Report #3:

Climate Change Projections for the West Kootenays

G. Utzig, P.Ag

Utzig, G. 2011. Climate Change Projections for the West Kootenays. Unpublished Report # 3 from the West Kootenay Climate Vulnerability and Resilience Project. Available at www.kootenayresilience.org

1.0 Background

Recent reports by the International Panel on Climate Change (IPCC) have confirmed that global climate change is underway, and likely to accelerate over the coming decades unless humans make drastic cuts to global greenhouse gas (GHG) emissions (IPCC 2007). Analysis of climate data collected over the last century has confirmed that parallel climatic changes are also occurring in BC (Spittlehouse 2008), and in the Columbia Basin (Murdock et al. 2007). Depending on assumptions about future GHG emissions, results from downscaled global climate models (GCMs) illustrate a range of potential climate changes for BC over the next century. These include increases in annual temperatures and precipitation, decreases in summer precipitation in southern BC, decreases in snowpack, increases in annual climate variability and increases in the frequency and magnitude of extreme weather events.

The British Columbia government has recognized that the uncertainties associated with climate change demand a forest management approach that differs from the traditional (MoFR 2008). With the establishment of the Future Forest Ecosystems Initiative (FFEI) in 2006, the province began a move toward adapting the forest and range management framework to address management issues arising from potential changes in climate. The province established the Future Forest Ecosystem Scientific Council[1] (FFESC) in 2008 to deliver research grants to support the objectives of the FFEI. This report summarizes some of the findings of one project[2] that was funded by the FFESC under their 2009 call for proposals.

The West Kootenay (WK) Resilience Project is a two year integrated vulnerability assessment, (see Figure 1), with goals of increasing local knowledge about climate change and ecological resilience, and enhancing the capacity of forest managers to adapt to the challenges of climate change. This report summarizes a range of the projected changes to seasonal climatic variables for the WK.

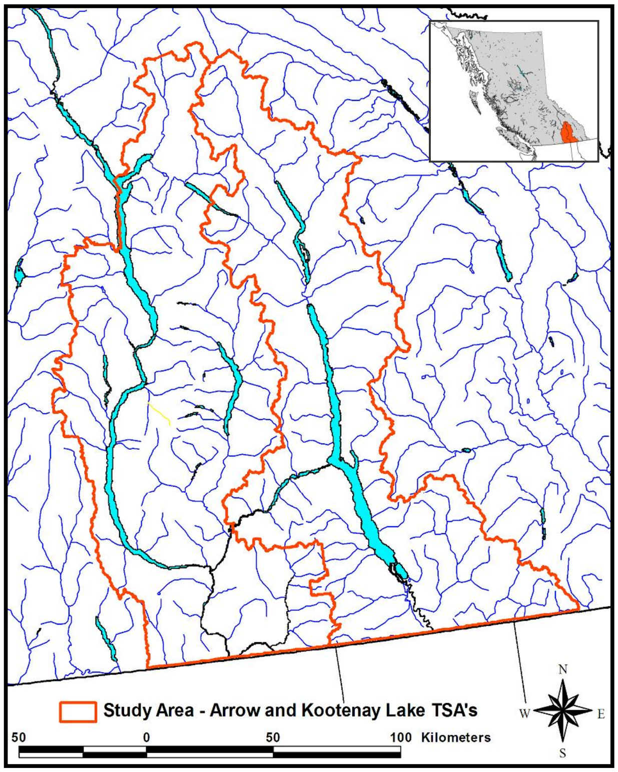

Figure 1. Study area for West Kootenay climate change resilience project.

---

[1] Further information on FFESC: http://www.for.gov.bc.ca/hts/future_forests/council/index.htm

[2] Resilience and Climate Change: Adaptation Potential for Ecological Systems and Forest Management in the West Kootenays. For further information on the project: http://westkootenayresilience.org

2.0 Modeling Climate

Individual Global Climate Models (GCMs) differ in the range of variables employed to model the global climate system, the equations that model the relationships between those variables, and the resolution at which those relationships are modeled. In addition, the output for each individual run of a given model will also differ, due to the stochastic nature of climate systems, and the starting conditions used to initiate a specific run. The models included in this report are summarized in Table 1.

Table 1. Information on global climate models (GCMs) referenced in this report (adapted from Murdock and Spittlehouse 2010).

Model Identification	Institution and Location
CCCMA-CGCM3.1	Canadian Centre for Climate Modeling and Analysis (Canada)
CSIRO-Mk3.0	CSIRO Atmospheric Research (Australia)
GFDL-CM2.0	US Dept. of Commerce, NOAA Geophysical Fluid Dynamics Laboratory (USA)
GISS-AOM	NASA/Goddard Institute for Space Studies (USA)
MIROC3.2hires	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC) (Japan)
MPI-ECHAM5	Max Planck Institute for Meteorology (Germany)
MRI-CGCM2.3.2	Meteorological Research Institute (Japan)
NCAR-CCSM3	National Center for Atmospheric Research (USA)
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research, Met Office (UK)
UKMO-HadGEM1	

Scenarios are descriptions of possible futures. A wide range of potential scenarios has been defined by the IPCC to represent a range of possible futures for global development over the next century (IPCC 2000). Each scenario includes a combination of factors such as projected population growth, economic development, technological advancements, degree of social/ cultural harmony and the balance between fossil fuels and alternative energy sources. From each of the scenarios, projections are made regarding the level of greenhouse gas emissions from all sources, landuse changes and other factors that may affect global climate (see Figure 2 and Table 2). Each individual model run is the result of a combination of a specific scenario with a particular GCM and a defined set of starting conditions.

