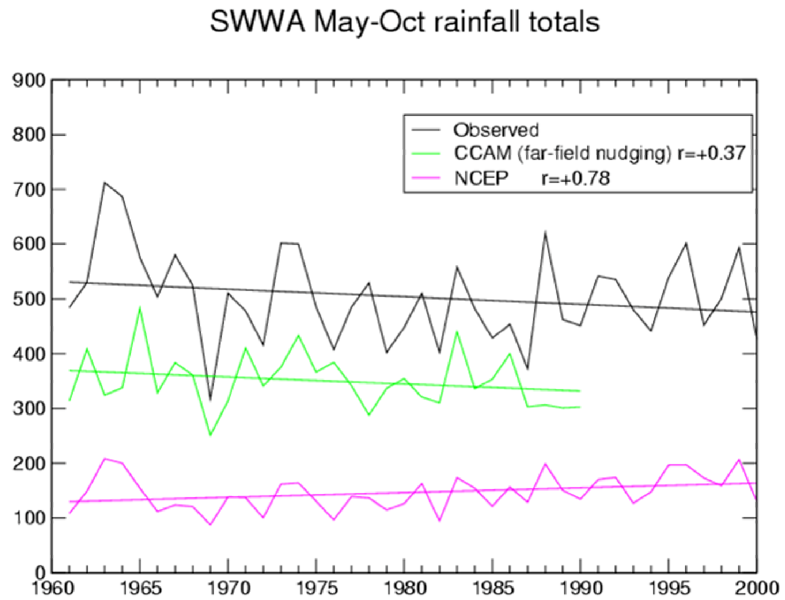

Figure 2.3. SWWA winter season (May to October) rainfall totals – observed (black), simulated by CCAM when forced by observed SSTs and far-field nudging of the winds (green), and as derived from the NCEP reanalysis product (mauve).

The results from the second CCAM experiment are shown in Figure 2.4. In this case the configuration of the CCAM experiment is such that the results can be compared to the NCEP results since both models are forced by observed synoptic events. The only other difference from the first set of results is that the period of interest is 1961 to 2000. In this case the CCAM rainfall totals are now highly correlated (r=+0.72) with the observed totals. While the correlation is less than that associated with the NCEP data, this is most likely due to the weaker coupling between the analysed atmospheric fields and the CCAM model. The important feature is the fact that the CCAM model reproduces both interannual fluctuations and also the negative trend in rainfall over this period. The CCAM trend is -0.3 mm per year compared to the observed trend of -1.4 mm per year.

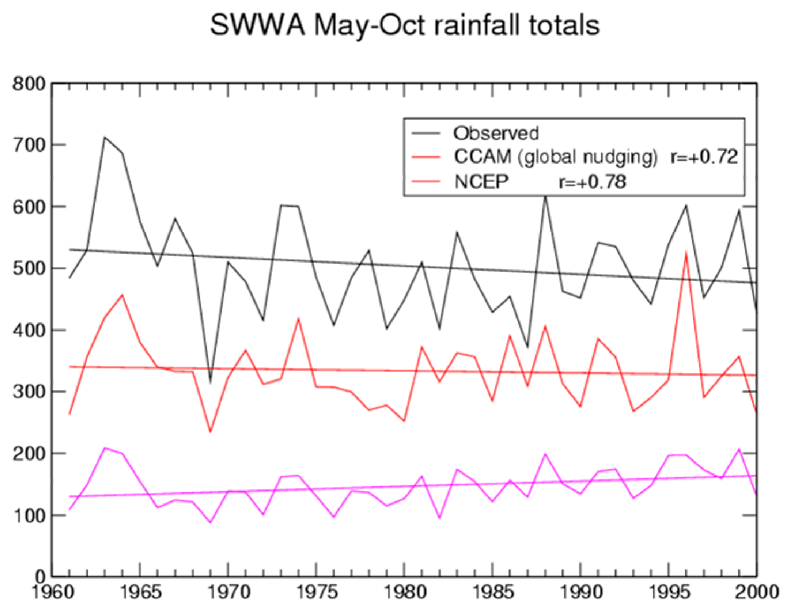

Figure 2.4. SWWA winter season (May to October) rainfall totals – observed (black), simulated by CCAM when forced by observed SSTs and global nudging of the winds (red), and as derived from the NCEP reanalysis product (mauve).

