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INTEROFFICE MEMORANDUM

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DATE	06/20/2013
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SUBJECT	Memo # GN-9.5.2

Enclosed is the Future Climate Scenarios Technical Memorandum # GN-9.5.1 for the Keeyask Generation Project Stage IV Studies- Physical Environment. The objective of this study was to present a series of future climate scenarios with respect to temperature and precipitation for the immediate Keeyask Generating Station study area. The results of this study can be used to assess the potential impacts of climate change on other physical environment parameters in the Keeyask Generating Station study area.

This technical memorandum is to be used in support of the Keeyask Generating Station Environmental Impact Statement. In order to provide appropriate interpretation and guidance, please consult the Water Resources Engineering Department prior to external distribution.

If you have any questions regarding this report please feel free to contact me at 204-360-6318 or at kkoenig@hydro.mb.ca.

Regards,

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KEEYASK GENERATION PROJECT

STAGE IV STUDIES - PHYSICAL ENVIRONMENT

FUTURE CLIMATE SCENARIOS

REV 1

DELIVERABLE GN 9.5.2

MANITOBA HYDRO FILE: 00195-11100-00176_02

06/20/2013

PREPARED FOR:
HYDRO POWER PLANNING DEPARTMENT
POWER PROJECTS DEVELOPMENT DIVISION
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EXECUTIVE SUMMARY

Future Climate Scenarios memo No. GN-9.5.2 outlines projections of future climate with respect to temperature and precipitation within the immediate proposed Keeyask Generating Station study area. The Keeyask project is to be located approximately 4 km upstream of Stephens Lake, 35 km west of Gillam, 57 km east of Split Lake, 62 km northeast of York Landing, 40 km northeast of Ilford, and 66 km west of Bird. The site is entirely within the Split Lake Resource Management Area.

Global Climate Models (GCMs) simulate past and present climate and are used to project future climatic change. There are many Modeling Centers around the world that have developed their own GCMs. A total of 24 GCMs were considered in this study, each with its unique grid resolution. Grid points falling into the area delimited by 54.34°N to 58.35°N in latitude and 93.2°W to 98.2°W in longitude were selected for this study. This area is centered on the proposed Keeyask generating station and is large enough to include sufficient GCM grid points to conduct the analysis. The Canadian Regional Climate Model (CRCM) was also studied, however the analysis was restricted due to the limited number of model runs available.

Projected climate simulations based on three emission scenarios SRESA1B (A-1 storyline), the SRESA2 (A-2 storyline), and SRESB1 (the B-1 storyline) were extracted from the GCM databank. Three future horizons were identified: 2010-2039, 2040-2069, and 2070-2099. These periods are commonly referred to as the 2020s, 2050s, and 2080s, respectively.

Annual **climate change** scenarios, developed from 139 different climate projections, showed that temperature and precipitation is projected to increase with time. Results show that the mean temperature will increase by +1.5°C for the 2020s, +2.8°C for the 2050s, and +4.1°C for the 2080s. Precipitation is also projected to increase by 5% for the 2020s, 10% for the 2050s and 14% for the 2080s. Seasonal projections of future climate showed that both temperature and precipitation will generally increase with time for all seasons. Furthermore, of the four seasons, winter will likely to experience the greatest range of mean temperature change. Generally, the CRCM temperature and precipitation projections fall within the same range of the ensemble of global climate models. In addition, the CRCM simulations have projected an increase in the annual rates of evapotranspiration.

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1 INTRODUCTION

Climate information required for environmental assessments (EAs) is generally derived from historical observations. However, it appears that greenhouse-induced climate change may result in these historical observations no longer being a valid representation of future climate as the future climate may deviate from the past range of observed natural climate variability. There is not an explicit requirement in the Canadian Environmental Assessment legislation for practitioners to incorporate climate change into EAs. However, the Canadian Environmental Assessment Act was recently amended to require EAs of proposed development projects to be consistent with the precautionary principle and therefore climate change must be incorporated into the EAs (CEA Agency, 2003).

To assess the future impacts of climate change a quantitative description of the projected climate is required. At the global scale the scientific community has confidence that increased **greenhouse gas** concentrations will increase global temperatures. However at the regional scale where climate change will have a direct impact on local weather conditions the scientific community has much less confidence in the estimate of how the climate will change (IPCC-TGICA, 2007). Due to this limitation the Intergovernmental Panel on Climate Change's Task Group on Data and **Scenario** Support for Impact and Climate Assessment has recommended when undertaking a climate impact assessment to rely on an approach which involves developing a number of plausible future climates termed **climate scenarios** (IPCC-TGICA, 2007).

Climate scenarios are plausible representations of the future that are consistent with assumptions of future emissions (greenhouse gas and aerosols) and our understanding of the effects of these emissions on the global climate (IPCC-TGICA, 2007). These climate scenarios also take into account other assumptions on land use change, energy demand as well as how the climate system will behave over a long time scale. There is a large amount of uncertainty surrounding these assumptions (IPCC-TGICA, 2007). However, with a range of climate scenarios available it helps identify any potential sensitive components in a climate impact assessment.

The climate scenarios produced for this report were developed by following the guidance of the Intergovernmental Panel on Climate Change (IPCC), Task Group on Data and Scenario Support for Impact and Climate Assessment "General Guidelines on the Use of Scenario Data for Climate Impact Adaptation Assessment (2007)".

The objective of this memo is to develop an ensemble of future climate scenarios that could potentially be used to examine the impacts of future climate (climate change) on the Keeyask Generation Station Project (Keeyask).

2 CLIMATE CHANGE

2.1 CLIMATE

When studying climate change, it is important to understand the difference between weather and climate. Weather refers to the day-to-day variable state of the atmosphere, and is characterized by temperature, precipitation, wind, clouds, and various other weather elements (IPCC, 2007). Weather results from rapidly developing and decaying weather systems and is difficult to predict on a daily basis. Climate, on the other hand, refers to the weather statistics (in terms of its long-term means, variability, extremes, etc.) over a certain time span and certain area (IPCC, 2007). Generally, climates are defined over several decades. Climate varies from place to place depending on the latitude, vegetation cover, distance to a large body of water, presence or absence of mountains, and several other significant geographic features.

2.2 CLIMATE CHANGE AND NATURAL VARIABILITY

The Intergovernmental Panel on Climate Change refers to the term **climate change** when there is a statistically significant variation to the mean state of the climate (or of its variability) that usually persists for decades or longer and which includes shifts in the frequency and magnitude of sporadic significant weather events as well as the slow continuous rise in global mean surface temperature (IPCC, 2007). The climate system is extremely complex with many physical, chemical, and biological interactions occurring along temporal and spatial scales. Each component of the system has very different properties; however, they are all linked by fluxes of mass, heat, and momentum. Any changes, either natural or **anthropogenic**, in a component of the system can cause climate change (IPCC, 2007).

Climate varies naturally on all time scales and can occur through both external and internal factors (IPCC, 2007). Natural climate variability can be related to external processes such as shifts in radiative forcing or internal processes such as the El Niño-Southern Oscillation (ENSO). The climate may respond slowly or rapidly and can lead to periods of colder or warmer temperatures. According to IPCC, the last 10 000 years have been relatively stable on a global scale, though locally, quite large changes have occurred.

