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Past and future climates in the tropical rainforest region of north Queensland

Suppiah, R. [1], **J. Bathols**[1], **I. Macadam** [1] **and P. H. Whetton** [1]

[1] *Centre for Australian Weather and Climate Research (CAWCR), CSIRO, Marine and Atmospheric Research, PMB No. 1, Aspendale, Victoria 3195, Australia*
Email: suppiah.ramasamy@csiro.au

Abstract: Tropical rainforest regions of north Queensland cover less than 1% of Australia's landmass but contain a highly disproportionate amount of the biodiversity. Extensive research on climate impacts on this biodiversity is being undertaken through a major research initiative, the Marine and Tropical Sciences Research Facility (MTSRF), coordinated by the Reef and Rainforest Research Centre (RRRC) in Cairns and Townsville. Results presented in this paper are based on the work carried out for the MTSRF.

Temperature in the tropical region has increased steadily between 1950 and 2008, but shows strong decadal and inter-annual variations. Since 1950, the tropical rainforest region's average maximum temperature has increased by 0.76°C (0.12°C per decade), the minimum by 0.79°C (0.14°C per decade) and the average by 0.78°C (0.13°C per decade). Cooler temperatures during the last few years have reduced the warming rate in this region. Variations in annual and seasonal rainfall in the rainforest region of north Queensland during the past century show no clear trend, but indicate fluctuations on multi-decadal time scales. In particular, the 1920s, 1960s and 1990s were dry decades and the 1970s was a wet period. Decadal fluctuations in annual rainfall are dominated by the wet season (January to March) rainfall variations. Rainfall in the dry season (August to October) shows strong variability. Rainfall in transitional seasons (Transitional 1 – November and December; Transitional 2 – April to July) also shows strong variability. The relationship between the Southern Oscillation Index (SOI) and rainfall is positive, but shows decadal-scale variations. The relationship was weak during 1930s and also during 1980s. The tendency for a weakening relationship in recent years began after the mid 1970s.

Projected changes in annual average temperature, rainfall and potential evaporation for decades from 2020 to 2080 for the three regions of were calculated, but annual values for 2030, 2050 and 2070 are described in detail. More details of temperature and rainfall projections for seasonal values and also for various decades from 2020 to 2080 are given in Suppiah *et al.* (2008). Projections were given for the 50th percentile as the best estimate and low and high ranges are given as 10th and 90th percentiles of temperature, rainfall and potential evaporation changes. The projections show that the inland areas of the MTSRF region will warm faster than the coastal areas. For a medium (AIB) emissions scenario the best estimate regional annual average temperature increase by 2030 is 0.8ºC with a range of uncertainty of 0.6 to 1.1ºC. Higher increases are projected for 2050 and 2070. For 2050, the ranges of uncertainty for regional average temperature increase for the different scenarios and span the range 0.7 to 2.2ºC. The corresponding range for 2070 is 0.9 to 3.5ºC.

Rainfall changes are more complex than temperature changes and show increases and decreases. For a medium emissions scenario the best estimate or the 50th percentile regional average rainfall change for 2030 is -1% with a range of uncertainty of -8 to +6%. Changes by 2050 and 2070 are dependent on emissions scenario. For 2050, the ranges of uncertainty for regional average rainfall change for the different scenarios span the range -16 to +11%. The corresponding range for 2070 is -26 to +18%. Percentage rainfall changes in Dry season and Transitional season 2 are greater than those for Wet season and Transitional season 1. Projected changes in potential evaporation (PE) indicate an increase. By 2030, the best estimate for PE change is 3% with the uncertainty range from 0 to 6%. By 2050, the increase in PE is 6% with a range between 3 and 10%. The change for 2070 is 8% with a range from 3 to 14%.