These results indicate that the correct atmospheric forcing the CCAM model provides a good simulation (both interannual fluctuations and long-term trends) of SWWA winter rainfall variability within the present climate. This, in turn, indicates that future CCAM can be used to estimate future changes in rainfall given a projection of future changes in the atmospheric circulation. The next phase of research will focus on downscaling of the results from the Mk3 coupled model for both the present climate, and a future period (2015-2045).

It is also apparent that SSTs have very little role to play in controlling SWWA winter rainfall. With the first experiment, the major driver of the rainfall fluctuations is the observed SST variations since the observed circulation changes (or synoptic events) are only imposed at the far-field boundaries. The poor result of rainfall suggests that either the SSTs are incorrectly specified or else they are not simple drivers. If the former, this could be the result of poor quality observations, especially at mid- to high latitudes. However, there is little evidence that SSTs outside of the tropics exert much influence on the atmosphere and previous work has indicated that the atmosphere tends to drive the SSTs. It is highly likely that SWWA rainfall is not driven by SSTs but is driven mainly by changes in the large scale circulation on interannual and decadal time scales. As to the cause of the circulation changes, we must conclude that they are driven by some (as yet) undetermined factor.

Analysis of results from the A2 scenario experiment with the Mk3 coupled model

As reported in IOCI (2002), the results of the A2 scenario experiment reveal changes to both SSTs and sea ice over time which accompanies a gradual decline in rainfall and a gradual increase in local pressure. These changes are all internally consistent and, although the rainfall decline and change in pressure over SWWA are similar to observations at the end of last century, they do not match the observations on the larger scale. Furthermore, the changes are not evident till later this century. Finally, there is little evidence of relatively sudden or 'step-like' changes to rainfall over time. As previously noted, it is difficult to explain the bulk of the observed changes to the effect of enhanced greenhouse gases and the driver for the observed atmospheric circulation changes and accompanying rainfall decline remains to be precisely identified.

Project 2.2: Statistical downscaling

The statistical downscaling of either the global model results or the CCAM results will be performed using the existing techniques developed by CLW under IOCI Stage 1. These results will indicate which of the key fields (e.g. pressure, winds, temperature, etc.) relevant to SWWA rainfall have changed over the period of interest. The results from the statistical downscaling techniques developed by CLW will be compared with the results from the downscaling methodologies used by BMRC.

Statistical downscaling for winter (May-October) rainfall in SWA has been undertaken using daily output from a CSIRO Mk3 transient A2 run and a CSIRO CCAM run, nested in the Mk3 run. Two 30 year time-slices, centred on 1990 and 2050, are statistically downscaled using the CSIRO NHMM and BMRC analogue techniques. This produces daily, multi-site precipitation simulations for a network of 30 rain gauges across SWA. It can be concluded that:

- The Mk3 grid rainfall is, not surprisingly, a totally unrealistic representation of rain gauge scale rainfall (Figure 2.5a).
- The CCAM rainfall at the 75km grid scale is a much better representation, although it still cannot reproduce the local rainfall (Figure 2.5b).
- SD can use atmospheric predictors from the Mk3 (Figure 2.6a) or CCAM (Figure 2.6b) to bypass this deficiency.
- Consistent climate change projections are obtained using both the Mk3 and CCAM atmospheric predictors to drive the CSIRO and BMRC SD techniques (Figure 2.7). Note: the two SD techniques are using different atmospheric predictor sets. The CSIRO SD model uses MSLP, north-south gradient in MSLP, and dew-point temperature depression at 850 hPa. The BMRC SD model uses MSLP and precipitable water.
- Assessing consistency between dynamical and statistical downscaling projections forced by different GCMs should be a focus of future research.