2.3 EVIDENCE OF CLIMATE CHANGE

It has been reported that the global-average surface air temperature has increased by about +0.74^{o}C (with a 95% confidence range of +0.56°C to +0.92°C) between 1906 and 2005 (IPCC, 2007). The linear warming trend over the last 50 years, 0.13°C per decade, is nearly twice that for the last 100 years (IPCC, 2007). While Northern Manitoba has experienced an increase in average annual temperature of approximately +1.3°C between 1950 and 1998 (Zhang et al. 2000). Since the mid 20th century, the earth has experienced a continual rise in the average global temperature and that increase in temperature is classified as the current climate change.

The IPCC states that "Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* (>90% probability) higher during any other 50-year period in the last 500 years and *likely* (>66% probability) the highest in at least the past 1,300 years." (IPCC 2007, pg. 9). It is understood that the earth's climate has changed in the past; however, the cause of the current climate change differs from the past. Natural factors may have contributed to the observed warming in the first half of the 20th century, however "it is *extremely unlikely* (<5% probability) that global climate change of the past 50 years can be explained without external forcing, and *very likely* (>90% probability) that it is not due to known natural causes alone (IPCC, 2007, pg.10). So far, models combining both anthropogenic and natural forcing factors have produced the best agreement with observations over the past 140 years (Meehl et al. 2007).

The Earth releases back into space as much energy as it receives in a self balancing system. The atmosphere generally lets visible light through without absorbing much of it. GHGs (which consist only of a small fraction - about 1 percent - of the Earth's atmosphere), however, absorb the infrared radiation. It is these gases (i.e. water vapor, carbon dioxide, methane, nitrous oxide, ozone and various chlorine, fluorine, and bromine-containing molecules) which absorb more outgoing infrared energy from the surface and retain it longer before eventually radiating it back into space this process is termed the **greenhouse effect**. With this greenhouse gas effect the Earth's lower atmosphere average temperature is about 14°C however without this process it would only be -19°C. Therefore the lower atmosphere is approximately 33°C warmer than it would be if the atmosphere did not contain these gases (IPCC, 2007, pg.97).

2.4 EXTREME EVENTS AND FUTURE PROJECTIONS OF WIND

The occurrence of historic extreme events is difficult to analyze due to the absence of globally distributed, long term records with sufficient detail. IPCC's Fourth Assessment Report (AR4) discusses extreme events, outlines the issues associated with extreme event analysis and provides a summary of the findings. The results are characterized by phenomenon type, expected changes, region affected, time period examined and confidence in the expected change. Table 1, Table 2 and Table 3 have been adapted from IPCC's report and are included for reference. In addition, the IPCC report states:

> "*"..the type, frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climatic changes…a number of modeling studies have also projected a general tendency for more intense but fewer storms outside the tropics, with a tendency towards more extreme wind events…."*
> (Meehl et al., 2007)

In general, the IPCC's assessment of extreme events is at the global or continental scale, and not specific to smaller regions such as the Keeyask study area.

Table 1: Phenomenon Definition Used to Asses Extremes (adapted from IPCC, 2007)

Phenomenon	Description
Low-temperature days/ nights and frost days	Percentage of days with temperature (maximum for days, minimum for nights) not exceeding some threshold, either fixed (frost days) or varying regionally (cold days/cold nights), based on the 10th percentile of the daily distribution in the reference period (1961–1990).
High-temperature days/nights	See low-temperature days/nights, but now exceeding the 90th percentile.
Cold spells/snaps	Episode of several consecutive low-temperature days/nights.
Warm spells (heat waves)	Episode of several consecutive high-temperature days/nights.
Cool seasons/warm seasons	Seasonal averages (rather than daily temperatures) exceeding some threshold.
Heavy precipitation events (events that occur every yr)	Percentage of days (or daily precipitation amount) with precipitation exceeding some threshold, either fixed or varying regionally, based on the 95th or 99th percentile of the daily distribution in the reference period (1961–1990).
Rare precipitation events (with return periods >~10 yr)	As for heavy precipitation events, but for extremes further into the tail of the distribution.
Drought (season/year)	Precipitation deficit; or based on the PDSI
Tropical cyclones (frequency, intensity, track, peak wind, peak precipitation)	Tropical storm with thresholds crossed in terms of estimated wind speed and organization. Hurricanes in categories 1 to 5, according to the Saffir-Simpson scale, are defined as storms with wind speeds of 33 to 42 m s^{-1}, 43 to 49 m s^{-1}, 50 to 58 m s^{-1}, 59 to 69 m s^{-1}, and >70 m s^{-1}, respectively. NOAA’s ACE index is a measure of the total seasonal activity that accounts for the collective intensity and duration of tropical storms and hurricanes during a given tropical cyclone season.
Extreme extratropical storms (frequency, intensity, track, surface wind, wave height)	Intense low-pressure systems that occur throughout the mid-latitudes of both hemispheres fueled by temperature gradients and acting to reduce them.
Small-scale severe weather phenomena	Extreme events, such as tornadoes, hail, thunderstorms, dust storms and other severe local weather.

Table 2: Change in Extremes for Phenomena (adapted from IPCC, 2007)

Phenomenon	Change	Region	Period	Confidence
Low-temperature days/ nights and frost days	Decrease, more so for nights than days	Over 70% of global land area	1951–2003 (last 150 years for Europe and China)	Very likely
High-temperature days/nights	Increase, more so for nights than days	Over 70% of global land area	1951–2003	Very likely
Cold spells/snaps	Insufficient studies,but daily temperature changes imply a decrease			
Warm spells (heat waves)	Increase: implicit evidence from changes of daily temperatures	Global	1951–2003	Likely
Cool seasons/warm seasons	Some new evidence for changes in inter-seasonal variability	Central Europe	1961–2004	Likely
Heavy precipitation events (that occur every yr)	Increase, generally beyond that expected from changes in the mean (disproportionate)	Many mid-latitude regions (even where reduction in total precipitation)	1951–2003	Likely
Rare precipitation events (with return periods > ~10 yr)	Increase	Only a few regions have sufficient data for reliable trends (e.g., UK and USA)	Various since 1893	Likely (consistent with changes inferred for more robust statistics)
Drought (season/year)	Increase in total area affected	Many land regions of the world	Since 1970s	Likely
Tropical cyclones	Trends towards longer lifetimes and greater storm intensity, but no trend in frequency	Tropics	Since 1970s	Likely; more confidence in frequency and intensity
Extreme extratropical storms	Net increase in frequency/intensity and poleward shift in track	NH land	Since about 1950	Likely
Small-scale severe weather phenomena	Insufficient studies for assessment			

Table 3: Trends and projections of extremes for which there is an observed late-20th century trend (adapted from IPCC, 2007)

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	Very likely[a]	Virtually certain[b]
Warmer and more frequent hot days and nights over most land areas	Very likely[c]	Virtually certain
Warm spells/heat waves. Frequency increases over most land areas	Likely	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	Very likely
Area affected by droughts increases	Likely in many regions since 1970s	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970	Likely
Increased incidence of extreme high sea level (excludes tsunamis)[d]	Likely	Likely[e]

Table notes:
[a] Decreased frequency of cold days and nights (coldest 10%).
[b] Warming of the most extreme days and nights each year.
[c] Increased frequency of hot days and nights (hottest 10%).
[d] Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[e] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed.