Keywords: *Climate change projections, tropical rainforest, Marine and Tropical Sciences Research facility (MTSRF)*

1. INTRODUCTION

Tropical rainforest regions of north Queensland and the Great Barrier Reef area support a rich diversity of habitats, which sustain regional economies through fisheries, tourism and other industries. The rainforest covers less than 1% of Australia's landmass but contains a highly disproportionate amount of the biodiversity. This region contains plant taxa representative of the earliest stages of the evolution of vascular plants and a very large number of regionally endemic plant and animal species. Climate change is one of the major threats that could affect the spatial distribution of diverse fauna and flora in the future. Sensitivity of rainforest to climate change has been investigated by Hilbert *et al.* (2001). The extinction risk of some species due to climate change has also been reported by Thomas *et al.* (2004). If strategies are not put into place to minimize potential impact of climate change, increased population pressure along the coast may have repercussions for the health of tropical and coastal ecosystems in the region and the economies and communities that they support. Extensive research on climate impacts on this biodiversity is being undertaken though a major research initiative, the Marine and Tropical Sciences Research Facility (MTSRF), coordinated by the Reef and Rainforest Research Centre (RRRC) in Cairns and Townsville.

Suppiah *et al*. (2007b) provided ranges of likely change in annual and seasonal temperature and rainfall averages for the 21st century for the tropical rainforest region of north Queensland and also for northern and southern halves of Queensland. Methods used to select climate models and to construct climate change projections were given in Whetton *et al*. (2005) and Suppiah *et al*. (2007a). These projections were derived from simulations of 15 global climate models (GCMs), selected from 23 GCMs on the basis of their reproduction of observed temperature and rainfall over Queensland and mean sea level pressure over the Australian continent averaged for the period from 1961-1990. Since then, CSIRO has developed new climate change projections for Australia using a probabilistic method that involves weighting the output of 23 GCMs according to the ability of models to reproduce the observed climate averages for the 1961-1990 period (CSIRO and Australian Bureau of Meteorology, 2007). The weighting method was developed by Watterson (2008). Following the release of probability based climate change projections for the Australian region in 2007, Suppiah *et al*. (2008) produced revised climate change projections for the tropical rainforest region using the method described by CSIRO and Bureau of Meteorology (2007). Although future projections will be the main focus of this paper, a brief description of trends and variability of temperature and rainfall over the past century will also be given.

In this paper, first a brief description of the new method used to construct climate change projections and its related uncertainty is given. Secondly, observed trends and variability of temperature and rainfall and changing nature of the link between rainfall and large scale circulation are given. Thirdly, projected changes in annual average temperature, rainfall and potential evaporation by 2030, 2050 and 2070 for the tropical rainforest region are discussed. Lastly, conclusions derived from this study are given.

2. METHOD USED TO GENERATE PROBABILISTIC CLIMATE CHANGE PROJECTIONS

This section provides a brief explanation of the generation of probabilistic projections for the tropical rainforest region. Changes in maximum, minimum, and average temperatures, rainfall and potential evaporation for the years 2020, 2030, 2040, 2050, 2060, 2070 and 2080 were calculated relative to averages for the 20-year 1980-1999 period. Although projections for selected variables were calculated for regions shown in Figure 1, detailed projections are given for 2030, 2050 and 2070 for the tropical rainforest or the MTSRF region. Since climate change projections are given for 30-year periods or decades, changes in any individual year will be strongly affected by natural climate variability (variability on inter-annual to decadal scales is not easily predicted and has not been accounted for). Three main sources of uncertainty are accounted for:

1) The uncertainty in the future evolution of greenhouse gases, sulphate aerosol emissions and other gases.
2) The uncertainty in how much the global average surface temperature will respond to increases in atmospheric greenhouse gas concentrations and changes in sulphate aerosol emissions.
3) The uncertainty in how the climate of Australia will respond to an increase in global average surface temperature.

The first uncertainty is addressed by considering six different scenarios for the future evolution of greenhouse gas and sulphate aerosol emissions described by the Special Report on Emissions Scenarios (SRES) (Nakićenović & Swart, 2000) of the Intergovernmental Panel on Climate Change (IPCC). Each of the scenarios, denoted A1B, A1FI, A1T, A2, B1 and B2 in Nakićenović & Swart, (2000) is based on a plausible storyline of future global demographic, economic and technological change in the 21st Century.