Further, more detailed intercomparison of these results is on-going and will lead to an international journal paper (currently *in preparation*).

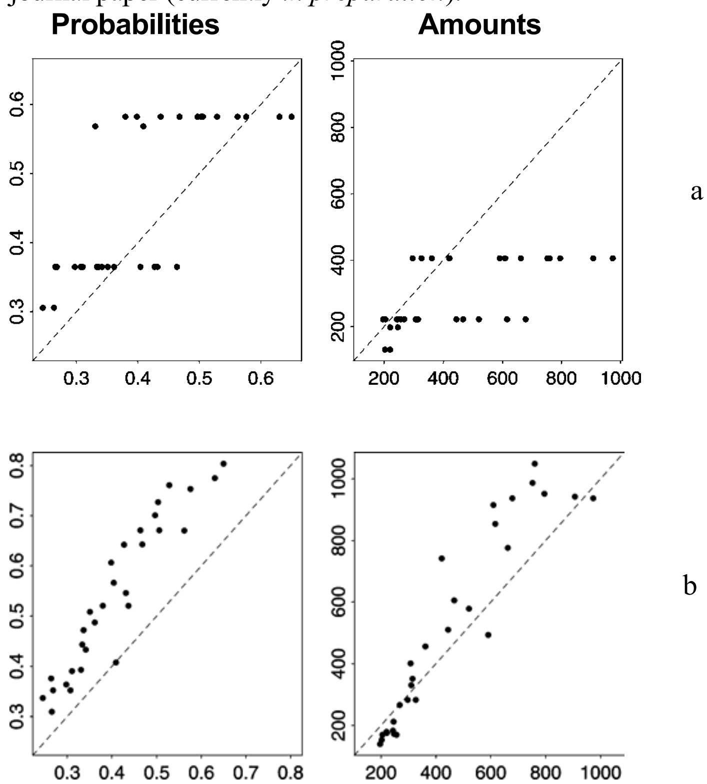

Figure 2.5. Observed (rain gauge) versus (a) Mk3 and (b) CCAM grid-scale rainfall probabilities (left panels) and amounts (mm, right panels) for 30 SWA sites for winter (May-October).

Probabilities **Amounts**

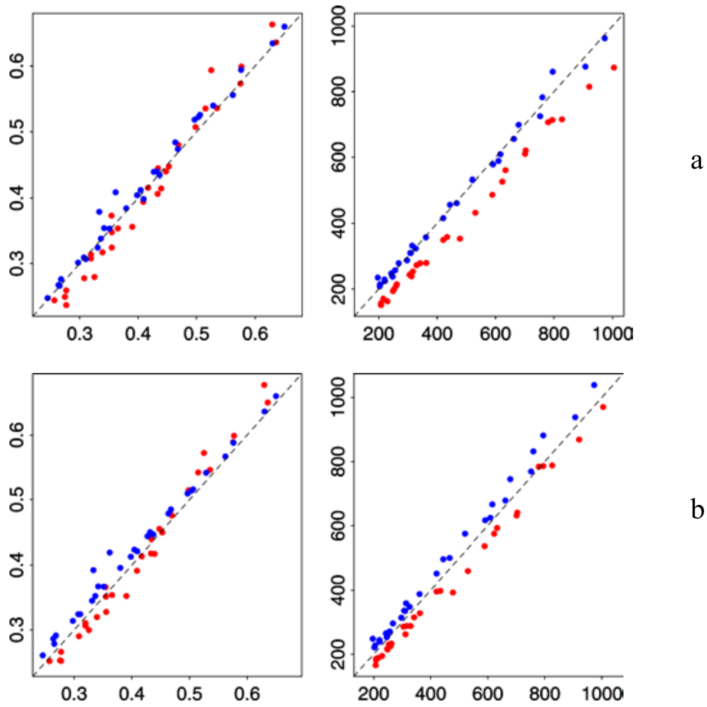

Figure 2.6. Current climate observed versus (a) Mk3 and (b) CCAM statistically downscaled rainfall probabilities (left panels) and amounts (mm, right panels) for 30 SWA sites for winter (May-October). Blue is the CSIRO NHMM and red is the BMRC analogue technique.

