Climate Scenarios for Saskatchewan

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PRAIRIE ADAPTATION RESEARCH COLLABORATIVE

SUMMARY DOCUMENT

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INTRODUCTION

The most recent assessment undertaken by the Intergovernmental Panel on Climate Change (IPCC, 2007) concluded that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level". This summary addresses the question of what projected changes in global average climate mean for Saskatchewan specifically.

CONSTRUCTION AND SELECTION OF CLIMATE CHANGE SCENARIOS

Following recommendations outlined by the IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (IPCC-TGICA, 2007), scenarios of climate change were constructed using the most recent global climate model (GCM) results available. GCMs are three-dimensional mathematical models of the Earth-atmosphere system driven by changes in atmospheric composition through the effect of these changes on the radiation balance of the global climate system. It is not known exactly how atmospheric composition will change in the future, since it is dependent on a number of factors, including population and economic growth and energy use. Thus, GCM experiments are usually undertaken using a number of different greenhouse gas emissions scenarios, spanning a range of possible socio-economic futures. For this study, results were available from GCM experiments undertaken at fourteen different climate modelling centres using three emissions scenarios (B1, A1B and A2). These three emissions scenarios represent a 'business-as-usual' world with moderate economic growth (A2), a world with very rapid economic growth but with a mix of technological developments and fossil fuel use (A1B), and a world focusing more on dematerialisation and clean technologies (B1). Best estimates of global-average surface warming by the end of the 21st century are 3.4°C, 2.8°C and 1.8°C for the A2, A1B and B1 emissions scenarios, respectively. Scenarios were constructed by determining the changes in average climate for the 30-year periods centred on the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099), relative to the 1961-1990 baseline climate period.

One of the main challenges in climate change scenario studies is selecting the number of scenarios to use. The ideal would be to use all available scenarios to build a complete picture of the range of possible future climate (to the best of our current knowledge). However, sufficient resources are seldom available for such studies and in any case the amount of data being dealt with soon becomes overwhelming. On the other hand, use of a single climate change scenario is not recommended for anything other than arbitrary exercises exploring the effect of a change in a particular climate variable on impact response. The IPCC TGICA currently recommends that a number of climate change scenarios should be used and that these scenarios should attempt to capture the range of possible future climate in a particular region.

For many studies, climate change scenarios may be selected based on examination of scatter plots of mean temperature change and precipitation change. From such a scatter plot, scenarios which represent cooler and drier, cooler and wetter, warmer and drier, and warmer and wetter conditions can be identified. For this study, a slightly different approach was taken, since we wanted to examine the *combined* effect of temperature and precipitation changes, since it was felt that this would be the single most important factor for determining Saskatchewan's vulnerability to climate change. To do this, the annual moisture index (AMI)[1] was used. This index combines the effect of temperature through the use of degree days above a threshold temperature of 5°C (i.e., a measure of the warmth available during the growing season) with that of annual precipitation. Larger values of the index indicate that moisture availability will be limiting, while smaller values indicate the availability of less heat and more moisture. Moisture balance is a key issue in the health of Saskatchewan's ecosystems and in the success of key industries such as agriculture, as well as affecting water supply to industry and cities and hydropower generation.

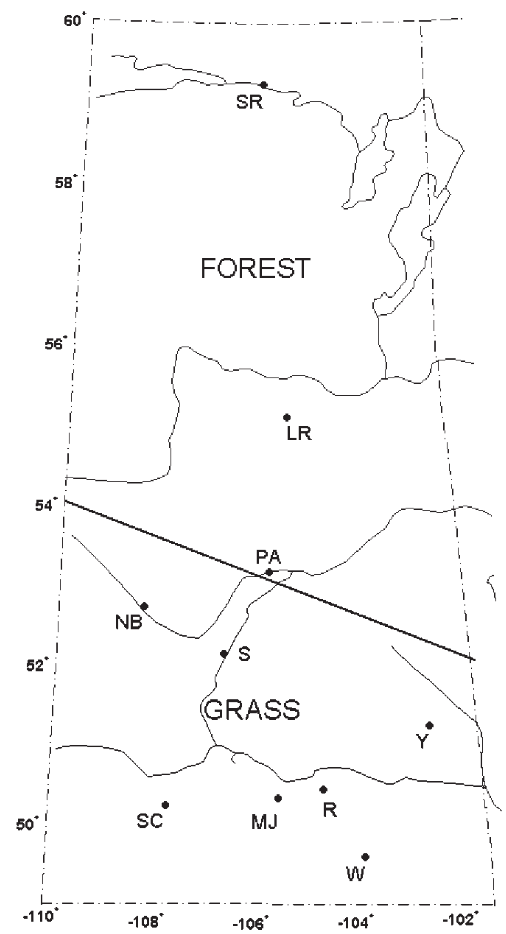


Figure 1: *Map of Saskatchewan showing boundary (black line) between forest and grassland regions and major towns: SR – Stony Rapids; LR – La Ronge; PA – Prince Albert; NB – North Battleford; S – Saskatoon; Y – Yorkton; SC – Swift Current; MJ – Moose Jaw; R – Regina; W – Weyburn.*

[1] Annual moisture index (AMI) is degree days > 5°C / mean annual precipitation

For climate change scenario selection purposes, Saskatchewan was divided into two regions – a northern forest region and a southern grassland region (Figure 1). Based on changes in annual moisture index for the 2050s, two scenarios were selected to represent the smallest and largest indicated change in moisture index for this region. A scenario representing the median change was also selected. For the forest region, these scenarios were from the Bjerknes Centre for Climate Research, Norway (BCM2 B1), the UK Meteorological Office (HadCM3 A1B) and the National Institute for Environmental Studies, Japan (MIMR B1). For the grassland region the scenarios were from the Canadian Centre for Climate Modelling and Analysis (CGCM3_T47_2 A1B), the Geophysical Fluid Dynamics Laboratory, USA (GFCM20 B1) and, again, from the National Institute for Environmental Studies, Japan (MIMR B1). Figures 2-5 illustrate scatter plots of annual and seasonal mean temperature change versus precipitation change for the forest and grassland regions. These figures give an idea of the range of climate change scenario values. The three scenarios selected for each region based on the change in annual moisture index are also indicated.

For the forest region, these scatter plots indicate that by the 2080s, annual changes in precipitation are positive in this region for all climate change scenarios considered in this analysis (Figure 2). For the 2020s and 2050s, a small number of scenarios indicate decreased precipitation, but these decreases are very slight – only around 5% in the 2020s and about 2% in the 2050s. Changes in mean annual temperature are positive – between 0 and 3°C in the 2020s, 1 to 5°C in the 2050s and between 2 and 7°C for the 2080s. The seasonal picture for the 2050s indicates that the largest spread in scenario results occurs in winter, with temperature changes between 0 and 7°C and mostly positive precipitation changes (up to 30%) (Figure 3). For spring, the picture is similar, although the temperature increases are not quite as large. The summer and fall scatter plots show some scenarios with larger precipitation decreases – as much as 10% in summer and around 5% in the fall.