3 REFERENCE CLIMATE

3.1 STUDY AREA

The Keeyask project is to be located approximately 4 km upstream of Stephens Lake, 35 km west of Gillam, 57 km east of Split Lake, 62 km northeast of York Landing, 40 km northeast of Ilford, and 66 km west of Bird (see Figure 1). The site is entirely within the Split Lake Resource Management Area.

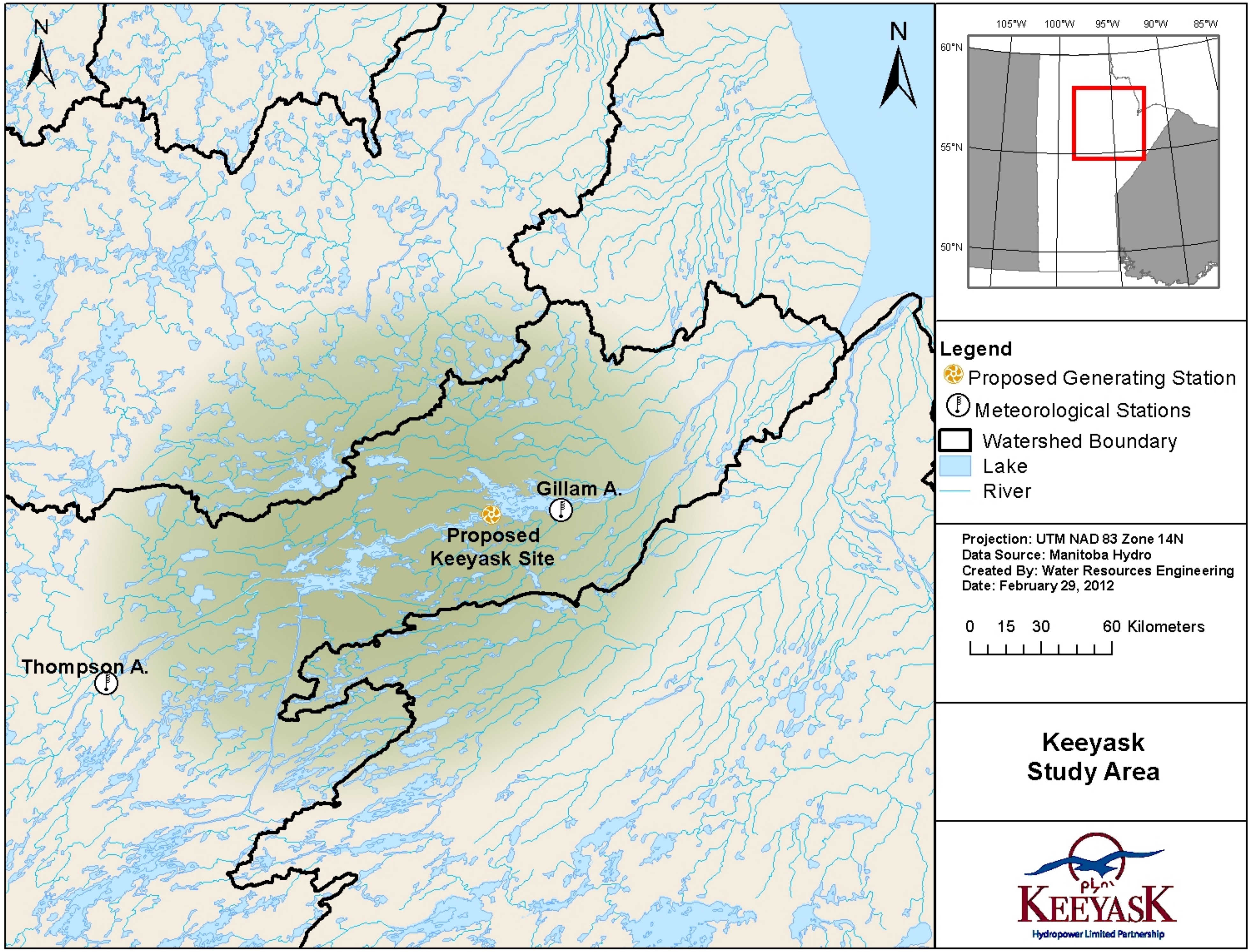

Figure 1: Study Area

3.2 REFERENCE CLIMATE

Reference or baseline climate information is necessary for calibrating and testing impact models across the current range of variability, for identifying possible ongoing trends or cycles, and for specifying the reference situation with which to compare future changes (IPCC-TGCIA 1999). The World Meteorological Organization (WMO) defines baseline climate or *reference period* as the historical climate of the current 30-year **normal** period. The WMO considers thirty years as a sufficient amount of time to eliminate year-to-year variations and has set the current thirty-year period to 1971-2000. They have also established that monthly normals should be arithmetic means calculated for each month of the year. The climate normals for the Keeyask study area that are used in this report have previously been defined in Deliverable GN 9.5.1 - "Historical Climate Analysis".

4 FUTURE CLIMATE

4.1 CLIMATE SCENARIOS DERIVED FROM GLOBAL CLIMATE MODELS

Climate scenarios provide alternative views of how the future might unfold, as compared to the baseline climate. Currently, there are three main methods available to develop a climate scenario, Synthetic Scenario, Analogue Scenario, and Scenarios from Global Climate Models (GCMs), which is the method used in this study. Global Climate Models (GCMs) have been designed to simulate past and present climate and are used to project future climatic change. GCMs aim to calculate the full three-dimensional characteristics of the atmosphere or ocean by solving a series of equations that describe the movement of energy, momentum, various tracers, and the conservation of mass (McGuffie and Henderson-Sellers, 1997). These models typically divide the atmosphere and oceans into a horizontal grid with a resolution of 1.1 to 5.0 degrees latitude and longitude and 18 to 56 levels in the vertical direction. Their resolution is therefore quite coarse relative to the scale of the components examined in a regional impact assessment. Many physical processes occur at scales smaller than those used by the GCM and therefore can not be modeled accurately. As a result these physical processes must be approximated over a coarse scale through parameterization which introduces a source of uncertainty in the GCM simulations. In addition, the complex climate feedback mechanisms are not fully understood making it difficult to model (IPCC-TGICA, 2007). Consequently various GCMs may simulate quite different responses to the same forcing because of the way certain processes and feedbacks are modeled (IPCC-TGICA, 2007). The simulations run by the GCMs are from approximately 1900 to 2100 allowing researchers to learn about the climate in a statistical sense (i.e. means and variability). Since they do not suffer from the same drawbacks as synthetic or analogue scenarios, GCMs are currently the most advanced tools available for simulating the response of the global climate system due to changes in external forcing due to future emission scenarios.

4.2 EMISSION SCENARIOS

To determine how the composition of the atmosphere (and subsequently how climate may change) in the future, it is necessary to construct scenarios of **greenhouse gas** and sulphate aerosol emissions for the next 100 years and beyond. To do so, a number of assumptions have to be made about how society will evolve in the future. Specifically, these scenarios must represent different demographic, social, economic, technological, and environmental developments in order to be considered accurate, after which they can be used in Climate Models (CMs) to simulate the evolution of climate over time.