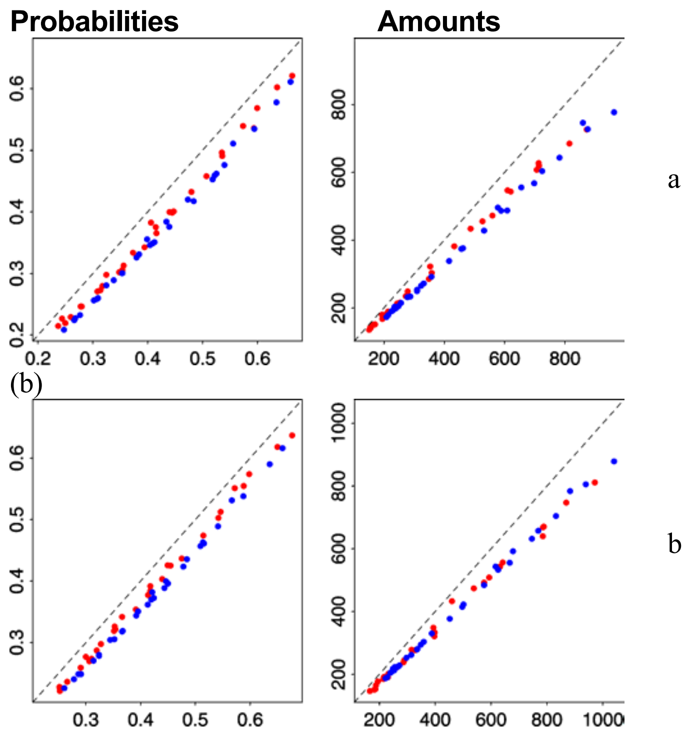

Figure 2.7. (a) Mk3 and (b) CCAM statistically downscaled current (1975-2004) versus projected (2035-2064) rainfall probabilities (left panels) and amounts (mm, right panels) for 30 SWA sites for winter (May-October). Blue is the CSIRO NHMM and red is the BMRC analogue technique.

Statistical downscaling has also been undertaken for a long transient A2 Mk3 run for 1871 to 2250. Two prominent weather state patterns of the SWWA winter SD model are the ‘dry everywhere’ and the ‘wet everywhere’ pattern. Figure 2.8 shows these patterns, and how their projected probability changes as climate change progresses. Thus a continued drying trend is projected for the region.