In the grassland region scatter plots, decreases in annual mean precipitation are projected by some scenarios into the 2080s. For the 2020s, temperature increases are between 0.5 and 3.0°C, between 1 and 5°C for the 2050s and between 2 and 6.5°C for the 2080s. Changes in the range of annual mean precipitation are similar for the 2020s and 2050s, between 10% and +25%, compared to between 5% and +35% for the 2080s (Figure 4). On a seasonal basis for the 2050s, scenarios projecting decreases in precipitation occur in all seasons (Figure 5). For summer and fall, about half the scenarios project precipitation decreases, and by as much as 20 or 30%. The range of temperature increase is largest in winter and spring (between 1 and 6°C), compared to summer and fall (1 to 4°C).

By combining these climate change scenarios with a high resolution 1961 1990 baseline climatology, in this case the PRISM climatology (Daly *et al.*, 1994; Milewska *et al.*, 2005), it was possible to construct climate scenarios for Saskatchewan for minimum, mean and maximum temperatures and precipitation, as well as for the following derived variables: degree days > 5°C, degree days > 18°C (cooling degree days), degree days < 18°C (heating degree days) and annual moisture index for the 2020s, 2050s and 2080s. This summary document details results for annual mean temperature, annual precipitation total and annual moisture index for the 2050s only.

FUTURE CLIMATES FOR SASKATCHEWAN

Figures 6-11 illustrate annual mean temperature, annual precipitation total and annual moisture index for the 2050s, for the forest and grassland regions. These maps show the spatial distribution of future climate over Saskatchewan. Ten sites across the province, three in the forest region and seven in the grassland region, are considered in more detail and these results are shown in Figures 12-14.

At all three sites (Prince Albert, La Ronge and Stony Rapids) in the forest region of Saskatchewan annual mean temperature increases over time (Figure 12). By the 2020s, the projected future climate range for La Ronge (0.01 to 0.98°C) is as warm as baseline conditions at Prince Albert (0.58°C). For Stony Rapids, it is only by the 2080s that the projected annual mean temperature range (1.91 to 0.4°C) approaches that of baseline conditions at La Ronge (0.45°C). Precipitation is projected to increase across all sites and all time periods (Figure 13). Prince Albert (406 mm) and Stony Rapids (391 mm) currently receive less precipitation than La Ronge (494 mm). By the 2080s, Prince Albert is projected to receive between 423 and 456 mm, La Ronge between 514 and 547 mm, and Stony Rapids between 419 and 446 mm. The annual moisture index gives an indication of moisture availability for plant growth and this index increases across all time periods for all three forest sites (Figure 14) – indicating drier conditions at these localities. By the 2080s, the index values are projected to increase by at least 1 degree day/mm at each site. The scenario range for La Ronge (2.96-3.77) and Stony Rapids (2.67-3.86) for this time period encompasses baseline conditions at Prince Albert (3.41).

For the grassland region, annual mean temperature at all seven sites (North Battleford, Saskatoon, Yorkton, Regina, Swift Current, Weyburn and Moose Jaw) increases over time such that by the 2020s, the annual mean temperature is at least 1°C warmer than baseline conditions at all sites, and for Yorkton 3°C warmer (4.3°C compared with 1.3°C). By the 2080s, the projected annual mean temperature is considerably warmer than baseline conditions (Figure 12). Increases in annual precipitation totals are projected over time at all seven grassland sites (Figure 13). For annual moisture index, increases occur across all sites and all time periods (Figure 14) – indicating more arid conditions at all localities. Yorkton and North Battleford currently exhibit the lowest annual moisture index values (3.4 and 4.2 degree days/mm, respectively). By the 2080s, these values have increased to between 3.9 and 4.7 degree days/mm for Yorkton and to between 4.7 and 5.6 degree days/mm for North Battleford.

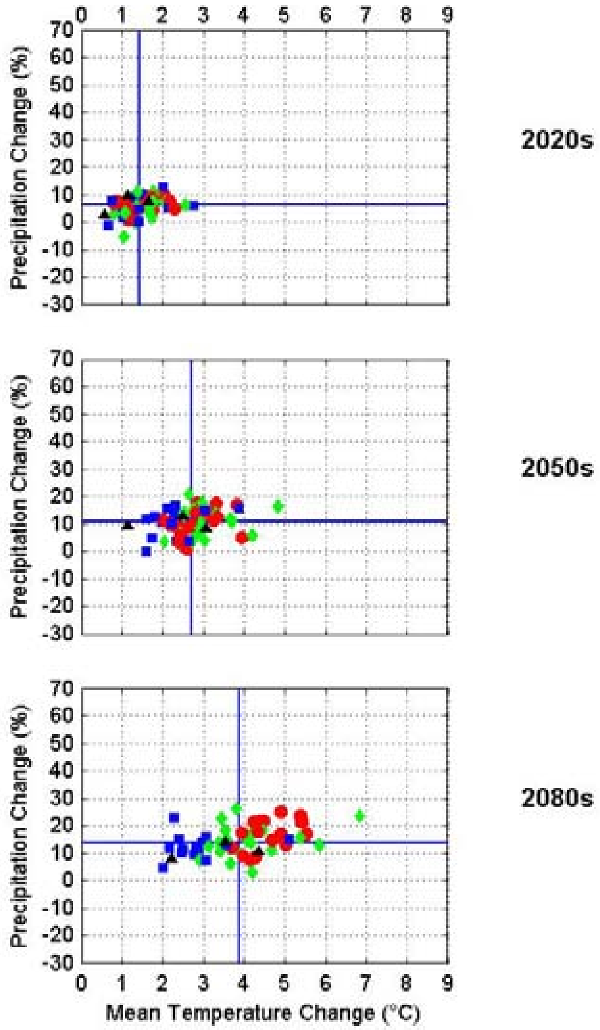


__Figure 2:__ Scatter plots indicating annual changes in mean temperature (°C) and precipitation (%) for the forest region of Saskatchewan for the 2020s, 2050s, and 2080s. The different coloured symbols represent different emissions forcings: green diamonds – A1B, blue squares – B1, red circles – A2. Black triangles indicate the three scenarios selected based on minimum, maximum and median change in annual moisture index. Blue lines indicate the median changes in mean temperature and precipitation for this suite of scenarios.