In 2000, the IPCC commissioned a Special Report on Emissions Scenarios (SRES) (IPCC, 2000). The SRES described several principal, yet different, narrative 'storylines' representing different possible future emission scenarios. Based on these storylines, “scenario families” were identified and a total of 40 emissions scenarios were developed. These have subsequently been converted into **projections** of future atmospheric composition. The associated storylines are summarized as follows: (IPCC-TGCIA, 1999).

- **A-1 Storyline:** The A-1 storyline and scenario family looks into the future, to a world with very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality. The A-1 storyline contains the A1B scenario group. A1 has projected carbon dioxide emissions between to the A2 and B1 Storyline (Figure 2). In terms of global warming, the A-1 storyline is projected to have a mid-level warming effect by year 2100 (Figure 3).

- **A-2 Storyline:** The A-2 storyline and scenario family looks at a world with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development. The underlying theme is that of strengthening regional cultural identities. A2 has the highest projected carbon dioxide emissions relative to the A1 and B1 Storyline (Figure 2). In terms of global warming, the A-2 storyline is projected to have the greatest warming effect by year 2100 (Figure 3).

- **B-1 Storyline:** The B-1 storyline and scenario family looks at a world with rapid change in economic structures, “**dematerialization**”, and the introduction of clean technologies. The emphasis is on global solutions to environmental and social sustainability, including concerted efforts for rapid technology development, dematerialization of the economy, and improving equity. B1 has lowest projected carbon dioxide emissions compared to the A1 and A2 Storyline (Figure 2). In terms of global warming, the B-1 storyline is projected to have the lowest warming effect by year 2100 (Figure 3).

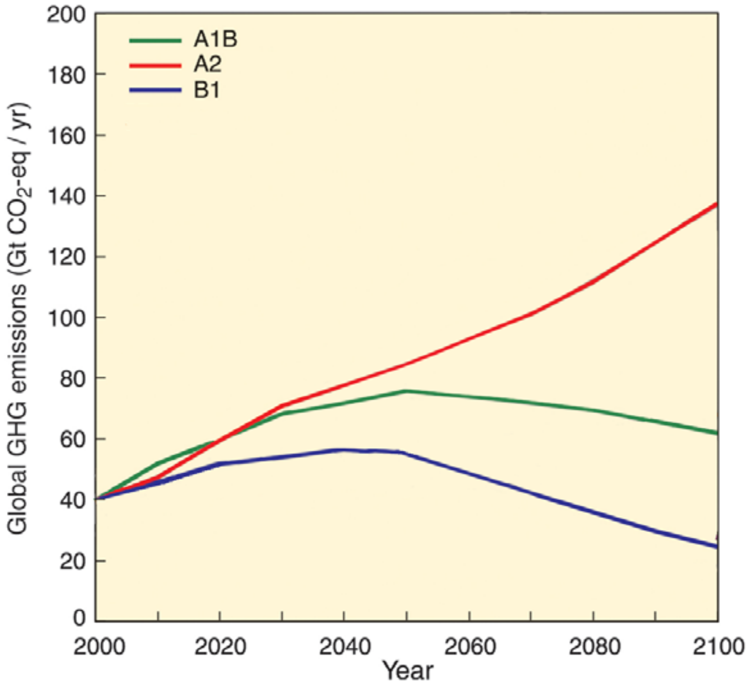

Figure 2: Global GHG emissions (in gigatonnes of GHG per year) for the A1B, A2 and B1 emission scenarios. (adapted from IPCC, 2007)

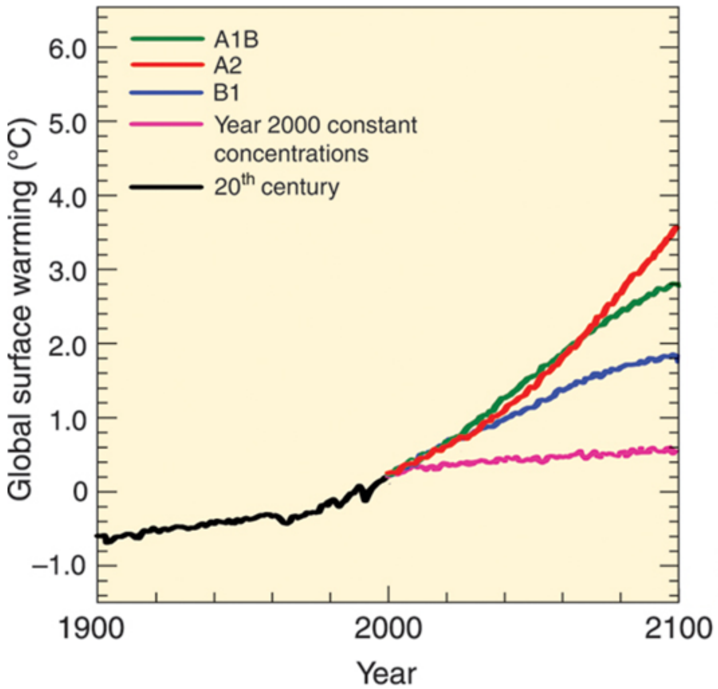

Figure 3: Coloured lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The pink line is for the experiment where concentrations were held constant at year 2000 values. (adapted from IPCC, 2007)

4.3 DYNAMICAL DOWNSCALING

Since GCMs have a coarse resolution, techniques have been developed to downscale the GCM projections to a regional scale (IPCC-TGCIA, 1999). One form of downscaling is using a high resolution limited area model which uses the GCM outputs to provide the boundary conditions for the limited area model. These types of models are often referred to as Regional Climate Models (RCMs). Just like the global climate models, these models are physically based but their resolution is typically 50km by 50km or less allowing them to be able to account for important local forcing factors which GCMs are unable to resolve. RCM rely on the GCM outputs for their boundary conditions which may not always be reliable. Errors that may be present in the GCM boundary conditions are transferred to the RCM simulations. Typically a RCMs' output can be used directly in a regional impact assessment. However, if a systematic bias is present in the RCM the delta method (Section 6) can be applied to its outputs. Since RCMs are modeled at a finer resolution than GCMs, their computational demands are considerably greater. As a result, the diversity of models, number of members and emissions scenarios available may not be the same as for the GCMs.

5 DATA SOURCES

Twenty-four international GCMs (Table 4) from the IPCC's Fourth Assessment Report (AR4) were employed for this report (Randall et al., 2007). Approximately three emission scenarios were available from each GCM (A1B, A1, and B1). A number of GCMs also have experiments which assumed identical radiative forcing but slightly different initial conditions referred to as member experiments. Each SRES and member experiment is equally plausible. In total of 139 GCM simulations were employed for this report.

The Canadian Regional Climate Model 4.2.3 (CRCM4.2.3) was also employed for this report (Music and Caya, 2007; Caya and Laprise, 1999). CRCM4.2.3 data has been generated and supplied by Ouranos (http://www.ouranos.ca/) and was run over the North-America domain with a 45km horizontally spaced mesh. CRCM4.2.3 runs used in this report were driven by atmospheric fields taken from; CGCM3 (A2), ECHAM5 (A2) and CNRM-CM3 (A1B) outputs. Currently, there are 3 model runs available for the 2020s, 9 runs for the 2050s and 3 runs for the 2080s. Each model run is differentiated by their boundary conditions.