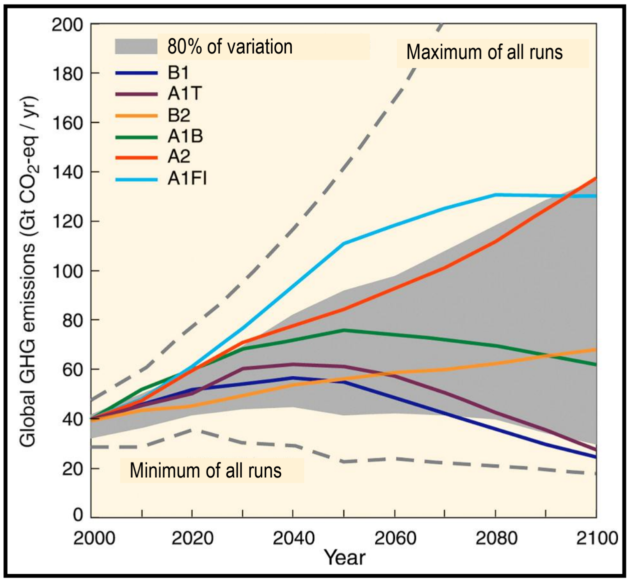

Figure 2. Emission scenarios (from IPCC 2007). Each solid line represents a particular set of assumptions about future global development.

Table 2. Summary of climate change scenario characteristics (adapted from IPCC 2000).

Scenario	General Description	Emission Levels 2000-2100
B1	Economic growth and technology advancement shift to an emphasis on environmental sustainability, , rapid population growth peaking mid-21st century, increasing global equity, increased global social/cultural harmony – a convergent world	Low / eventually decreasing
B2	Intermediate levels of regionalized economic growth, slow continuous population growth, slow shift to an emphasis on sustainability, but advancements are regionally fragmented, as are social/cultural communities – local solutions and a heterogeneous world	Low / steady
A2	Slow regionalized economic growth, moderate continuous population growth, social/cultural communities and technological advancement are regionally fragmented – heterogeneous world	Moderate / continuously increasing
A1T	Rapid economic growth, rapid population growth peaking mid-21st century, increasing global equity, increased global social/cultural harmony, rapid technology advancement, non-fossil fuel energy sources – a convergent world	Low / eventually decreasing
A1B	As A1T but balanced energy sources	Moderate/ eventually decreasing
A1FI	As A1T, but emphasis on fossil fuel energy sources	High / eventually plateauing

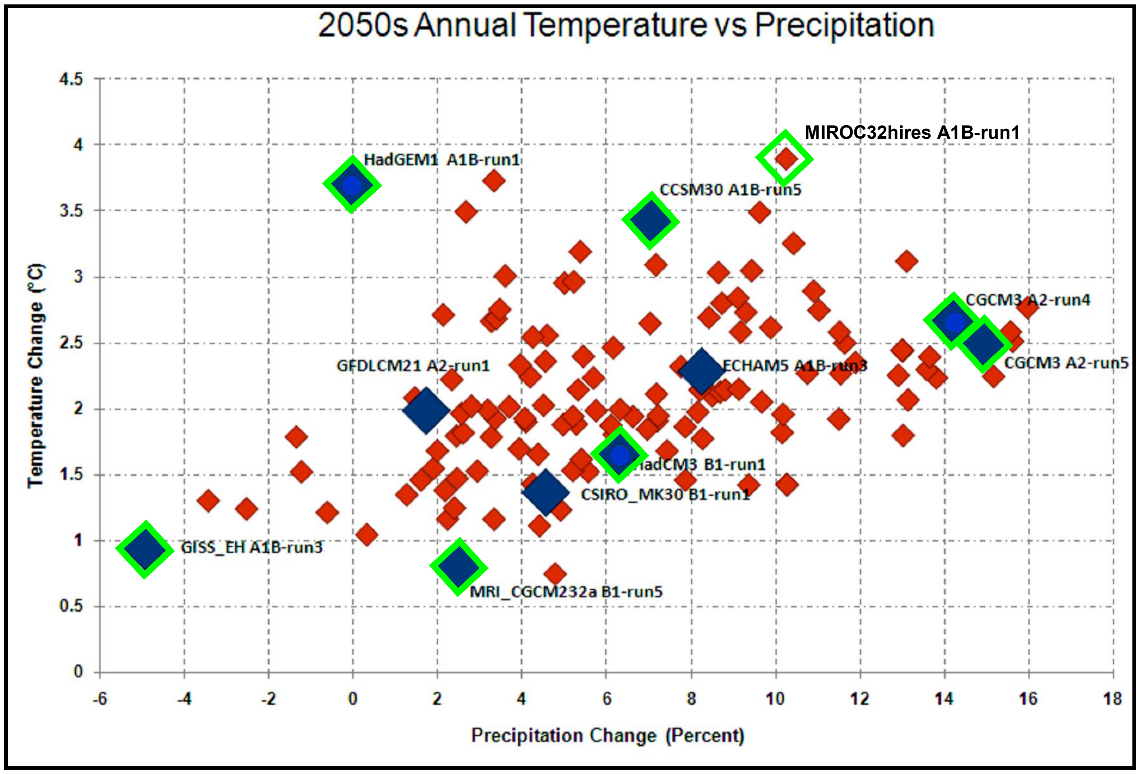

Figure 3. Range of projected changes in temperature and precipitation for British Columbia in the 2050s for all models and emissions scenarios (all diamonds), including the set of recommended GCM/scenario combinations (blue diamonds). GCM/scenarios outlined in green are summarized for the West Kootenays in this report. (adapted from Murdock and Spittlehouse 2010, data source: PCIC).

Figure 3 on the previous page displays the range of projected changes in annual temperature and precipitation averaged over BC for various GCM/scenario combinations. As discussed above, the variation in projected future climates is in part due to what scenarios and starting conditions are selected for parameterization of the GCM runs, and variations between the various models themselves.

The GCM/scenario combinations chosen for the WK assessment were selected to bound the range of possible futures, and also illustrate various issues related to interpretation of the projections (see Figure 3). The selections are also consistent with recommendations by Murdock and Spittlehouse (2010) in a report that summarizes information relevant for selecting GCM/scenario combinations for use in climate change assessments for BC. At this time there is not sufficient certainty to unequivocally predict the future climate for the WK. All of the projections should be considered as possible climatic futures for the WK. More information on the GCMs, scenarios and the results of various model runs can be found in the latest IPCC assessment report[3].