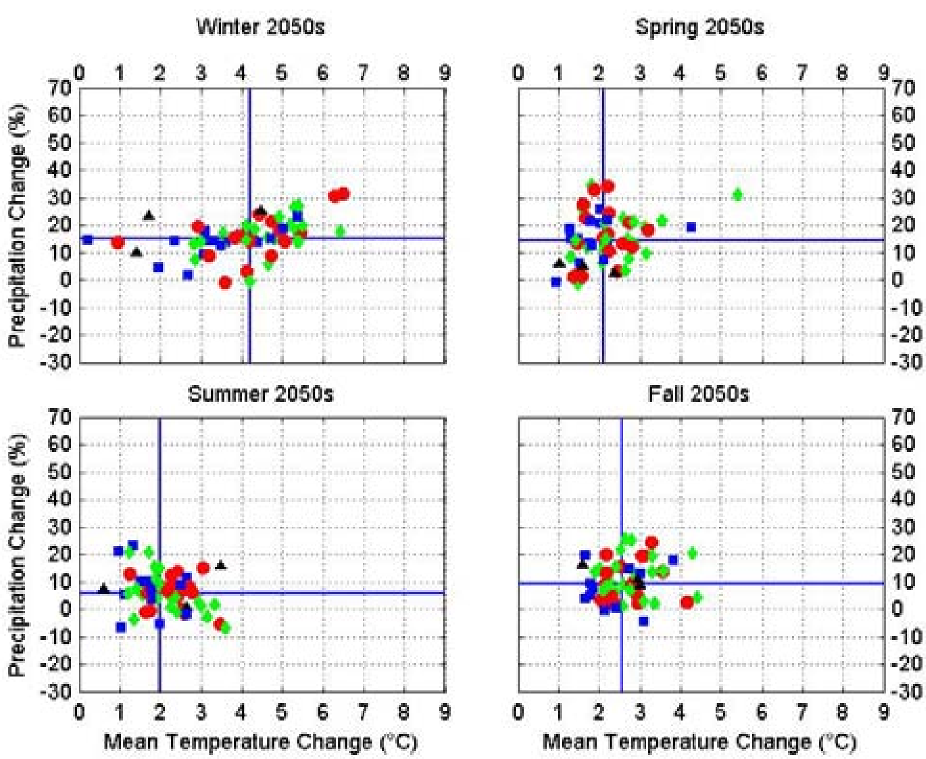


__Figure 3:__ Scatter plots indicating seasonal changes in mean temperature (°C) and precipitation (%) for the forest region of Saskatchewan for the 2050s. The different coloured symbols represent different emissions forcings: green diamonds – A1B, blue squares – B1, red circles – A2. Black triangles indicate the three scenarios selected based on minimum, maximum and median change in annual moisture index. Blue lines indicate the median changes in mean temperature and precipitation for this suite of scenarios.

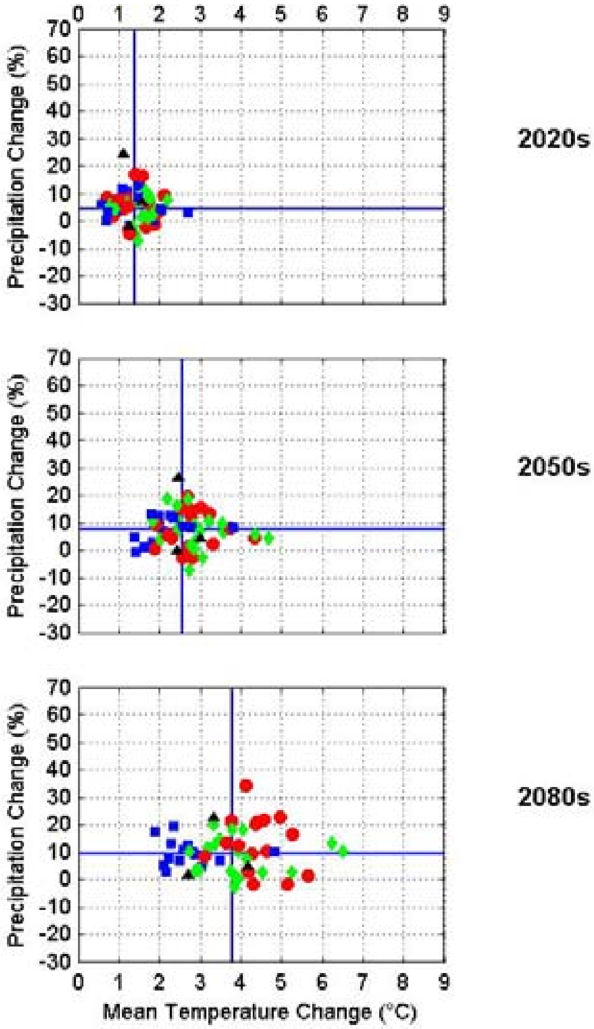


Figure 4: Scatter plots indicating annual changes in mean temperature (°C) and precipitation (%) for the grassland region of Saskatchewan for the 2020s, 2050s, and 2080s. The different coloured symbols represent different emissions forcings: green diamonds – A1B, blue squares – B1, red circles – A2. Black triangles indicate the three scenarios selected based on minimum, maximum and median change in annual moisture index. Blue lines indicate the median changes in mean temperature and precipitation for this suite of scenarios.

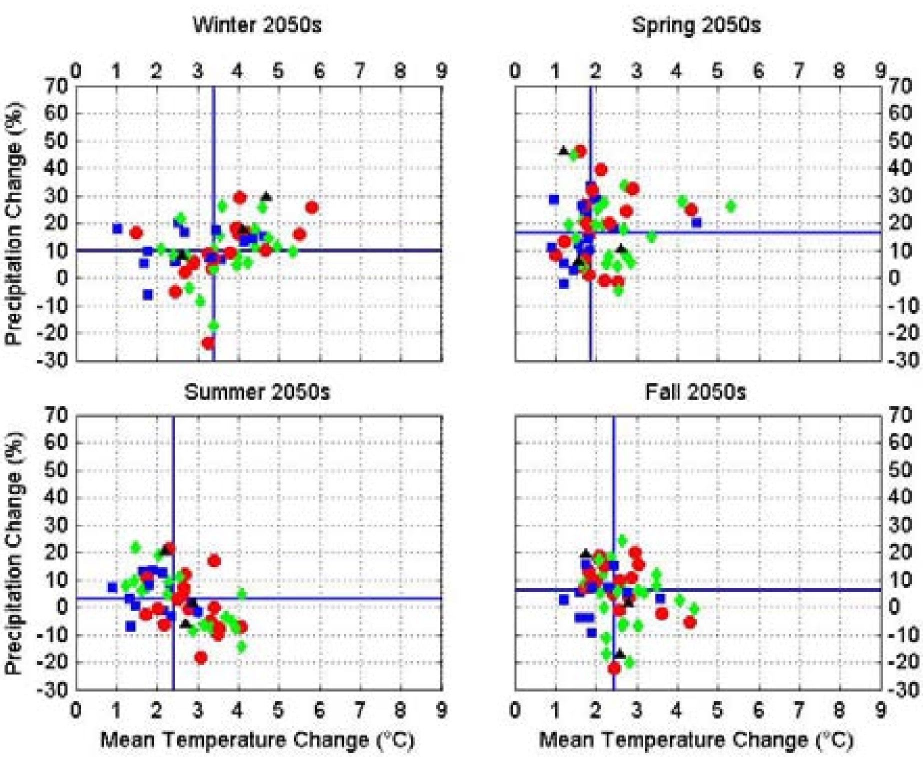


Figure 5: Scatter plots indicating seasonal changes in mean temperature (°C) and precipitation (%) for the grassland region of Saskatchewan for the 2050s. The different coloured symbols represent different emissions forcings: green diamonds – A1B, blue squares – B1, red circles – A2. Black triangles indicate the three scenarios selected based on minimum, maximum and median change in annual moisture index. Blue lines indicate the median changes in mean temperature and precipitation for this suite of scenarios.