Three future horizons were identified: 2010-2039 (2020s), 2040-2069 (2050s), and 2070-2099 (2080s). The period from 1971-2000 was selected as the reference period. For the GCMs and CRCM4.2.3 the grid points having centroids that fall into the area delimited by 54.3°N to 58.3°N in latitude and 93.2°W to 98. 2°W in longitude were selected for this report. An example of a GCM and the CRCM4.2.3 grid layout over the study region can be found in Figure 4 and 5. It is important to note that for some CRCM4.2.3 runs, the year 2040 is part of the spin-up period and not included as output. For these simulations, the 2050s are represented by the years 2041-2070.

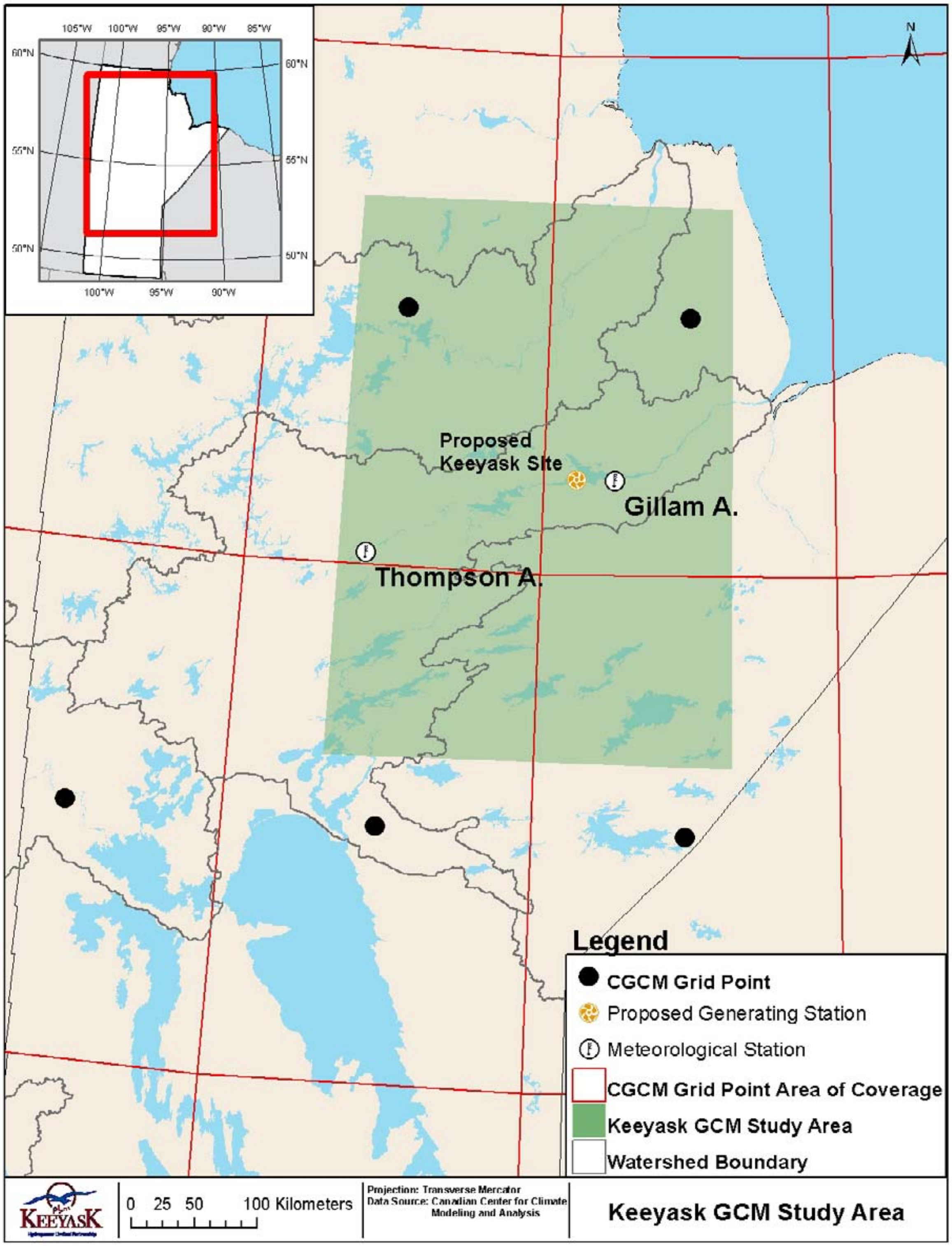

Figure 4: Map of study area and example of GCM grid

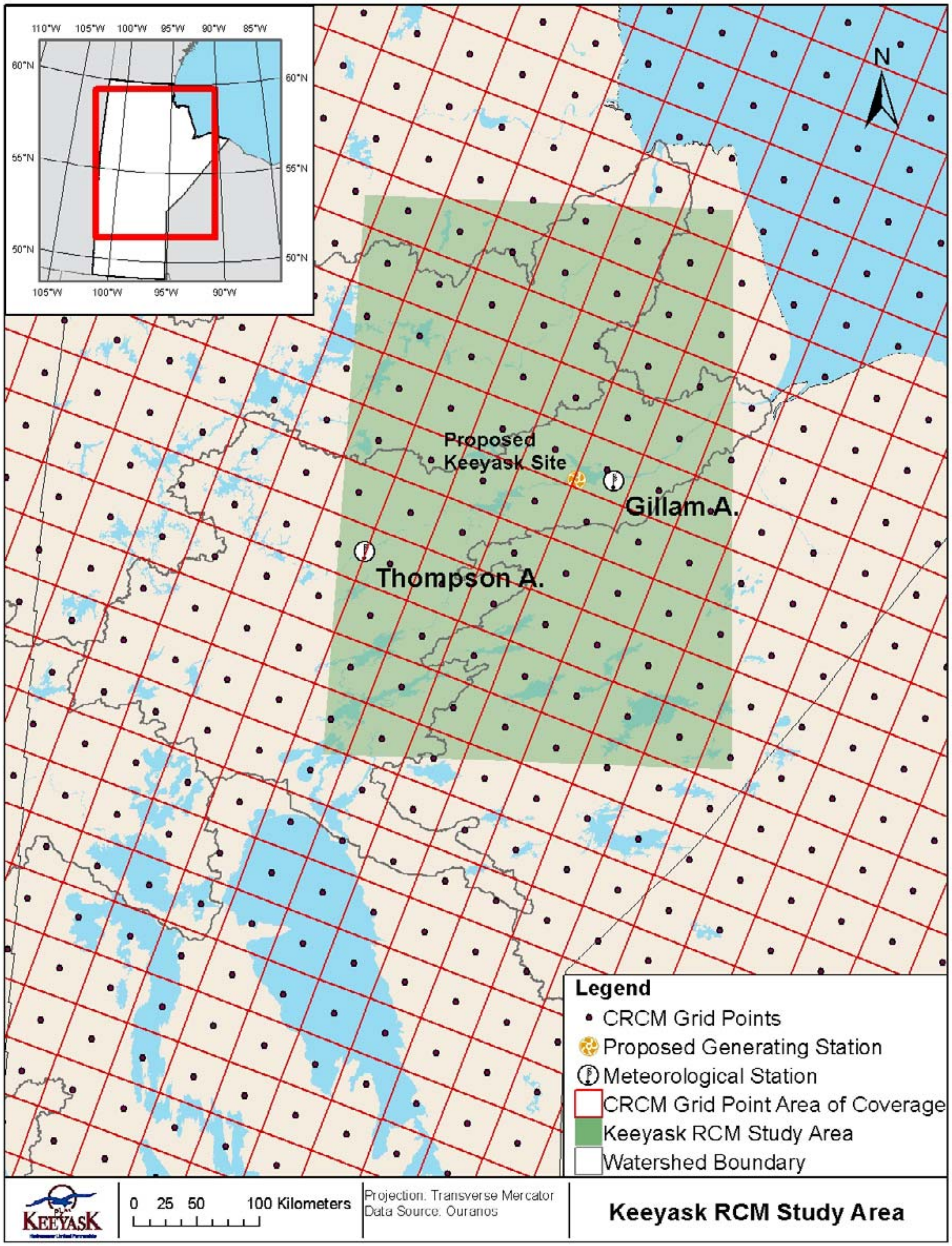

Figure 5: Map of Study Area and Example of CRCM Grid

Table 4: Global Climate Model Information

Model ID, Vintage	Sponsor(s), Country	Scenarios	Members	Atmosphere Resolution[a]	Number of Grid Points in Study Area
BCCR-BCM2.0, 2005	Bjerknes Centre for Climate Research, Norway	A1B, A2, B1	1	T63 (2.8º x 2.8º) L31	2
CGCM3.1(T47), 2005	Canadian Center for Climate Modeling and Analysis, Canada	A1B, A2, B1	1, 2, 3, 4, 5	T47(~3.8º x 3.8º) L31	2
CGCM3.1(T63), 2005		A1B, B1	1	T63 (~2.8º x 2.8º) L31	2
CNRM-CM3, 2004	Météo-France/Centre National de Recherches Meteorologiques, France	A1B, A2, B1	1	T42(~2.8º x 2.8º) L45	2
CSIRO-MK3.0, 2001	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	A1B, A2, B1	1	T63 (~1.9º x 1.9º) L18	6
CSIRO-MK3.5, 2001		A1B, A2, B1	1	T63 (~1.9º x 1.9º) L18	6
GFDL-CM2.0, 2005	U.S. Department of Commerce/National Oceanic and Atmospheric Administration (NOAA)/Geophysical Fluid Dynamics Laboratory (GFDL), USA	A1B, A2, B1	1	(2.0º x 2.5º) L24	4
GFDL-CM2.1, 2005		A1B, A2, B1	1	(2.0º x 2.5º) L24	4
GISS-AOM, 2004	National Aeronautics and Space Administration for (NASA)/Goddard Institute Space Studies (GISS), USA	A1B, B1	1, 2	(3.0º x 4.0º) L12	2
GISS-EH, 2004		A1B	1, 2, 3	(4.0º x 5.0º) L20	1
GISS-ER, 2004		A2, B1	1	(4.0º x 5.0º) L20	1
		A1B	2,4		
FGOALS-g1.0, 2004	National Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG)/Institute of Atmospheric Physics, China	A1B, B1	1, 2, 3	T42 (~2.8º x 2.8º) L26	2
INGV-SXG ECHAM4, 2005	National Institute of Geophysics and Volcanology, Bologna, Italy	A1B, A2	1	T106 (~1.1º x 1.1º)	20
INM-CM3.0, 2004	Institute for Numerical Mathematics, Russia	A1B, A2, B1	1	(4.0º x 5.0) L21	1
IPSL-CM4, 2005	Institut Pierre Simon Laplace (France)	A1B, A2, B1	1	(2.5º x 3.75º) L19	4
MIROC3.2(hires), 2004	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	A1B, B1	1	T106 (~1.1º x 1.1º) L56	20
MIROC3.2 (medres), 2004		A1B, A2, B1	1, 2, 3	T42 (~2.8º x 2.8º) L20	2
MIUB-ECHO-G, 1999	Meteorological Institute of the University of Bonn, Meteorological Research Institute of Korea Meteorological Administration (KMA), and Model and Data Group, Germany/Korea	A1B, A2, B1	1, 2, 3	T30 (~3.7º x 3.7º) L19	2
MPI-ECHAM5/ MPI-OM, 2005	Max-Planck-Institute for Meteorology (Germany)	A1B	1, 2, 3, 4	T63 (~1.9º x 1.9º) L31	6