3.0 Data Acquisition for the West Kootenays

To provide detailed climatic information relevant for assessing potential impacts on forest ecosystems and land management, monthly and seasonal climatic data were assembled. Only seasonal data will be summarized in this report. Past temperature and precipitation data for the West Kootenay (WK) study area were derived from the ClimateBC dataset[4] (Spittlehouse 2006, Wang et al. 2006). ClimateBC provides detailed spatial climate data based on interpolated monthly climate normals derived from long term climate stations throughout BC (i.e. data derived from real observations). Using GIS overlays of the WK study area, means of mean monthly temperatures and precipitation were calculated from gridded monthly climate data for the 1961-1990 baseline reference period (400m x 400m). The study area consists of 164,374 grid points (see Figure 4a)

Data produced by various GCMs to simulate past climates, and project future climates were obtained from the Pacific Climate Impacts Consortium (PCIC) web-based Regional Analysis Tool[5]. As indicated above, various combinations of GCM runs and scenarios from the Intergovernmental Panel on Climate Change (IPCC) were selected to explore the potential range of climate change projections, and the applicability of individual model results to the WK study area.

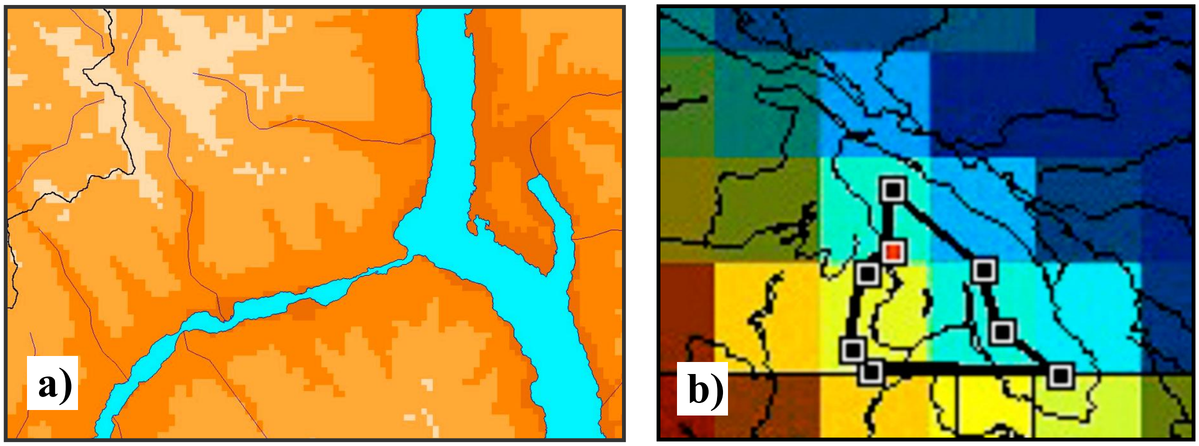

Figure 4. Examples of a grid from ClimateBC (a, left), and a GCM output grid from PCIC's Regional Analysis Tool (b, right; AR4_NCAR_CCSM30).

---

[3] The fourth IPCC assessment report: http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html

[4] Available now as ClimateWNA from: http://www.genetics.forestry.ubc.ca/cfcg/ClimateWNA/ClimateWNA.html

[5] Available at: http://pacificclimate.org/tools/regionalanalysis/

PCIC's analysis tool was applied to a "custom region" that approximated the study area for each combination of GCM model run and scenario (see Figure 4b). Means of monthly and seasonal temperature and precipitation for the study area were produced for four time periods (1961-1990 baseline, 2020s, 2050s, 2080s) for each GCM/scenario combination. The GCM "back-casting" simulations for the 1961-1990 baseline period were then compared with the observational data from ClimateBC for the same period. The results of the GCM projections for future time periods were also summarized.

4.0 Results for Baseline Period (1961-1990)

Simulations of seasonal mean temperature and precipitation from various GCM/scenario combinations for the baseline period of 1961-1990 are presented in Table 3 and Figures 5 and 6. Both the tables and figures also present observational data from ClimateBC for comparison (dashed red lines in the figures).

Table 3. Comparison of GCM simulations and observational ClimateBC data for mean seasonal temperature and precipitation during the baseline period.

Mean Temperature Values (^{o}C)				
	Winter	**Spring**	**Summer**	**Fall**
ClimateBC	-7.8	1.9	12.7	2.5
GCM Mean*	-8.7	0.3	12.8	1.8
GCM Minimum	-11.5	-1.8	10.2	-0.1
GCM Maximum	-7.6	2.6	15.6	3.7

Mean Daily Precipitation Values (mm/day)				
	Winter	**Spring**	**Summer**	**Fall**
ClimateBC	4.45	2.58	2.57	3.15
GCM Mean*	2.80	2.17	2.03	2.49
GCM Minimum	1.26	1.47	1.16	1.35
GCM Maximum	3.80	2.69	2.69	3.37

* To avoid bias, only one projection from the CGCM3 model is included in the mean calculation, A2-r5.

The pattern of mean seasonal temperatures simulated by the GCMs for the baseline period is in general agreement with the climatic normals from ClimateBC. The simulated seasonal temperatures generally surround the climatic normals, with individual models varying by up to 3.5^{o}C in winter and spring. On average the GCMs are 1-2^{o}C lower, except in the summer where the average is 0.1^{o}C higher.

The seasonal mean daily precipitation values simulated by the GCMs for the baseline period are generally lower than the extrapolated climatic normals from ClimateBC for the spring, summer and fall, and substantially lower in the winter (except the MIROC32hires predictions). The means of the model/scenario combinations assessed for seasonal precipitation are about 16-21% less than the ClimateBC values for spring, summer and fall and about 37% less for winter.