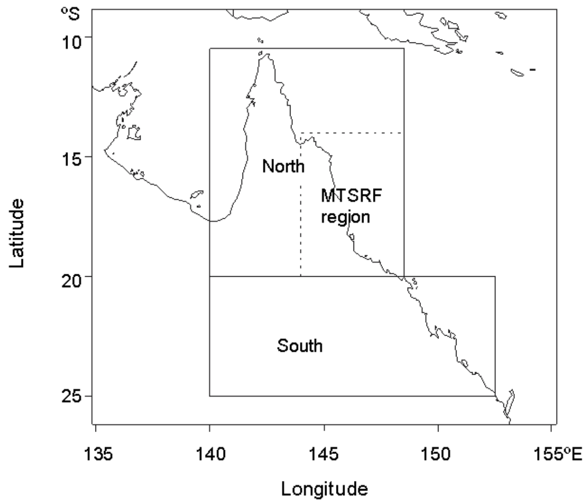

Figure 1. Regions for which climate change projections are provided

The second uncertainty is addressed by considering information on the response of the global average surface temperature to the emissions scenarios from multiple climate models and the IPCC's Fourth Assessment Report (Meehl *et al.* 2007b). Meehl et al (2007b) projected warming between 0.5 and 1.6°C by 2030 and between 1.1 and 6.4°C by 2100 relative to the average temperature for the 1980-2000 period. This is summarized in Figure 2, Their study also suggested that simulated global average surface temperature anomalies for the 20th Century agree well with observed anomalies on the timescale of several decades, giving us some confidence in the ability of climate models to accurately simulate anomalies on such a timescale.

For each period of interest and each scenario, the range of warmings is described using a probability distribution, which comprises a set of probabilities assigned to the numerous plausible values of change.

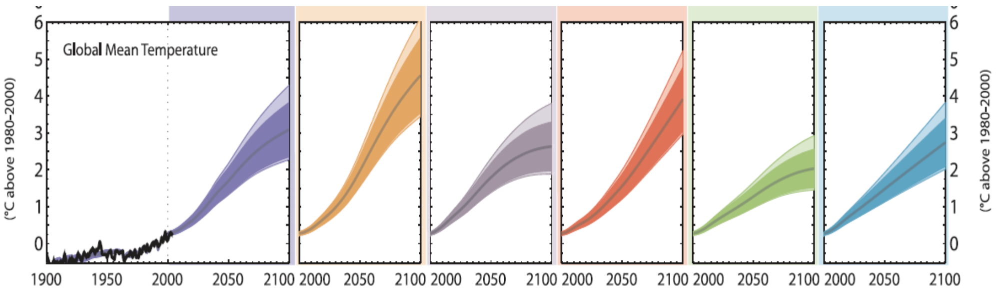

Figure 2. Changes, relative to the average for the period 1980-2000 in global average surface temperature for the 21st Century for the A1B, A1FI, A1T, A2, B1 and B2 SRES emissions scenarios. The dark shaded areas represent uncertainties in changes based on the consideration of the response of 19 climate models to the emissions scenarios. The light shaded areas represent uncertainties in changes based on the consideration of the response of the models to the emissions scenarios and uncertainty in carbon cycle feedbacks in the climate system. The coloured lines indicate changes based on the mean average response of the models and mid-range assumptions about carbon cycle feedbacks. The black line indicates changes recorded during the 20th Century. Source: Meehl *et al.* (2007b).

The third uncertainty is addressed by considering the response of the climate of Australia to global warming in 23 climate models. Model output from the Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (see Meehl *et al.*, 2007a) of the World Climate Research Programme (WCRP) was processed using the pattern scaling technique described by Mitchell *et al.* (1999), Mitchell (2003) and Whetton *et al.* (2005). From the simulations of the 21st century from each model, the trend in each variable at each model grid point was calculated, relative to the global mean warming. Projected regional changes in temperature are computed as degree of change per degree of global warming and rainfall changes are calculated as percentage change per degree of global warming. The results from the 23 models were then combined to form a probability distribution for local change per degree of warming. In this process, models were given differing weights (Watterson, 2008), or emphasis, depending on their ability to simulate average patterns of temperature, precipitation and mean sea level pressure in the Australian region for the 30-year period, 1961-1990. An assessment of the simulations of mean sea level pressure, temperature and rainfall by 23 GCMs over the Australian region is given by Suppiah *et al.* (2007a).