		A2, B1	1, 2, 3		
MRI-CGCM2.3.2, 2003	Meteorological Research Institute, Japan	A1B, A2, B1	1, 2, 3, 4, 5	T42 (~2.8º x 2.8º) L30	2
NCAR-CCSM3, 2005	National Centre for Atmospheric Research, USA	A1B	1, 2, 3, 5, 6, 7, 9	T85 (1.4º x 1.4º) L26	9
		A2	1, 2, 3, 4		
		B1	1, 2, 3, 4, 5, 6, 7, 9		
NCAR-PCM, 1998		A1B, A2	1, 2, 3, 4	T42 (~2.8º x 2.8º) L26	2
		B1	2, 3		
UKMO-HadCM3, 1997	Hadley Centre for Climate Prediction and Research/Met Office, UK	A1B, A2, B1	1	(2.5º x 3.75º) L19	4
UKMO-HadGEM1, 2004		A1B, A2	1	(~1.3º x 1.9º) L38	9

Notes:

[a] Horizontal resolution expressed either as degrees latitude by longitude or as triangular (T) spectral truncation with a rough translation to degrees latitude and longitude. Vertical resolution (L) is the number of vertical levels.

6 METHODOLOGY

Temperature and precipitation were the two main variables of interest for developing climate scenarios for this report.

The delta method is used to develop the climate scenarios for this study. This method involves adjusting the baseline observations data by an *adjustment factor* (difference or ratio) between period-averaged results for the future GCM experiment and the corresponding averages for the GCM simulated baseline period (e.g. 1971-2000). One of the limitations of this method is that into the future it assumes that there will be no change in the frequency or variability of weather events compared to present-day climate. It also assumes that any biases in the simulation of present-day climate are the same as in the simulation of future climate. If this assumption is valid, using the delta method effectively eliminates any bias that may be present.

Adjustment factors for mean temperature (Tmean) and precipitation (P) were calculated by comparing mean monthly values for the future and reference period (1971-2000). The adjustment factors are a difference for mean temperature ($\Delta TMEAN$, equation 1) and a ratio for precipitation (rP, equation 2).

$$\Delta TMEAN(m) = \frac{\sum_{y=2010}^{2039} Tmean_{GCM}(m.y)}{30} - \frac{\sum_{y=1971}^{2000} Tmean_{GCM}(m.y)}{30} \qquad \text{Eq 1}$$

$$rP(m) = \frac{\dfrac{\sum_{y=2010}^{2039} P_{GCM}(m.y)}{30}}{\dfrac{\sum_{y=1971}^{2000} P_{GCM}(m.y)}{30}} \qquad \text{Eq 2}$$

Where *m* is the month (from 1 to 12) and *y* is the year

The adjustment factors were then applied to measured daily values of TMEAN, and P for the Gillam Airport meteorological station (equations 3 and 4).

$$TMEAN_{future}(i,m) = TMEAN_{inital}(i.m) + \Delta TMEAN(m) \qquad \text{Eq 3}$$

$$P_{future}(i,m) = P_{inital}(i,m) \bullet rP(m) \qquad \text{Eq 4}$$

Where *i* is the day. The method of adjusting the historical climate by an adjustment value is commonly referred to as the *delta method*. This method forms a time series of data referred to as a *climate scenario.* The monthly adjustment factors from the 139 GCM projections were applied to the baseline climate, creating 139 future climate scenarios.