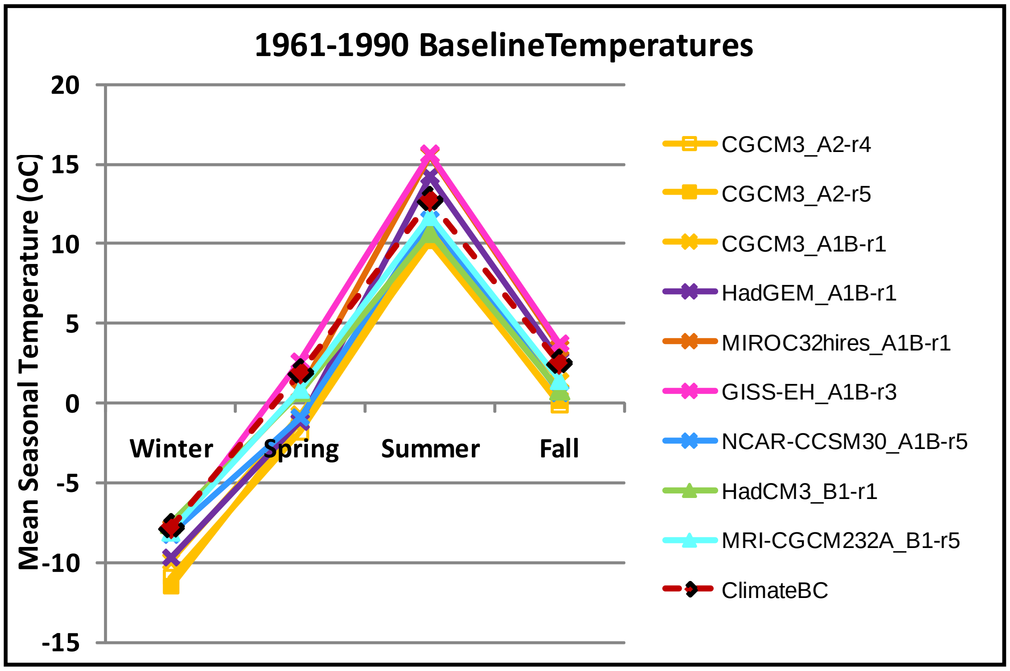

Figure 5. Comparison of mean seasonal temperatures for the study area from observational ClimateBC data (dashed red), and data from various GCM/scenario simulations, for the baseline reference period (various colours indicate individual GCMs, various symbols indicate individual scenarios, open and closed symbols indicate differing runs).

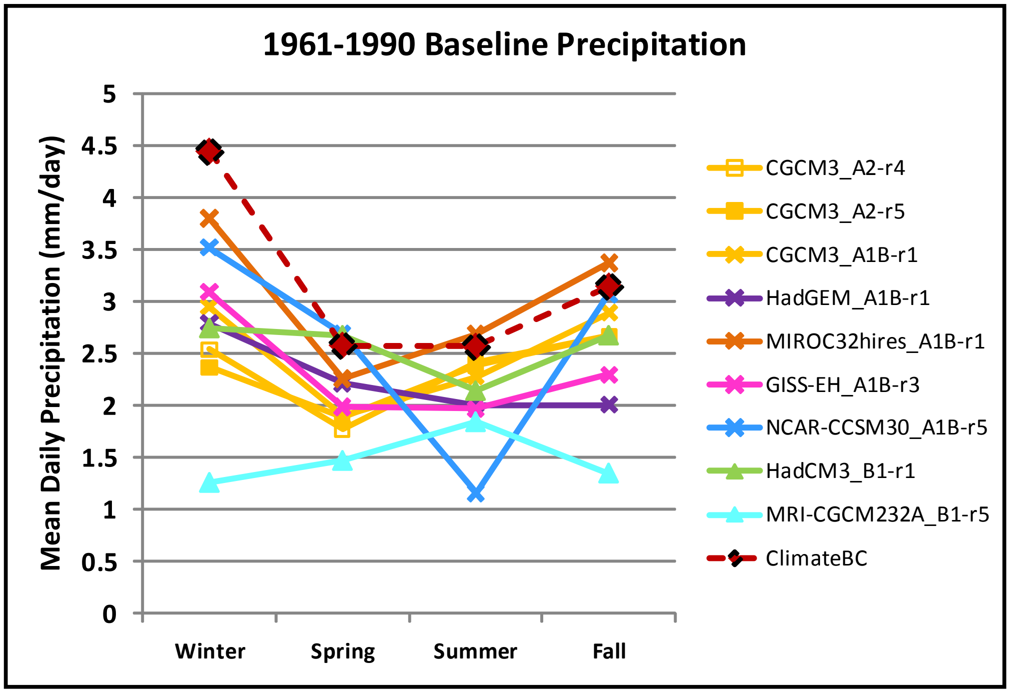

Figure 6. Comparison of mean seasonal precipitation for the study area from observational ClimateBC data (dashed red), and from various GCM/scenario simulations, for the baseline reference period (various colours indicate individual GCMs, various symbols indicate individual scenarios, open and closed symbols indicate differing runs).

4.1 Discussion of Baseline Reference Period Simulations

In general, all of the models appear to be reasonably capable of simulating seasonal patterns of temperature for the study area during the baseline period, although on average, they tend to slightly under-estimate temperatures in all seasons except summer. This provides us with some evidence that models may be potentially useful for projecting future temperatures for the study area.

The seasonal pattern of spring, summer and fall precipitation for the baseline period is reasonably well simulated by most of the GCMs, although slightly under-estimated on an absolute basis. Winter precipitation however, is poorly estimated by all of the GCMs. An assessment of model bias for the Pacific Northwest by the Climate Impacts Group at the University of Washington (Salathe and Peacock 2008) found similar results for both temperature and precipitation anomalies. Their assessment concluded that most of the models had a “dry bias” in winter for the period of 1949-1999 for the Canadian portion of the Columbia Basin, including the WK study area (see Figure 7). They ascribe the differences partly to modeling scale (i.e. insufficient resolution) and the models’ inability to fully capture the effects of topography on precipitation, and partly to “underlying dynamical deficiencies” – i.e. inherent limitations in some of the models themselves. These results give us reasonable confidence in the potential utility of the models for projecting future precipitation changes, with some concern for winter values.