3. OBSERVED CLIMATE TRENDS AND VARIABILITY

3.1. Temperature

We have analyzed observed temperature from 1950 to the present, as the high-quality data set is available from the Australian Bureau of Meteorology for this period. Temperature in the tropical rainforest region shows steady warming between 1950 and 2000 and reduced warming after 2000. Observed records also show strong decadal and interannual variations. Since 1950, the tropical rainforest region's average maximum temperature has increased by 0.76°C (0.12°C per decade), the minimum by 0.80°C (0.14°C per decade) and the average by0.78°C (0.13°C per decade). Figure 3a shows strong interannual variations in mean annual temperature over the tropical rainforest region embedded with an increasing trend since 1950. Compared to national trends, the tropical rainforest region's temperatures show slower increases during the last five decades. The year 1998 was the warmest on record in the rainforest region, as it was globally (Jones and Moberg, 2003).

3.2. Rainfall

Rainfall data from the Australian Bureau of Meteorology for the domain have been analysed. Variations in annual rainfall in the rainforest region during the past century show no clear trend, but there are fluctuations on multi-decadal time scales as shown in Figure 3b. In particular, the 1920s, 1960s and 1990s were drier decades and the 1970s was a wetter period. Decadal fluctuations in annual rainfall are dominated by the wet season (January to March) and the Transitional season 1 (November and December) rainfall variations. Rainfall in the dry season (August to October) shows strong interannual variability (not shown here). Rainfall in transitional seasons (Transitional 1 – November and December; Transitional 2 – April to July) also shows greater variability. Observed rainfall shows significant decrease in the south of the region compared to the north of the tropical rainforest region (Suppiah *et al*., 2007b).

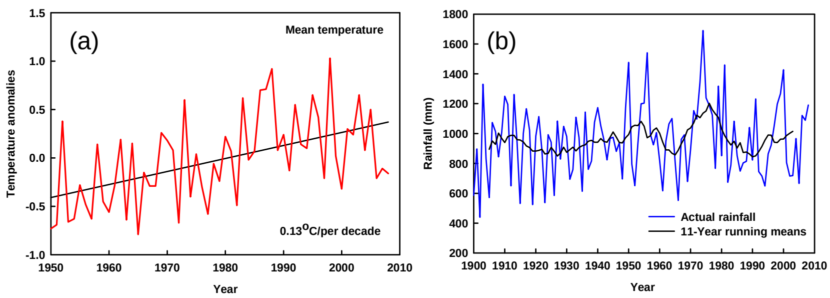

Figure 3. (a) Trends and fluctuations in mean annual temperature anomalies from the climatological period (1961-1990) for the period 1950-2008 and (b) in annual mean rainfall from 1900 to 2008 in the tropical rainforest region of north Queensland. The long-term increasing trend in mean annual temperature anomalies is shown by a linear trend line, while decadal-scale fluctuations in rainfall are shown by 11-year running means.

3.3. El Niño-Southern Oscillation (ENSO) and Rainfall

The El Niño-Southern Oscillation phenomenon has significant influences on the interannual variability of rainfall over northern and eastern Australia. Previous studies (McBride and Nicholls, 1983) demonstrated that relationship between rainfall and the southern oscillation is relatively stronger during spring compared to other seasons. The relationship between the Southern Index (SOI), a measure of ENSO variability, and rainfall is positive, but shows multi-decadal variations. The relationship was weak during 1930s and after the mid 1970s (Nicholls *et al.,* 1996; Suppiah, 2004). Such a weakening of the SOI-rainfall relationship is due to increasing pressure over the Western Pacific represented by Darwin as pressure records at Tahiti do not show clear trends (Suppiah, 2004). The weakening of the relationship between the SOI and rainfall has led to more rainfall for a given value of the SOI after mid 1970s, compared to previous periods. We have repeated the analysis shown in Suppiah (2004) using area-average rainfall for the tropical rainforest region of north Queensland. Correlations for wet, dry, Transitional 2 and Transitional 1 are 0.46, 0.52, 0.19, and 0.63. The correlation between annual rainfall of this region and the annual SOI is 0.46. Except for the transitional 2 seasons, all other seasons and the annual relationship are statistically significant at the 95% confidence level. However, the relationship has changes on decadal-time scales a shown in Figure 4. In particular, the