The simulations from the CRCM4.2.3 that was employed for this report displayed a systematic bias and therefore the delta method was also applied to its outputs. In addition to temperature and precipitation parameters, CRCM4.2.3 results were also used to assess changes to evapotranspiration. Since long term baseline measured values are not available, an unbiased projection of future conditions is not possible. The process for assessing evapotranspiration changes is therefore limited to only calculating the *adjustment factor*. The calculated adjustment values provide an estimate of the expected change in evapotranspiration, instead of a future evapotranspiration scenario. Appendix H includes the evapotranspiration data as well as supporting details.

Scatter Plots with Distribution Ellipses: To analyze the precipitation and temperature adjustment factors over a specific time period, scatter plots were developed for each month and future horizon (Appendix B and Appendix G). The scatter plots illustrate the **correlation** between two variables; temperature on the x-axis and precipitation on the y-axis. Each point on the graph represents the temperature adjustment factor and the corresponding precipitation adjustment factor by one GCM or RCM. To analyze the range of the future climate projections distribution ellipses were superimposed on the scatter plots. The distribution levels selected for this study are: 50%, 75% and 95%. These ellipses illustrate where the specified percentage of the adjustment factors fall, assuming a bivariate normal distribution. In other words, the percentage of adjustment factors falling inside each ellipse should closely agree with the specified percentage level. This analysis does not represent the probability of occurrence, all projections are equally probable. The geometry of these ellipses reflects the degree of correlation between the variables under consideration. The ellipse collapses diagonally as the correlation between the two variables approaches +1 (i.e. **positive covariance,** Fig.6a) or -1 (i.e. **negative covariance,** Fig.6b). Figure 6c represents no correlation between the two variables (i.e. no covariance).

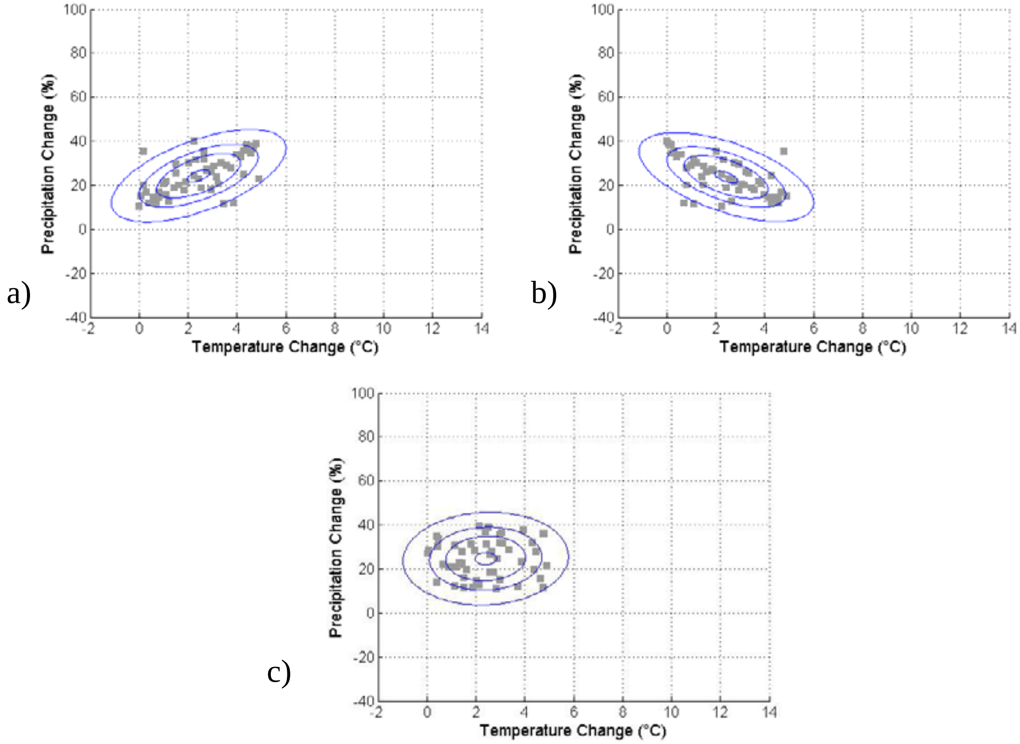

Figure 6: Example of a (a) positive correlation (b) negative correlation (c) no correlation

Distribution of Adjustment Factors: An analysis was performed to assess the distribution of the adjustment factors (139 in total) for temperature and precipitation individually for the ensemble of GCMs. Additionally, a comparison between time periods was conducted to demonstrate the temporal change in the distribution. Given that the distribution of adjustment factors followed a normal distribution, the 5th, 50th, and 95th percentiles were obtained (Figure 7). These percentiles represent the probability of a given temperature or precipitation adjustment factor occurring equal to or below this value, according to the GCM climate change projections. The values reported at the 5th percentile indicate there is a 5% probability that the temperature or precipitation adjustment factor will be smaller or equal to this value and 95% probability it will be larger. The 5th percentile will contain the lower end of the adjustment factors. The 50th percentile represents the median adjustment factor. The 95th percentile represents a 95% probability the temperature or precipitation adjustment factors will be smaller or equal to this value and a 5% probability it will be larger. If the adjustment factors are temporally sensitive, then a shift in the distribution may be observed when the 2020s, 2050s and 2080s' distributions are compared (Illustrated Figure 8). Since there were very few simulations available from the RCM, the distribution analysis was only conducted on GCMs.

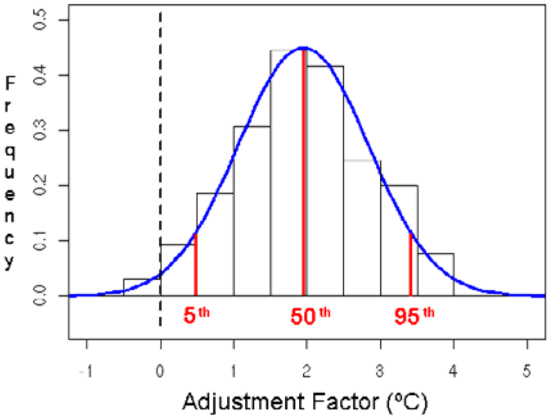

Figure 7: Example of a normal distribution (blue curve) and the 5th, 50th and 95th percentiles.