The MRI-CGCM32A model significantly underestimates annual precipitation, and also fails to simulate the past seasonal pattern of precipitation, indicating wetter summers and drier winters (Figure 5). The NCAR-CCSM30 model simulates the general seasonal pattern, but suggests much drier summers than the ClimateBC normals. The poor performance of both of these models in simulating past precipitation patterns for the study area suggests that future projections of precipitation patterns from these models should be viewed with less confidence than those of the other models.

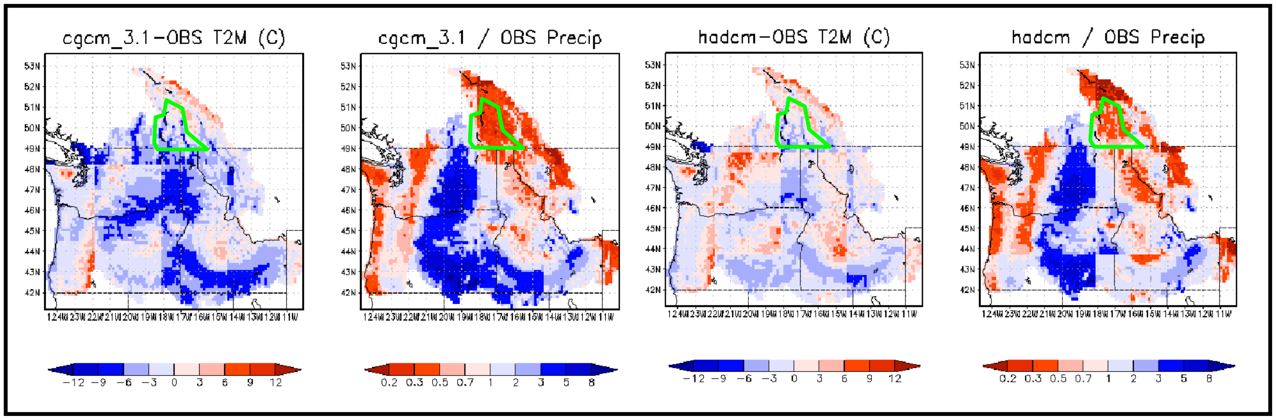

Figure 7. Examples of differences between winter (Dec/Jan/Feb) data simulated by two GCMs and spatially averaged data from weather station records for 1949-1999. The left pair of maps is from the Canadian CGCM model and the right pair from the British HadCM3 model. The left map in each pair is deviation in temperature, blue too cool, red too warm; the right map deviation in precipitation, blue too wet, red too dry. The approx. West Kootenay study area is in green (from Salathe and Peacock 2008).

5.0 Results for Future Periods (2020s, 2050s, 2080s)

Projections of mean seasonal temperatures for the study area as determined by various GCMs for various scenarios at three future time periods are shown in Figure 8. With two minor exceptions for winter in the 2020s, all models and all scenarios project continuously increasing mean seasonal temperatures through all three time periods. The models differ with respect to which seasons show the greatest relative