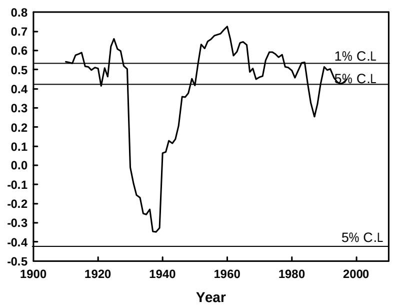

Figure 4. Variations of correlation coefficients with a 21 year sliding window between area-averaged annual rainfall over the tropical rainforest region of north Queensland and the annual SOI. The horizontal lines show the 5% and 1% significance levels.

relationship is strong between 1900 and 1920 and also between 1940 and mid 1970s, weak between 1900 and 1940s and also during 1980s. The reason for very weak correlation between 1920 and 1940 needs further investigation. In particular, there is a tendency for weakening relationship since the mid 1970s.

Since the relationship between rainfall and ENSO shows decadal variations, it is necessary that future GCMs adequately simulate the observed pattern of relationship and its low frequency variations that help to produce reliable climate change projections for the region.

4. CLIMATE CHANGE PROJECTIONS

4.1. Temperature

Figure 5 shows the 10th, 50th and 90th percentiles of annual average temperature increase for low (SRES B1), medium (SRES A1B) and high (SRES A1FI) emissions scenarios for 2030, 2050 and 2070. This figure shows that inland areas of the tropical rainforest region will warm faster than coastal areas. Temperature increases by 2030 do not differ greatly between low, medium and high emissions scenarios. For a medium emissions scenario the best estimate (50th percentile) regional average temperature increase by 2030 is 0.8ºC with a range of uncertainty of 0.6 to 1.1ºC. Temperature increases by 2050 and 2070 increasingly diverge dependent on emissions scenario. For 2050, the ranges of uncertainty for regional average temperature increase for the different scenarios and span the range 0.7 to 2.2ºC. The corresponding range for 2070 is 0.9 to 3.5ºC. Temperature increases for the different seasons are not greatly different from increases in annual average temperature. Projected changes in magnitudes of maximum and minimum temperature are very similar to those magnitudes for average temperature.

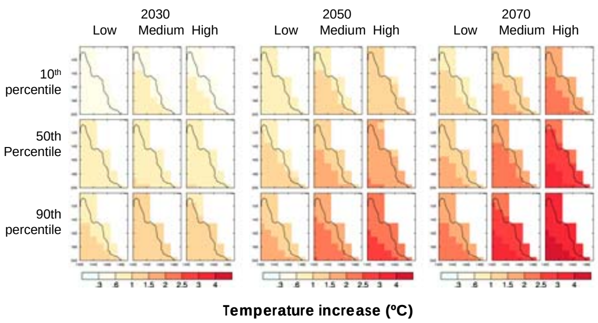

Figure 5. 10th, 50th and 90th percentile increases in annual average temperature (ºC) for low, medium and high emissions scenarios for 2030, 2050 and 2070.

4.2. Rainfall

Projected changes in the 10th, 50th and 90th percentiles of annual average rainfall for low (SRES B1), medium (SRES A1B) and high (SRES A1FI) emissions scenarios for 2030, 2050 and 2070 are shown in Figure 6. Rainfall changes are more complex than temperature changes, as their signs and magnitudes show strong spatial variations. Model to model variations in rainfall are also large. As for temperature, changes by 2030 do not differ greatly between low, medium and high emissions scenarios. For a medium emissions scenario the best estimate (50th percentile) regional average rainfall change for 2030 is -1% with a range of uncertainty of -8 to +6%. Changes by 2050 and 2070 are dependent on emissions scenario. For 2050, the ranges of uncertainty for regional average rainfall change for the different scenarios span the range -16 to +11%. The corresponding range for 2070 is -26 to +18%. As mentioned earlier, projected changes in rainfall are based on a linear relationship between temperature and rainfall, and therefore, variations on inter-decadal scales are not easily predictable.