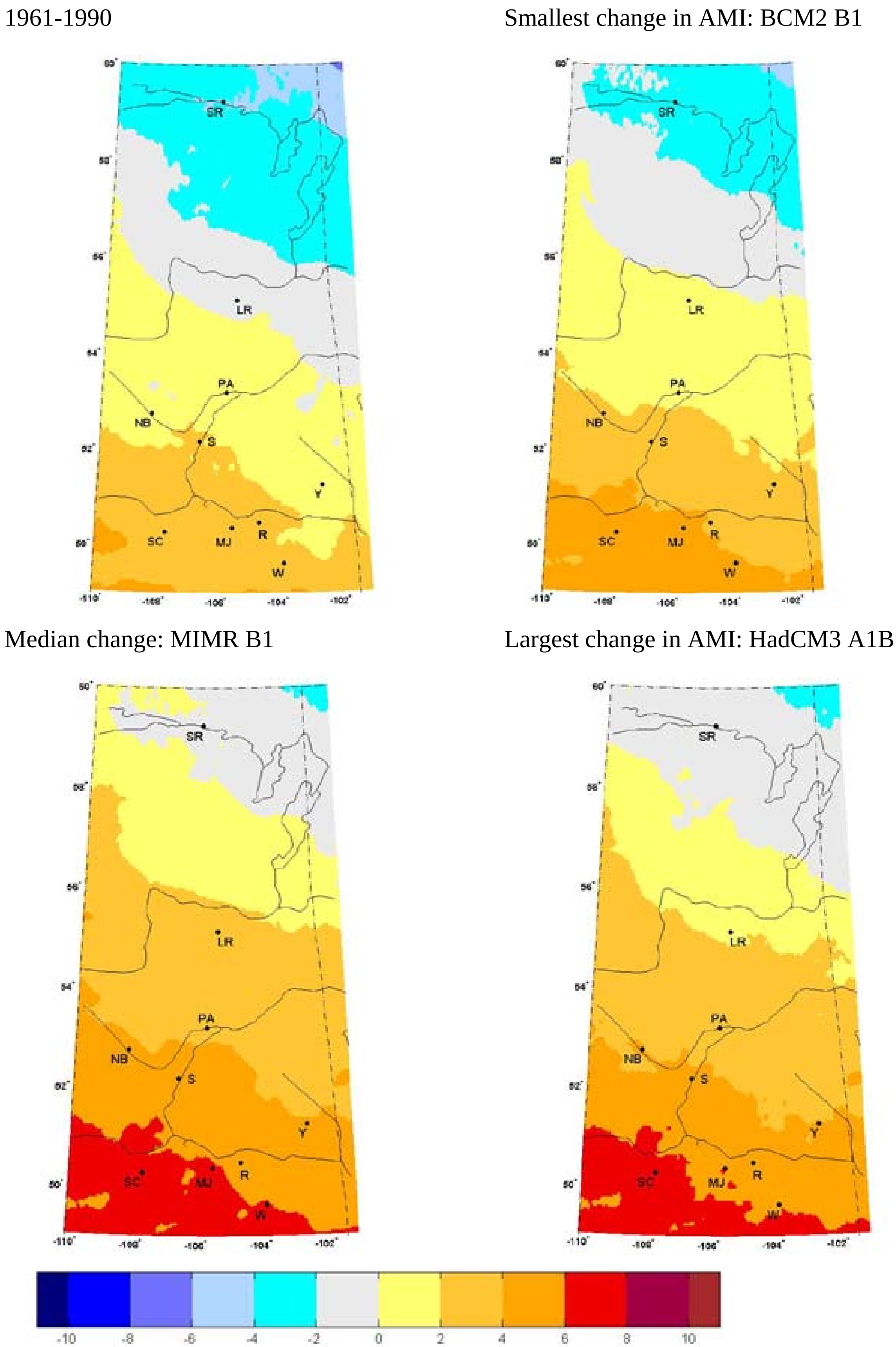


Figure 6: *Annual mean temperature (°C) for the 2050s, selected based on AMI change over forest region of Saskatchewan.*

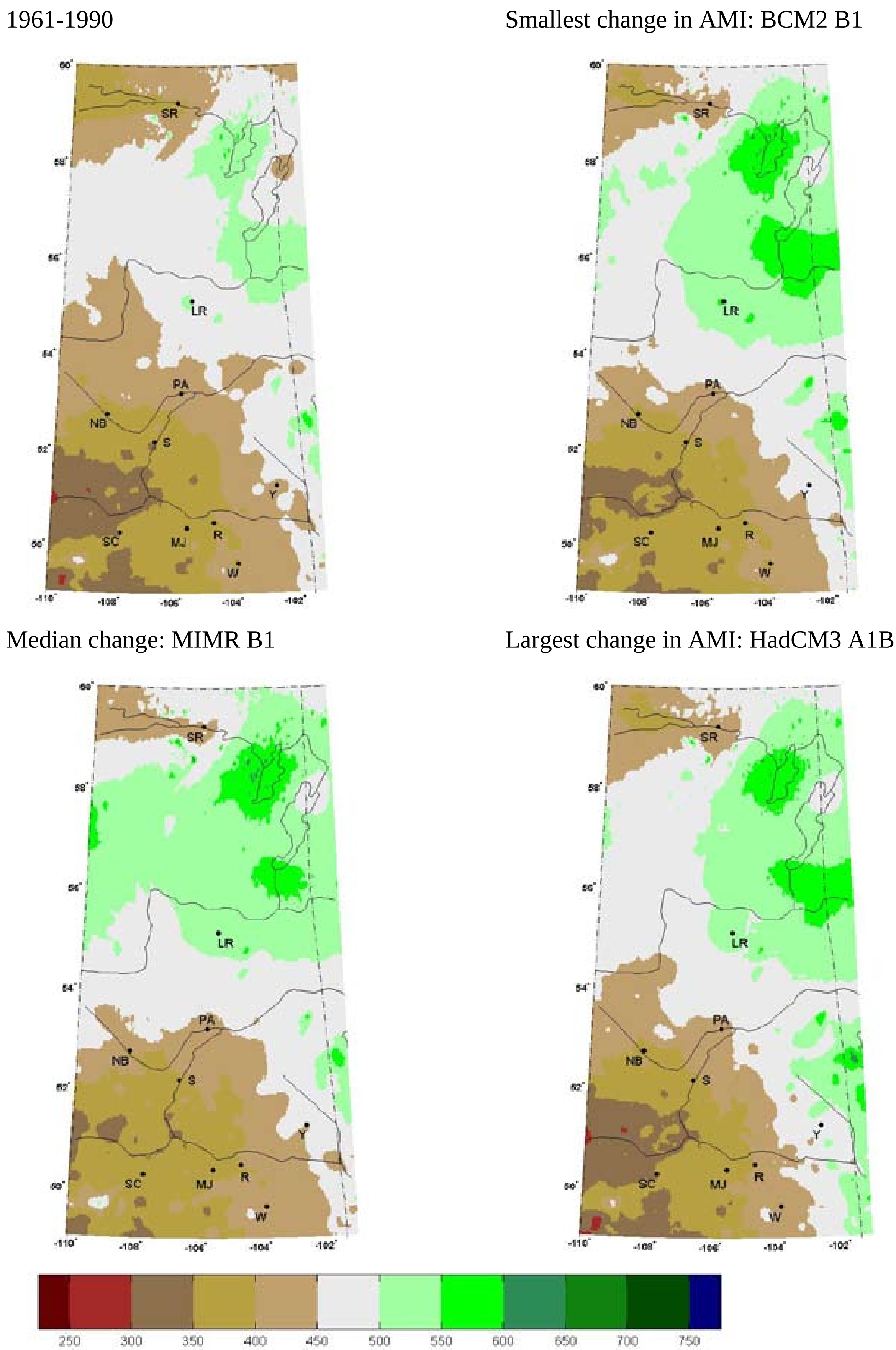


Figure 7: *Annual precipitation (mm) for the 2050s, selected based on AMI change over forest region of Saskatchewan.*