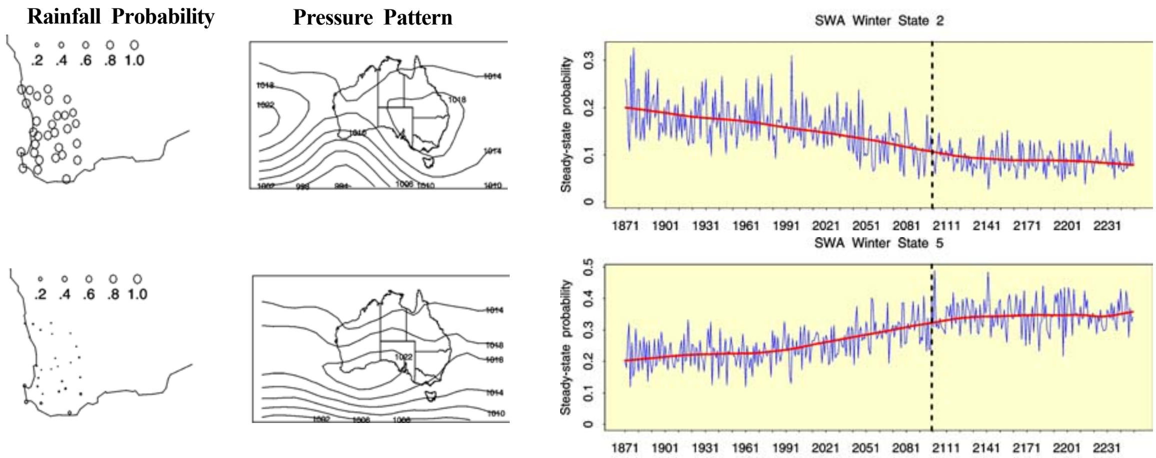

Figure 2.8. SWWA SD model winter (May-Oct) weather state rainfall probability, MSLP (from observed data), and time-series (from Mk3 A2 transient run) for the ‘wet everywhere’ State 2 and the ‘dry everywhere’ State 5. For the time-series, the vertical dashed line at year 2100 indicates when CO2 increases ceased in the Mk3 A2 model run.

References

Charles, S.P., Bates, B.C., Smith, I.N. and Hughes, J.P. (2004). Statistical downscaling of daily precipitation from observed and modelled atmospheric fields. *Hydrological Processes*, 18(8), 1373-1394.

Timbal, B. (2004). Southwest Australia past and future rainfall trends. *Climate Research*, 26, 233-249.

Project 2.5: Synthesis of global model results for key climate variables

The latest transient model results will include the CSIRO Mk3 A2 emissions scenario run and the Hadley Centre model (Hadcm) run. These results are usually generated as monthly averages but the CSIRO Mark3 model also generates results at the daily time scale. The resultant data set is expected to comprise a suite of results based on different models and results based on different scenarios.

Previous climate change projections based on IS92 emission scenarios by CSIRO showed a decline in winter rainfall taking place over southwestern Western Australia under enhanced greenhouse conditions. In this study, a number of simulations based on SRES emission scenarios are analysed in order to update the projections and to better define the levels of uncertainty.

Results from Global and Regional Climate Models

As an initial step, we analysed 19 global and regional climate model simulations to see how well these models capture features of the present climate over southwest Western Australia. Statistical methods were employed to test whether the simulations satisfactorily resemble observed patterns of mean sea level pressure, temperature and precipitation. Simulated and observed patterns for 1961-1990 were compared using both the pattern correlation coefficient, which measures pattern similarity, and the root mean square error (RMS). A domain centred on southwestern western Australia (115-122ºE, 28-38ºS) was used for testing temperature and precipitation. However, a relatively larger region (110-160ºE, 10-45ºS) was chosen to test mean sea level pressure. Since most of the precipitation falls within the winter-half of the year, we have analysed the data separately for winter and summer-half years. The winter-half season includes the months from May to October and the summer half season includes the months from November to April. In the case of multiple experiments with a single model, particularly for SRES scenarios, we have averaged the results.

Most models capture the basic features of the regional climate circulation in terms of mean sea level pressure, precipitation and temperature, although a few simulations were relatively poor. The temperature results indicate that the models represent the spatial pattern well during the summer-half of the year, when a continental scale effect on temperature is dominant. However, the pattern during the winter-half of the year is not well simulated by many models, particularly the coarse resolution GCMs. In this season topographical variations more strongly drive the temperature patterns, and not surprisingly the high resolution models perform better. Most of the models capture the observed pattern of precipitation during the winter-half of the year, but some do poorly for the summer-half.

On the basis of the results of statistical analyses, we selected the nine better performing models to construct climate change projections for the selected domain. We also compared these projections with those based on the full set to see if this technique of model "screening" makes a significant difference and found no significant difference over the selected domain.

New Climate Scenarios for south west Western Australia

Scenarios for the southwestern Western Australia are presented here with ranges of uncertainty. The ranges allow scenarios of future growth in greenhouse gases and aerosols, and resultant global warming, the IPCC SRES scenarios without policies to reduce greenhouse gas emissions, the IPCC scenario for stabilising CO_2 concentrations at 550 ppm by the year 2150 and the IPCC scenario for stabilising CO_2 concentrations at 450 ppm by the year 2090. Results from the GCM simulations were expressed as a change per degree of global warming, then scaled for 2030 and 2070 using IPCC global warming values.