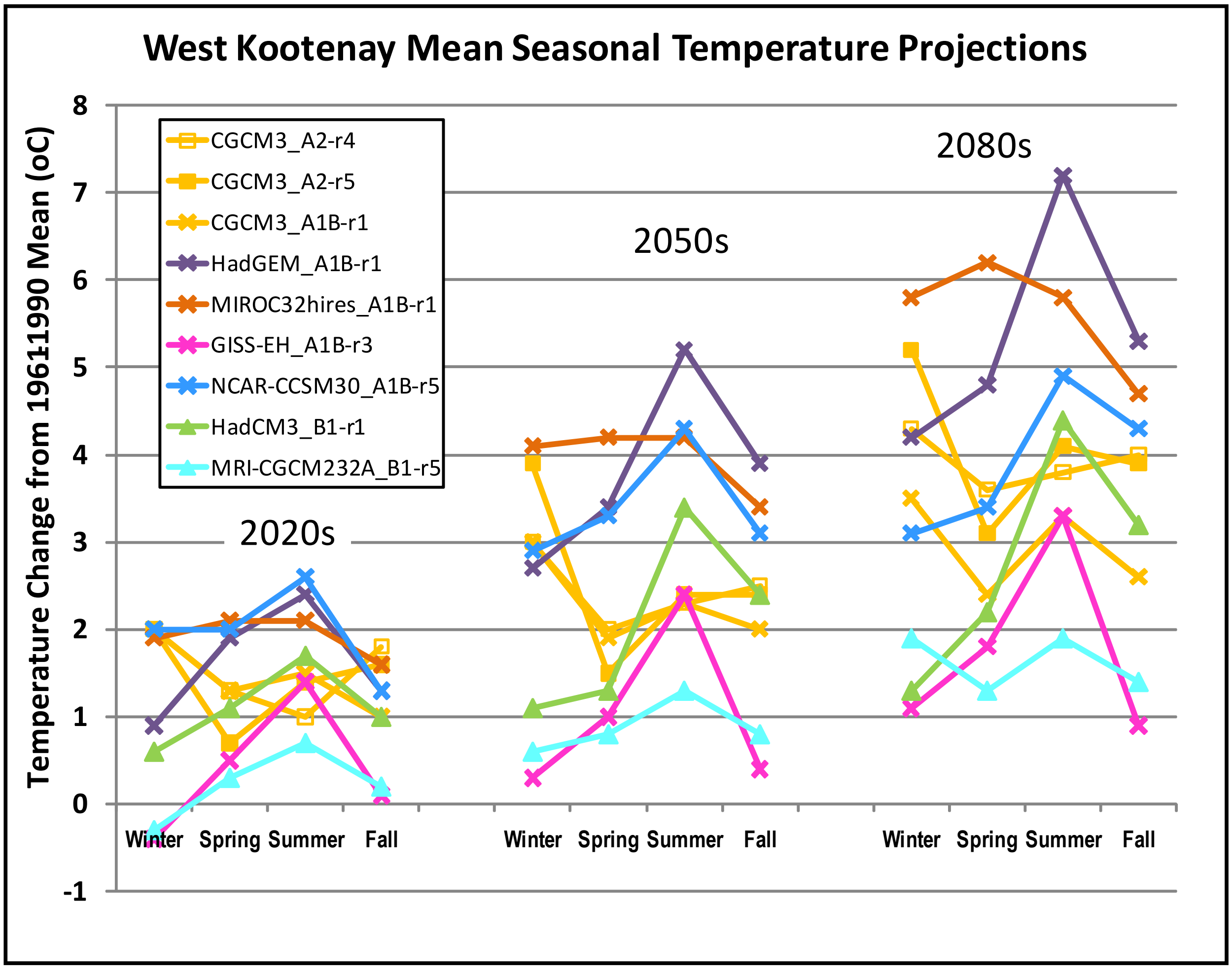

Figure 8. Comparison of projected mean seasonal temperatures for the study area as modeled by various GCMs for the 2020s, 2050s and 2080s (various colours indicate individual GCMs, various symbols indicate individual scenarios, open and closed symbols indicate differing runs).

increases; however, summer and winter seasons are often the seasons with the greatest increases. For the 2050s and 2080s, some GCM/scenario combinations indicate the potential for rapidly increasing mean summer temperatures.

Projections of changes in mean seasonal precipitation for the study area as determined by various GCM/scenario combinations are shown in Figure 9. The various combinations differ in magnitude of projected changes in seasonal precipitation for winter, spring and fall, but generally show small to moderate increases over all three time periods for those seasons, with the exception of GISS-EH, NCAR-CCSM30 and HadCM3 which sporadically show small decreases at various times. In contrast, almost all the GCM/scenario combinations project small to moderate decreases in summer precipitation for all three time periods. The exceptions are the CGCM3_AR2-r4 that shows an increase in the 2020s, and the NCAR-CCSM30 and the CGCM3_A2 scenarios that show very small increases for summer in the 2050s.

In general, the models are projecting that by the 2080s, winters, springs and falls will be warmer by 1 to 5°C and 10-25% wetter, and that summers will be 2 to 7°C warmer, with precipitation that may be similar to today or decreased by up to 30%. Excluding the model which had the poorest performance simulating past precipitation would change the projections for winters, springs and falls to be 2 to 5°C warmer and summers that are 3 to 7°C warmer (see Figure 6, MRI-GCM232A).

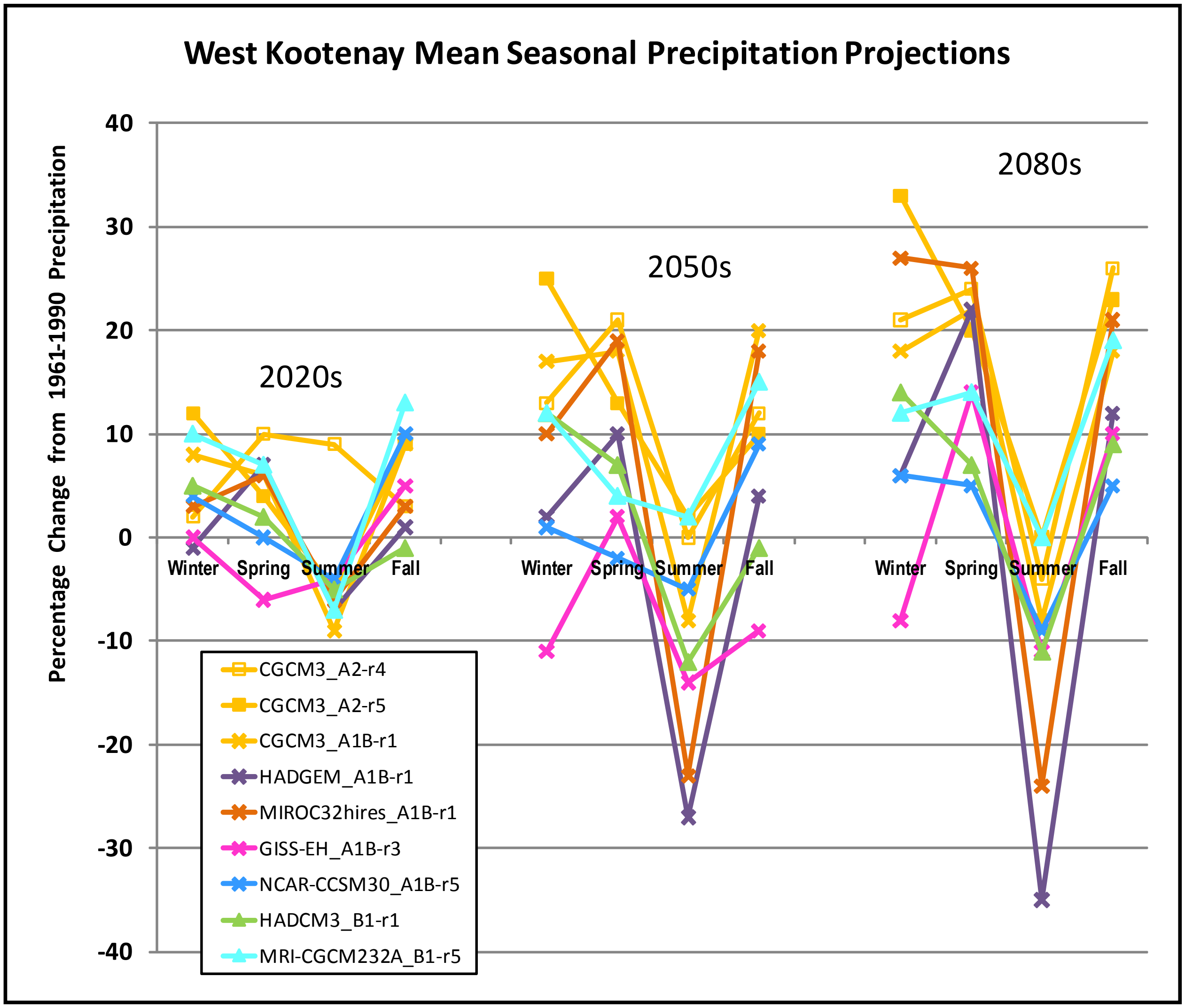

Figure 9. Comparison of projected mean seasonal precipitation for the study area as modeled by various GCMs for the 2020s, 2050s and 2080s (various colours indicate individual GCMs, various symbols indicate individual scenarios, open and closed symbols indicate differing runs).