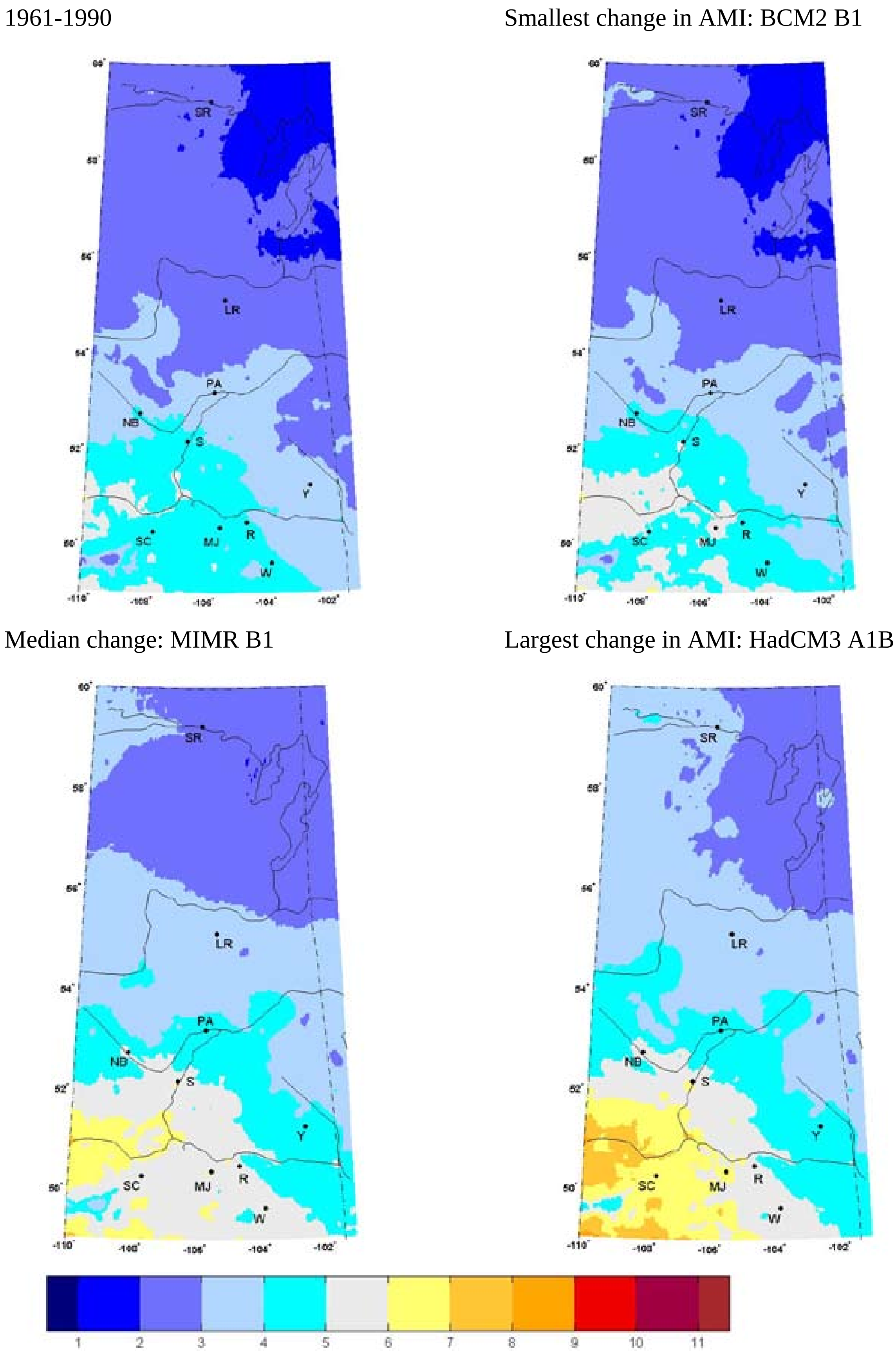


Figure 8: *Annual moisture index for the 2050s, selected based on AMI change over forest region of Saskatchewan.*