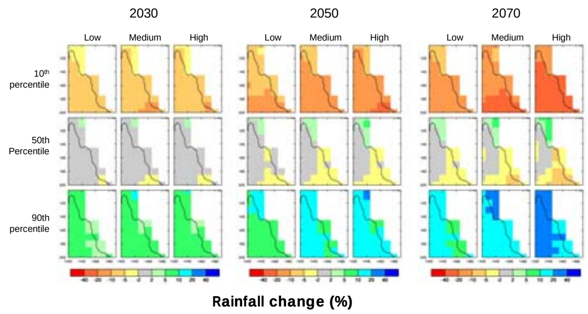

Figure 6. 10th, 50th and 90th percentile changes in annual average rainfall (%) for low, medium and high emissions scenarios for 2030, 2050 and 2070 in the region.

4.3. Potential Evaporation

We had simulations only from 11 GCMs to construct projected changes in potential evaporation over the domain. Increases in temperature and overall decreases in rainfall lead to an increase in annual potential evaporation in the study domain. Figure 7 shows that southern and central parts of the area show strong increases in potential evaporation. Increases of 2 to 8% by 2030 and 4 to 18% by 2070 are projected by the range of emission scenarios.

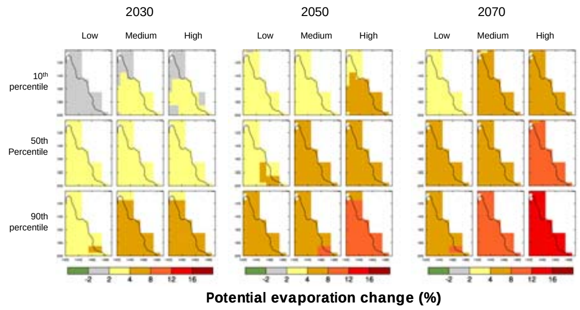

Figure 7. 10th, 50th and 90th percentile changes in annual average potential evaporation (%) for low, medium and high emissions scenarios for 2030, 2050 and 2070 in the region.

5. CONCLUSIONS

Observed temperature in the study region has increased steadily between 1950 and 2008, but shows strong decadal and inter-annual variations. Since 1950, the tropical rainforest region's average maximum temperature has increased by 0.76°C (0.12°C per decade), the minimum by 0.79°C (0.14°C per decade) and the average by 0.78°C (0.13°C per decade). Variations in annual and seasonal rainfall in the rainforest region of north Queensland during the past century show no clear trend, but there are fluctuations on multi-decadal time scales. In particular, the 1920s, 1960s and 1990s were drier decades and the 1970s was a wetter period. The relationship between the SOI and rainfall is positive, but shows decadal-scale variations. The relationship was weak during 1930s and also during 1980s. The tendency for a weakening relationship in recent years began after the mid 1970s.

Probabilistic based temperature and rainfall projections were derived from the output of 23 GCMs and potential evaporation projections from 11 GCMs. In this method, each of 23 or 11 GCMs is assigned a weight based on its ability to simulate the observed climate averages for Australia. Projections were given for 10th, 50th and 90th percentiles of temperature, rainfall and potential evaporation changes for low, medium and high emissions scenarios, but projections for other decades from 2020 to 2080 are also available. The upper end of warming is slightly reduced in this new method compared to temperature projections based on a selected set of models. However, range of rainfall changes has winded with this method. Further details are given in Suppiah *et al.* (2008).

Projected temperatures show that the inland areas of the tropical rainforest region and its surroundings will warm faster than the coastal areas. For a medium emissions scenario the 50th percentile regional average temperature increase by 2030 is 0.8ºC with a range of uncertainty of 0.6 to 1.1ºC. For 2050, the ranges of uncertainty for regional average temperature increase for the different scenarios and span the range 0.7 to 2.2ºC. The corresponding range for 2070 is 0.9 to 3.5ºC.

Rainfall changes are more complex than temperature changes and show increases and decreases. For a medium emissions scenario the 50th percentile regional average rainfall change for 2030 is -1% with a range of uncertainty of -8 to +6%. Changes by 2050 and 2070 are dependent on emissions scenario. For 2050, the ranges of uncertainty for regional average rainfall change for different scenarios span the range -16 to +11%. The corresponding range for 2070 is -26 to +18%. Percentage rainfall changes in dry season and transitional season 2 are greater than those for wet season and transitional season 1. Projected increases in temperature and slight decreases in rainfall lead to increases in potential evaporation. Increases in potential evaporation of 2 to 8% by 2030 and 4 to 18% by 2070 are projected between low and high emission scenarios.

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