Temperature and rainfall changes due to enhanced greenhouse conditions are very small by 2005. Temperature increase shows a range between 0.13 and 0.16°C by 2005 relative to 1990. The rainfall changes show ranges between -2.6% and +1.3% for 2005. Temperature and rainfall projections are given for the years 2030 and 2070 based on SRES emission scenarios and also for stabilized emissions scenarios at 450 and 550 ppm (Figure 2.9, Figure 2.10). The new climate change projections for the SWWA region indicate an increase in temperature and decrease in rainfall under enhanced greenhouse conditions. Inland regions show warming between 0.5 and 2.1°C by 2030 and between 1 and 6.5°C by 2070 during the summer-half of the year for SRES emission scenarios. Relatively less increases are projected for stabilized scenarios for 550 and 450 ppm. During the winter-half of the year, increases are between 0.5 and 2°C by 2030 and between 1 and 5.5°C by 2070. Southern coastal regions show relatively less warming. Rainfall projections for both winter and summer –half years show decreases, in which, the winter-half shows a stronger decrease. Projected rainfall decreases are between 2 and 20% by 2030 and 5 and 60% by 2070 in the extreme southwestern Western during the winter-half of the year for SRES emission scenarios, but magnitudes of decreases are relatively smaller for stabilized emission scenarios. Rainfall changes during the summer-half of the year show decreases and some increases, particularly in the inland regions.

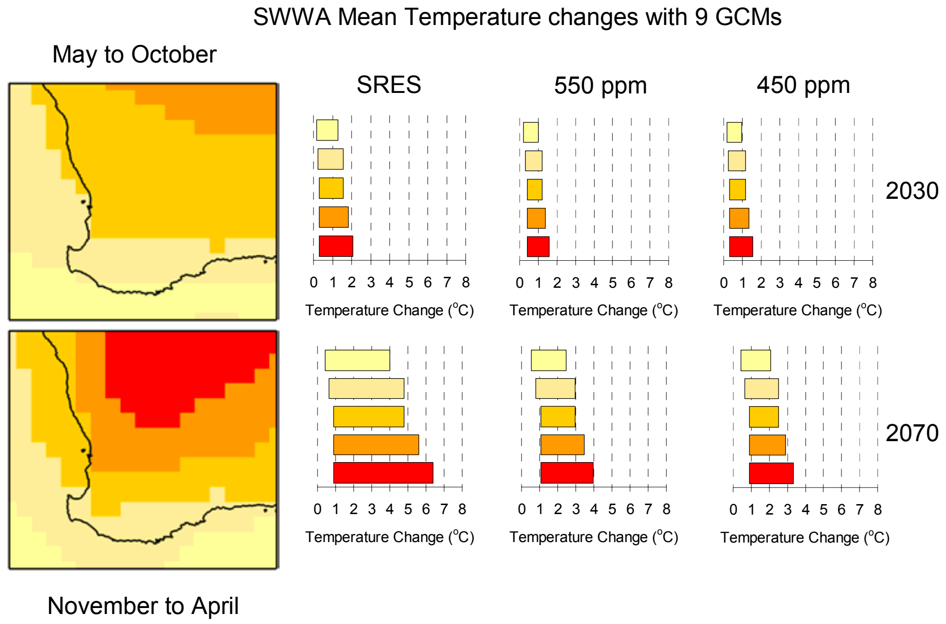

Figure 2.9. Projected temperature changes for the southwestern Western Australia by 2030 and 2070. Units are in °C.