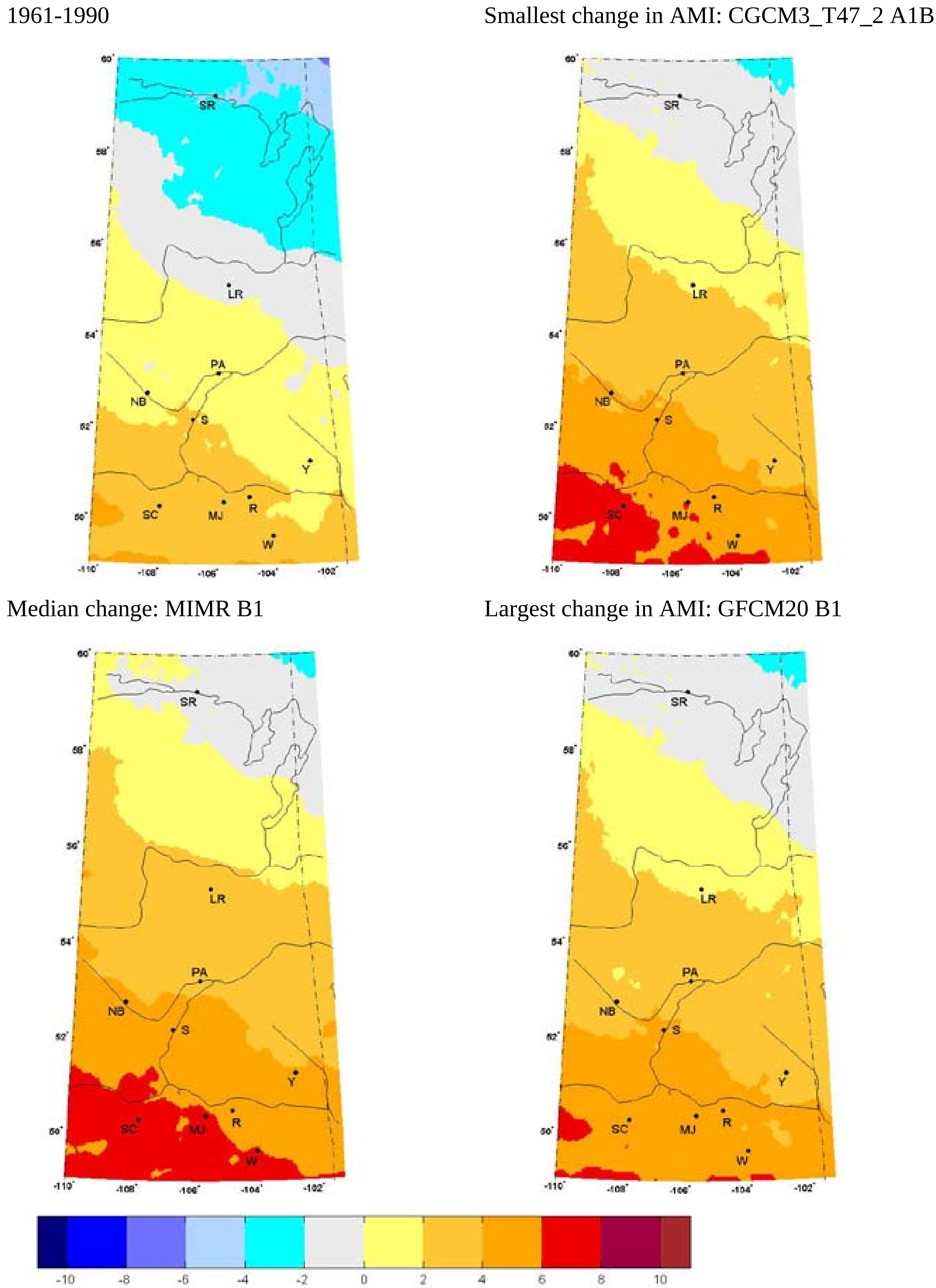
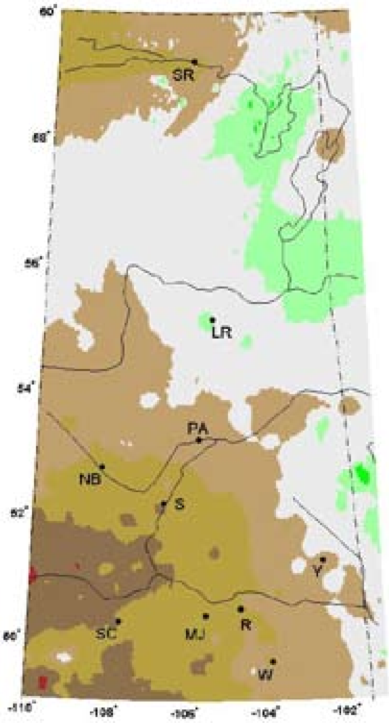
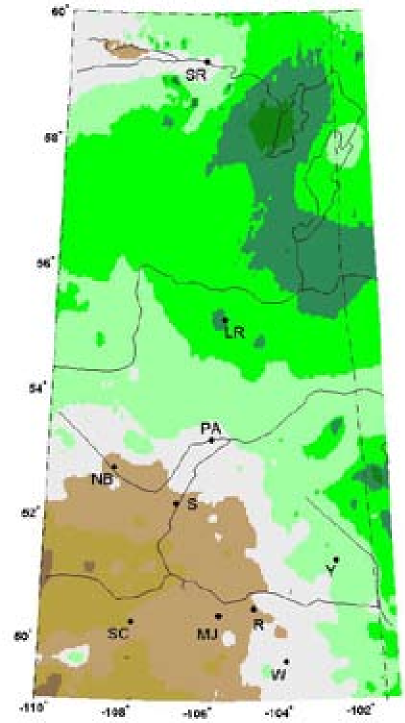


Figure 9: *Annual mean temperature (°C) for the 2050s, selected based on AMI change over grassland region of Saskatchewan.*

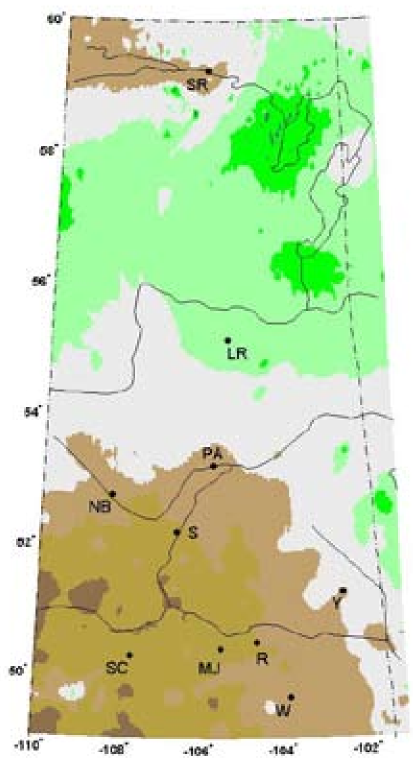
1961-1990



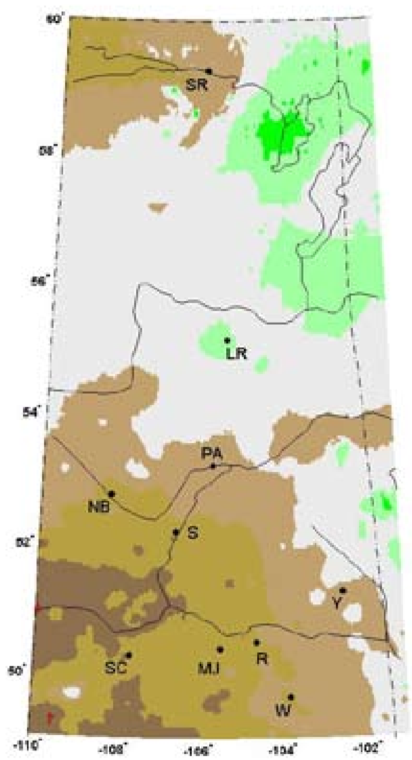
Smallest change in AMI: CGCM3_T47_2 A1B



Median change: MIMR B1



Largest change in AMI: GFCM20 B1



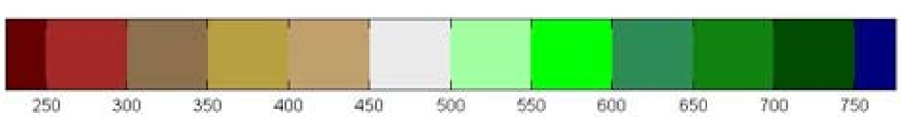


Figure 10: *Annual precipitation total (mm) for the 2050s, selected based on AMI change over grassland region of Saskatchewan.*