5.2 Discussion of Future Projections

The most obvious trend shown by the models is an increase in summer moisture stress. All of the models are projecting increases in summer temperatures, and most of the models are projecting simultaneous decreases in summer precipitation. These changes will likely have implications for regeneration success, tree vigour and growth rates, and disturbance agents such as fire and insect and disease outbreaks. The increase in fall, winter and spring temperatures will also likely decrease snowpacks, even with a moderate increase in winter precipitation. All of these changes will affect seasonal stream flow patterns.

Comparing the projections for 2020s, 2050s and 2080s it should be noted that most of the variation is between the various models, rather than between the scenarios. When larger regions are examined, the scenario variation tends to overwhelm model variation in the 2080s. This emphasizes that there is significant uncertainty associated with downscaling global models to this small of an area. In addition, it may also be useful to examine more of the higher emission scenarios (A1FI and A2). Over the past few years, without effective emission reductions, global emissions have been exceeding all of the modeled emission scenarios (Allison et al. 2009).

The differences between runs 4 and 5 of the CGCM3_A2 projections for precipitation in the 2020s demonstrate the impact that variation in starting conditions may have on short- to medium-term projections within a model/scenario combination (see Figure 9). Note that these two runs show increasing agreement into the 2050s and 2080s. It can also be noted that by the 2080s the A2 scenario temperature projections of the CGCM3 are beginning to increase more rapidly than the A1B scenario of the same model, reflecting the increased GHG levels driving the A2 scenario (see Figure 8).

6.0 Extreme Events

In addition to changes in mean temperatures and precipitation, climate modeling is also generally projecting increases in the magnitude and frequency of extreme events, such as high intensity rainfall, heatwaves and windstorms. These events are often more important than long term averages in determining the distribution of species and the frequency of major disturbances such as fire or insect epidemics.

The IPCC Fourth Assessment Report (Meehl et al. 2007) projects increases in precipitation intensity and dry days for southern BC, and these projections are consistent across at least 5 of the 9 GCM runs that were considered (see Figure 10).

A report on changes in the frequency of extreme precipitation across the US between 1948 and 2006 showed statistically significant increases in all regions, with the Mountain and Pacific regions increasing by 25% and 18% respectively (Madsen and Figdor 2007). Another study assessing extreme precipitation events in urban areas of Washington state between 1949 and 2007 showed a 9% increase in the magnitude of maximum annual precipitation events for Spokane over that period, despite a 13% decrease in total annual precipitation (Rosenberg et al. 2009). That report also examined output of regionally downscaled GCM projections for two climate change scenarios comparing values from 1970-2000 to projections for 2020-2050. The results were inconclusive with regard to short duration maximum annual events (<12 hours), but showed potential 4-22% increases in the magnitude of 12-hour to 2-day events (Rosenberg et al. 2009). However, almost none of the Rosenberg et al. results were statistically significant.

There is little information on extreme climatic events available specific to the WK region, except some preliminary projections by PCIC for Castlegar (Murdock 2010). This work indicates that a 3-hour high intensity precipitation event that presently occurs once every 100 years could occur as often as every 19 years in the future (other models project future return intervals of 32 to 199 years). The same group of model results indicate that an extreme maximum temperature that now occurs once in every 100 years is projected to occur once every 4-18 years in the future.

7.0 Further Work

Subsequent analyses for the West Kootenay resilience project will examine the implications of the projected climate changes on disturbance processes and the distribution of various species. The project will also be attempting to gather more specific information related to the potential increase in extreme events and their implications for ecosystems, streamflow and infrastructure planning.

Check the project website for further information. http://westkootenayresilience.org