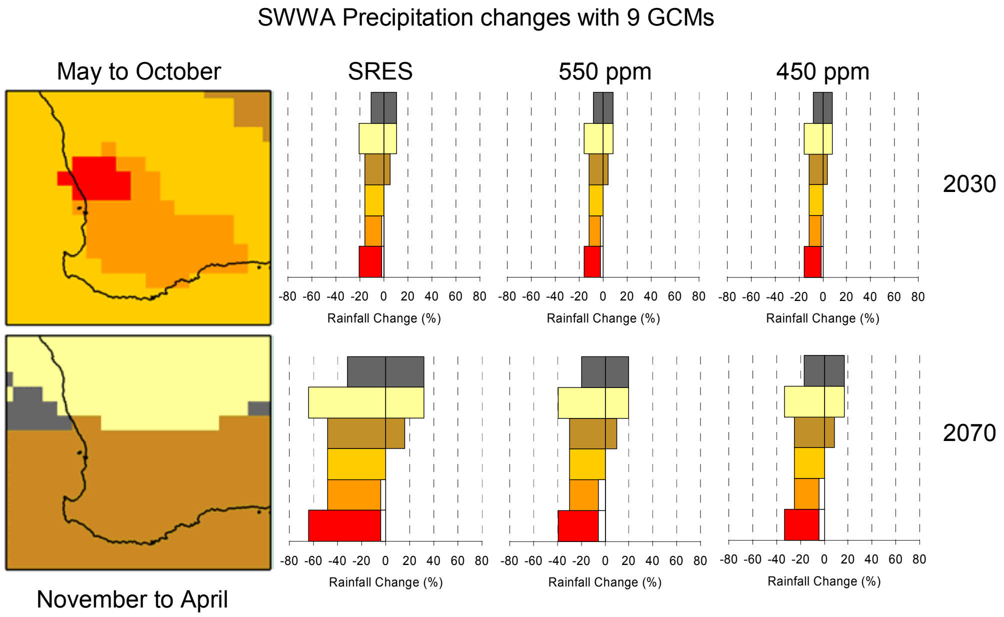

Figure 2.10. Projected percentage changes in rainfall for the southwestern Western Australia by 2030 and 2070.

Point potential evaporation increases are simulated over the domain (Figure 2. 11). Changes in point potential evaporation increases up to 10%by 2030 and up to about 30% by 2070 for SRES scenarios. Increases in point-potential evaporation are relatively low for stabilized scenarios.

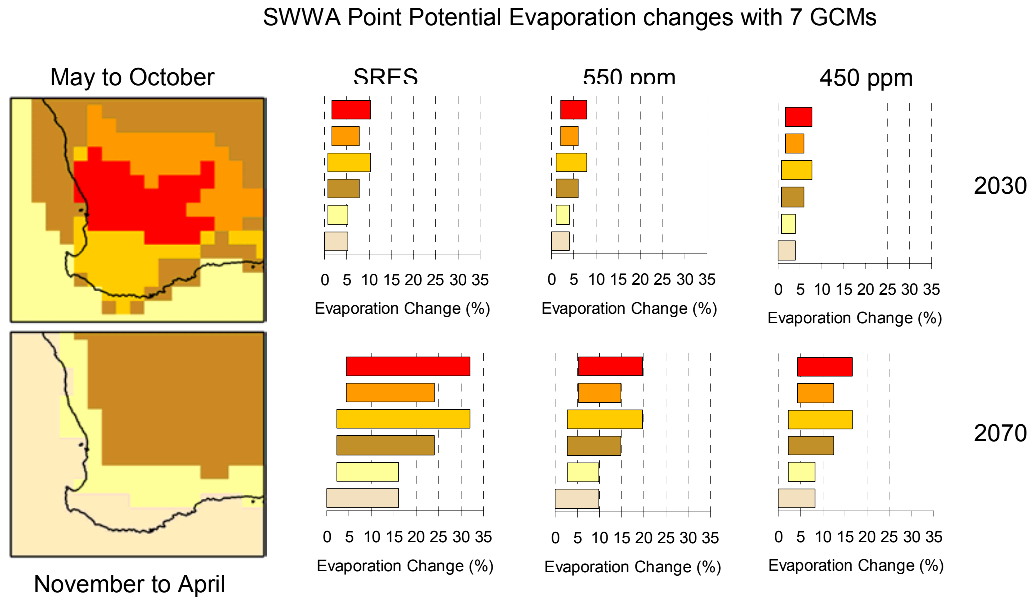

Figure 2. 11. Projected percentage changes in potential evaporation for the southwestern Western Australia by 2030 and 2070.