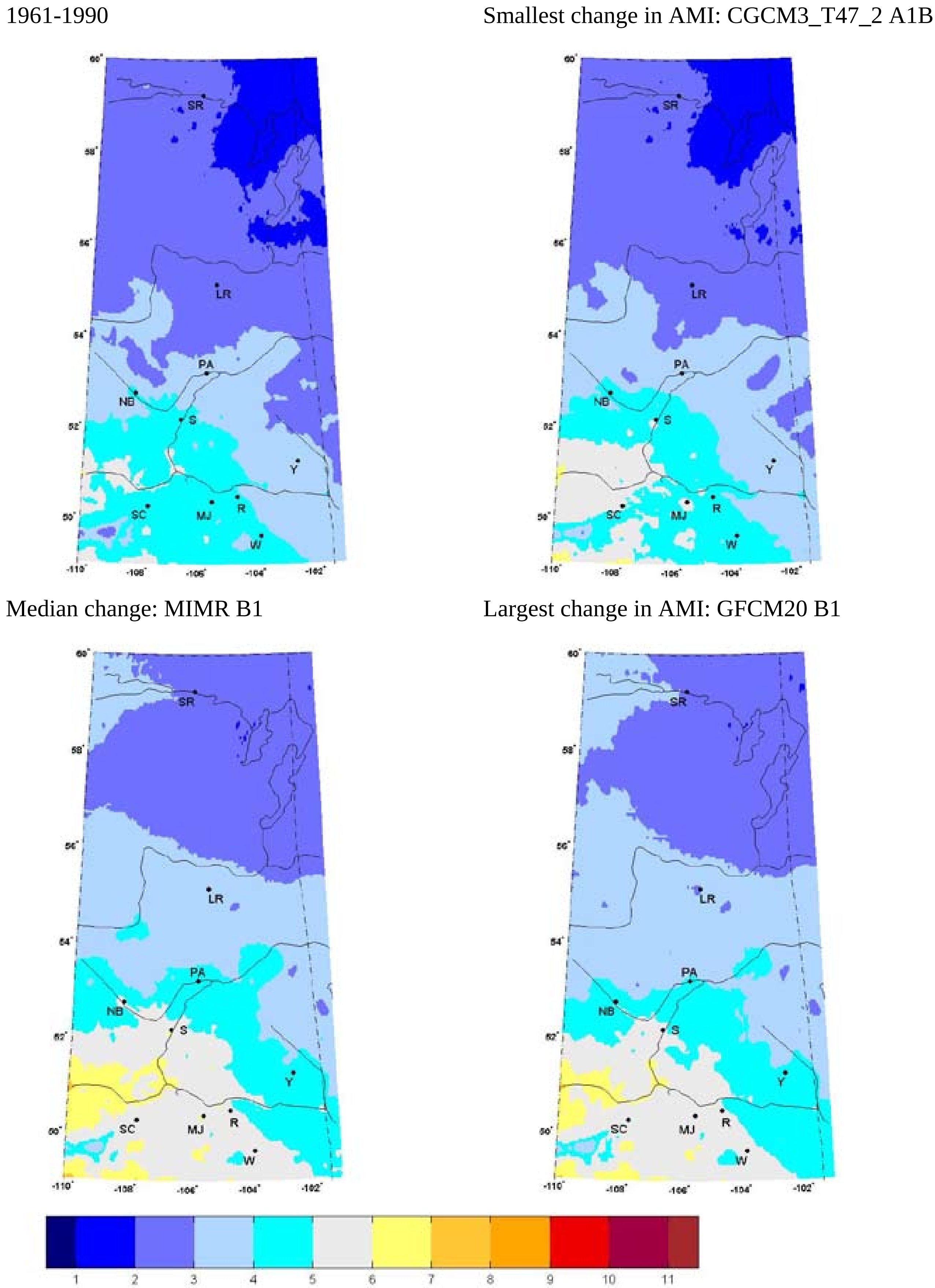


Figure 11: *Annual moisture index for the 2050s, selected based on AMI change over grassland region of Saskatchewan.*

Moose Jaw and Saskatoon currently exhibit the largest baseline values (both 4.7 degree days/mm). By the 2080s, annual moisture index values are projected to be between 5.3 and 6.4 degree days/mm for Moose Jaw and between 5.2 and 6.2 degree days/mm for Saskatoon.

For much more detail on Saskatchewan's climate futures, the reader is referred to Barrow (2009), which is available for download from the PARC website (www.parc.ca).

FUTURE RESEARCH DIRECTIONS

For the construction of physically-plausible and internally-consistent climate change scenarios for a large region like Saskatchewan, the techniques described and applied by Barrow (2009) really represent the only currently available means of developing regional-scale scenarios. To advance this work, there are a number of options available:

1. To consider an expanded set of derived climate variables, such as mean frost-free period, mean growing season precipitation and summer moisture index.
2. To expand the number of scenarios used, so that the scenario ranges, such as those illustrated in Figure 12, can be expressed in terms of box-and-whisker plots. In this type of statistical plot, the box represents 50% of the scenario results and the whiskers the extreme scenarios. A box-and-whisker plot would give a much better idea of the spread of the scenario results and prevents the range of results being dominated by any one scenario.
3. Consideration of all available scenarios (which is not a trivial task) may allow a probabilistic analysis of the results so that information about risk and uncertainty could be included. For example, this may allow us to make a statement such as: "We are 90% confident that future temperature increases by the 2050s will be below 2°C".
4. To link the scenarios with information about GCM-simulated 'natural' climate variability and to express the projected scenario changes in terms of their significance, i.e., whether or not the projected changes are within the range of model-simulated 'natural' climate variability.
5. To continue to update the scenarios as new global climate model results are released for use.
6. To focus on specific locations. Statistical downscaling of the climate change scenarios is a possible avenue for research.
7. Inclusion of results from the Canadian Regional Climate Model (CRCM). While only a limited number of climate change experiments have been undertaken with the CRCM, the results could be included with those from GCMs to give an indication of the effect of dynamical downscaling on future climate scenarios for Saskatchewan.
8. To consider GCM performance in simulating current climate when selecting scenarios for use in impacts studies.

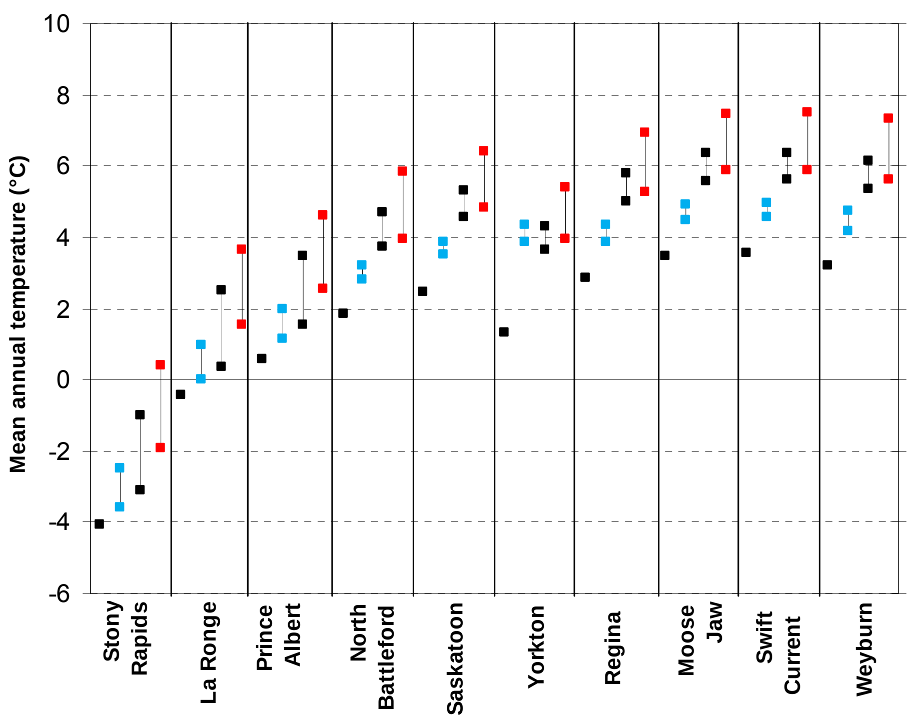


Figure 12: *Annual mean temperature (°C) for the forest and grassland sites in Saskatchewan. At each site there are four blocks of data: 1961-1990 baseline (black square), and the scenario ranges for the 2020s (blue high-low lines), the 2050s (black high-low lines) and the 2080s (red high-low lines). The scenario range has been calculated from the results of the three selected scenarios for each region.*