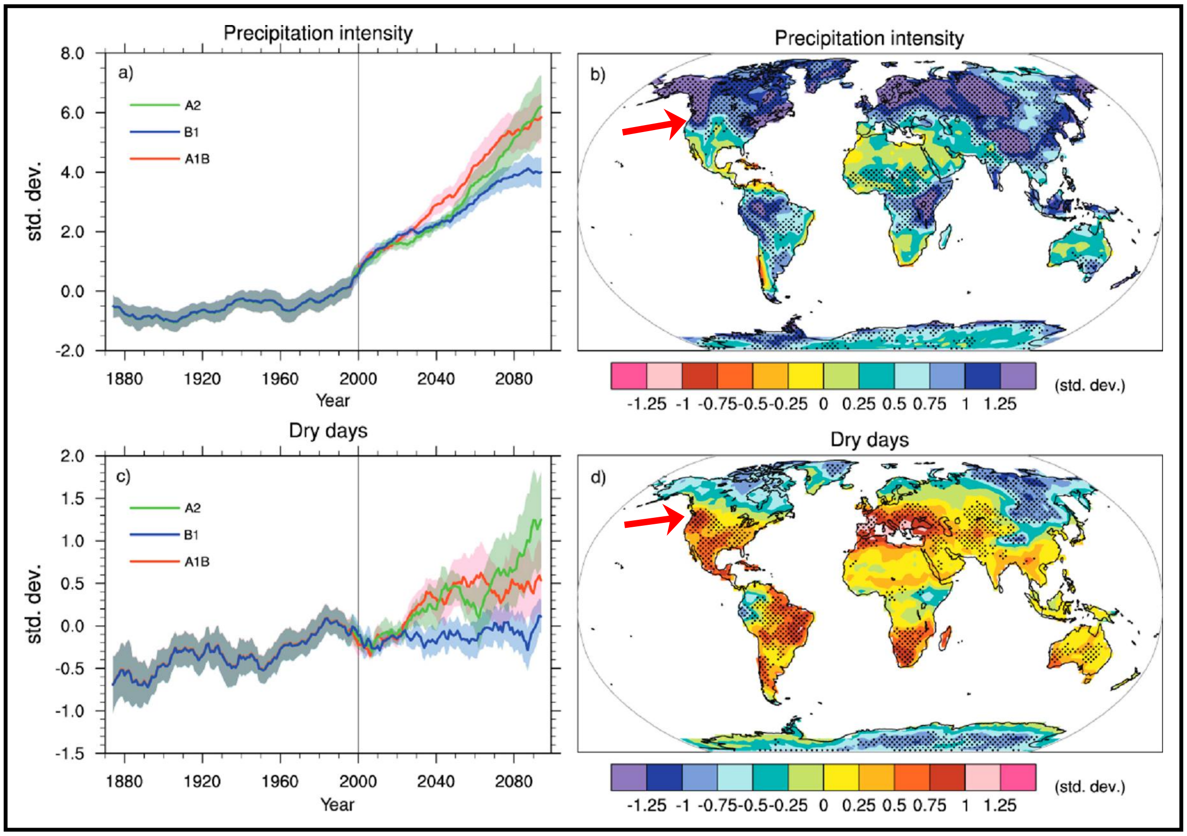

Figure 10. Illustrations of the predicted global increases in extreme weather events. Changes in extremes based on nine model projections. (a) Globally averaged changes in precipitation intensity (defined as the annual total precipitation divided by the number of wet days) for three scenarios. (b) Changes in spatial patterns of simulated precipitation intensity. (c) Globally averaged changes in dry days (defined as the annual maximum number of consecutive dry days). (d) Changes in spatial patterns of simulated dry days. Both (c) and (d) represent changes between two 20-year means (2080–2099 minus 1980–1999) for the A1B scenario. Solid lines in (a) and (c) are the 10-year smoothed multi-model ensemble means; the envelope indicates the ensemble mean standard deviation. Stippling in (b) and (d) denotes areas where at least five of the nine models concur in determining that the change is statistically significant. Each model's time series was centred on its 1980 to 1999 average and normalized (rescaled) by its standard deviation computed (after de-trending) over the period 1960 to 2099. The models were then aggregated into an ensemble average, both at the global and at the grid-box level. Thus, changes are given in units of standard deviations (from Meehl et al. 2007, p.785).

8.0 References

Allison, I., N.L. Bindoff, R.A. Bindschadler, P.M. Cox, N. de Noblet, M.H. England, J.E. Francis, N. Gruber, A.M. Haywood, D.J. Karoly, G. Kaser, C. Le Quéré, T.M. Lenton, M.E. Mann, B.I. McNeil, A.J. Pitman, S. Rahmstorf, E. Rignot, H.J. Schellnhuber, S.H. Schneider, S.C. Sherwood, R.C.J. Somerville, K. Steffen, E.J. Steig, M. Visbeck, A.J. Weaver. 2009. The Copenhagen Diagnosis, 2009: Updating the World on the Latest Climate Science. The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia, 60pp. Available at: www.copenhagendiagnosis.com

Intergovernmental Panel on Climate Change. 2000. Emissions Scenarios – Summary for Policy Makers. Available at: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Synthesis Report. This report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report. 73pp.

Madsen T. and E. Figdor. 2007. When it rains, it pours: global warming and the rising frequency of extreme precipitation in the United States. Report prepared for Environment California Research and Policy Center. 47pp. Available at: www.environmentcalifornia.org

Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao. 2007. Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. WG I Chpt. 10.

Ministry of Forests and Range. 2008. Adapting to climate change: Future Forest Ecosystem Initiative 2007/08 – 2009/10 strategic plan. http://www.for.gov.bc.ca/ftp/hts/external/!publish/web/ffei/project/FFEI_Strategic_Plan.pdf

Murdock, T. 2010. Past and future climate in Castlegar for stormwater engineering – PIEVC Workshop. Unpubl. Powerpoint Presentation. Pacific Climate Impacts Consortium. Victoria, BC. 48pp.

Murdock, T. and D. Spittlehouse. 2010. Selecting and using climate change scenarios for British Columbia, Pacific Climate Impacts Consortium. 27 pp.

Murdock, T.Q., J. Fraser, and C. Pearce, editors, 2007. Preliminary Analysis of Climate Variability and Change in the Canadian Columbia River Basin: Focus on Water Resources 2006. Pacific Climate Impacts Consortium, University of Victoria, Victoria BC, 57 pp. Available at: http://pacificclimate.org/docs/publications/CBT.Assessment.pdf

Rosenberg, E.A., P.W. Keys, D.B. Booth, D. Hartley, J. Burkey, A.C. Steinemann, and D.P. Lettenmaier. 2010. Precipitation extremes and the impacts of climate change on stormwater infrastructure in Washington State. Climatic Change 102(1-2):319-349

Salathe, E. and C. Peacock. 2008. IPCC AR4 Climate Model Comparisons – Discussion of Temperature and Precipitation Biases in Simulated 20th Century Climate. Website accessed on 1/18/11: http://www.atmos.washington.edu/~salathe/AR4_Climate_Models/

Spittlehouse, D. L. 2006. ClimateBC: Your access to interpolated climate data for BC. Streamline Watershed Management. Bull. 9:16-21.

Spittlehouse, D. 2008. Climate change, Impacts and Adaptation Scenarios: Climate Change and forest and range management in British Columbia. BC Ministry of Forests and Range, Victoria, British Columbia. Technical Report 45.

Wang, T., A. Hamann, D. L. Spittlehouse, and S. N. Aitken. 2006. Development of scale-free climate data for western Canada for use in resource management. Intl. J. Climatol. 26:383-397.