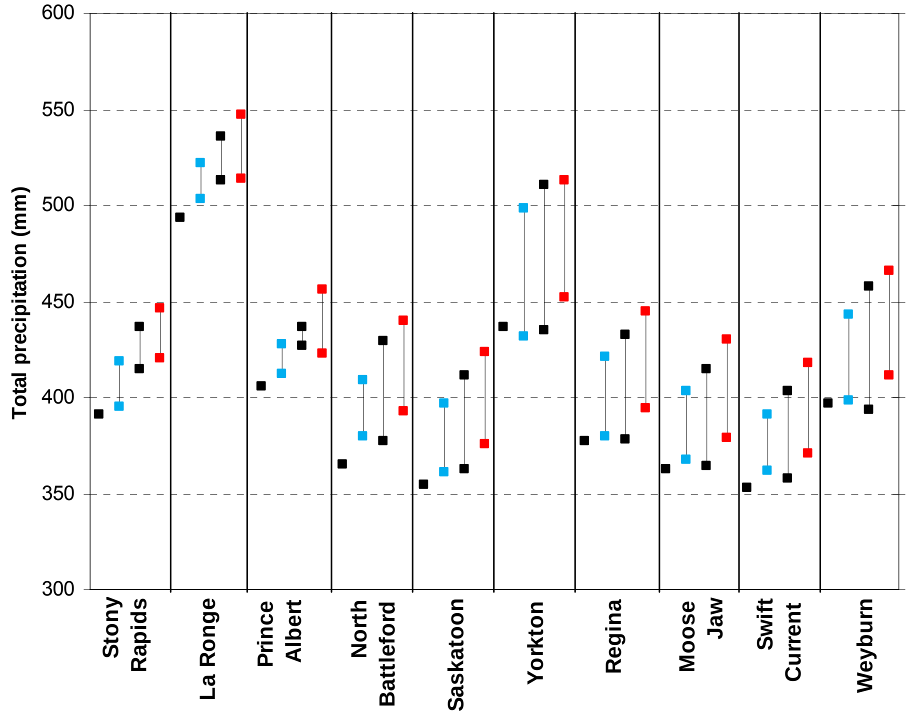


Figure 13: *Annual total precipitation (mm) for the forest and grassland sites in Saskatchewan. At each site there are four blocks of data: 1961-1990 baseline (black square), and the scenario ranges for the 2020s (blue high-low lines), the 2050s (black high-low lines) and the 2080s (red high-low lines). The scenario range has been calculated from the results of the three selected scenarios for each region.*

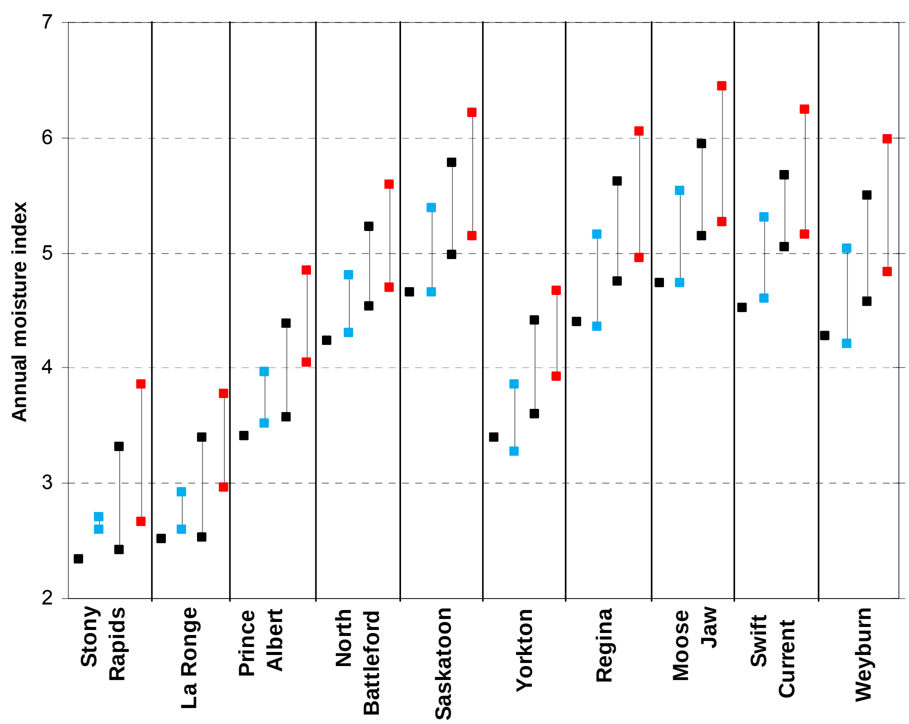


Figure 14: *Annual moisture index for the forest and grassland sites in Saskatchewan. At each site there are four blocks of data: 1961-1990 baseline (black square), and the scenario ranges for the 2020s (blue high-low lines), the 2050s (black high-low lines) and the 2080s (red high-low lines). The scenario range has been calculated from the results of the three selected scenarios for each region.*

A particularly important possible future research direction centres on the study of climate variability. The climate change scenarios described in this paper represent plausible changes in future *average* climate. Changes in climate variability are not included. It is changes in variability which are likely to have the largest effect on the frequency and magnitude of extreme climate events. These in turn tend to have the largest impact on our environment. Understanding changes in climate variability as well as changes in mean climate is not a trivial task. Statistical techniques (such as stochastic weather generators) exist which allow the perturbation of observed time series by both changes in means and variability. These techniques are best applied at the site scale, so one option would be to focus on specific locations in Saskatchewan (such as the ten sites used in this report).

Another option for consideration is the use of past climate information, i.e., from prior to the beginning of the instrumental record. Where paleo-climate information exists, this may be used to contextualise GCM-derived climate change scenarios and also to provide valuable information about environmental responses to particular climate conditions or events. Also, a more detailed examination of the instrumental record for sites in Saskatchewan, rather than simply using the 30-year climate normal (average), would provide more information about observed climate variability and thus also help contextualise the climate scenarios.

ACKNOWLEDGEMENTS

All of the global climate model data used for climate change scenario construction, with the exception of the Canadian global climate models CGCM3_T47 and CGCM3_T63, were obtained from the IPCC Data Distribution Centre (www.ipcc-data.org). The Canadian GCM data were obtained from the Canadian Centre for Climate Modelling and Analysis (www.cccma.bc.ec.gc.ca). The observed baseline data (PRISM) for Saskatchewan were obtained from Ron Hopkinson, on behalf of Environment Canada.

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