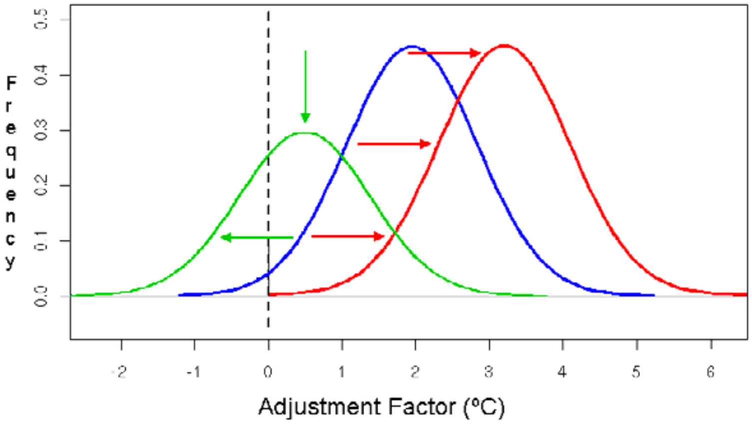

Figure 8: Example of shifts in the distribution of adjustment factors

Line Graphs: Line graphs were used to display Gillam's monthly normals plotted against the range of adjustment factors by the ensemble of GCMs (Figure 9). The range of GCM adjustment factors were determined by selecting the minimum and maximum monthly adjustment factors and then applied to the normals using the delta method. The range of future projections are presented in Appendix E by an envelop. The upper and lower limits of the envelop are composed from various GCM models, since not one model consistently produces the minimum or maximum adjustment factor for each month.

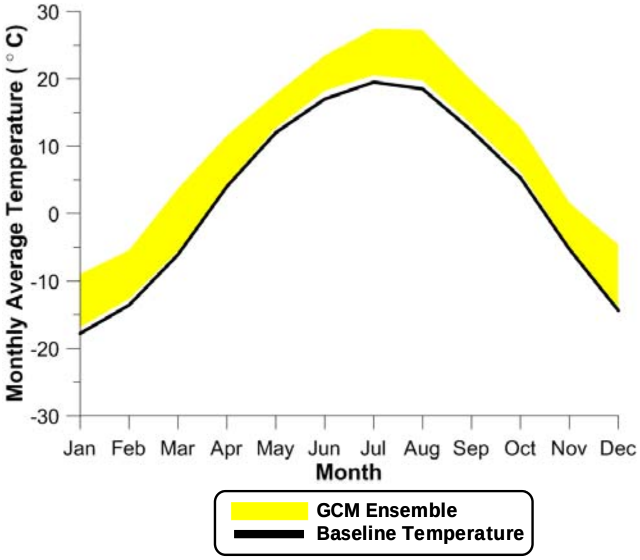

Figure 9: Example of an envelop plot

7 RESULTS

Global Climate Models: Monthly scatter plots of climate change with their corresponding distribution ellipses are shown in Figures B-2 to B-5. The legend for these plots can be found in Figure B-1. Details pertaining to the distribution ellipses found on these scatter plots can be found in Tables C-1 to C-4 for temperature and C-5 to C-8 for precipitation. The annual scatter plots are shown in Figure B-6 and details pertaining to the distribution ellipses are summarized in Table C-9. The scatter plots depict the projected change in temperature and precipitation as projected by the GCMs and their respective emissions scenarios compared to the reference period 1971-2000.

Canadian Regional Climate Model: Due to the limited number of runs conducted, meaningful statistic cannot be conducted on this data. A simple comparison was conducted in order to compare the projections from the CRCM to the GCM ensemble. Monthly scatter plots from the CRCM runs against the GCM projections are shown in Figures G-1 to G-4 for the 2020s, 2050s and 2080s. The annual scatter plots are shown in G-5. Generally, the CRCM runs fall within the same range of those from the GCM ensemble. Evapotranspiration data from CRCM4.2.3 is presented in Appendix H.

7.1 MEAN TEMPERATURE

With respect to 1971-2000, the average temperature of the GCM ensemble, indicate that (Figures B):

- The average annual temperature is projected to increase with time: 1.5°C for the 2020s, 2.8°C for the 2050s and 4.1°C for the 2080s.
- Generally, certain months into the future are projected to experience a similar degree of warming:
    - For the 2020s:
        - January, February, November, and December have the *greatest* increase in mean temperature: 1.9 ^{o}C to 2.3 ^{o}C
        - March and October have a *middle range* increase in mean temperature: 1.3 ^{o}C to 1.5 ^{o}C
        - April, May, June, July, August and September have the *least* increase in mean temperature: 1.0^{o}C to 1.1 ^{o}C.
    - For the 2050s:
        - January, February, November, and December have the *greatest* increase in mean temperature: 3.4 ^{o}C to 4.3 ^{o}C
        - March and October have a *middle range* increase in mean temperature: 2.4 ^{o}C to 2.9 ^{o}C
        - April, May, June, July, August and September have the *least* increase in mean temperature: 1.9 ^{o}C to 2.2 ^{o}C.
    - For the 2080s:
        - January, February, November, and December have the *greatest* increase in mean temperature: 4.8 ^{o}C to 6.3 ^{o}C
        - March and October have a *middle range* increase in mean temperature: 3.4 ^{o}C to 4.3 ^{o}C
        - April, May, June, July, August and September have the *least* increase in mean temperature: 2.9 ^{o}C to 3.2 ^{o}C.

7.2 PRECIPITATION

The precipitation scatterplots show that, with respect to 1971-2000 (Figures B):

- The annual precipitation is projected to increase with time: 5% for the 2020s, 10% for the 2050s and 14% for the 2080s.
- Generally different months into the future are projected to experience a different percentage of increase in precipitation:
    - For the 2020s:
        - January, April, May, November and December have the *largest* increase at 7 % to 8%
        - February, March, July and October have a *middle* range increase which falls in the range of 5% to 6% and;
        - June, August and September have the *least* increase which falls in the range of 3% to 4%.
    - For the 2050s:
        - January, February, April, May, November, and December have the *greatest* increase which falls in the range of 12% to 17%.
        - March, June and October have a *middle* range increase which falls in the range of 9% to 12% and;
        - July, August and September have the *least* increase which falls in the range of 4% to 7%.
    - For the 2080s:
        - January, February, March, April, May, November and December have the *greatest* increase which falls in the range of 17% to 26%,
        - June and October have a *middle* range increase which falls which falls in the range of 11% to 14% and;
        - July, August, and September have the *least* increase which falls in the range of 5% to 10%.

7.3 COVARIANCE: TEMPERATURE AND PRECIPITATION

- The distribution ellipse shapes and orientation show a high degree of positive covariance for the future projected winter data which indicates increased temperatures in connection with increased precipitation levels.

- Compared to the other seasons, spring change values have the greatest dispersion in model output. Correlation between temperature and precipitation change range from zero to slightly negative or slightly positive. The spring correlation is not only less consistent between months but between time periods as well. Therefore, no significant interpretations can be made regarding the spring data. (See Figure B-3 in Appendix B).

- Contrarily to the winter months, the summer months are negatively correlated. While small increases in temperature tend to be associated with an increase in precipitation, model projections with larger increases in temperature tend to be associated with small changes or decrease in precipitation.

- The autumn months do not follow a consistent correlation. The correlation between temperature and precipitation range from somewhere between slightly negative to slightly positive correlation for September and October. However, November resembles the winter months with a positive correlation for all time periods.

7.4 FREQUENCY ANALYSIS: TEMPERATURE AND PRECIPITATION

To determine the probability of a given temperature or precipitation change from the various models, a frequency analysis was conducted for the 5th, 50th and 95th percentiles (see Tables D-1 and D-2). These percentiles represent the probability of a given temperature or precipitation change occurring equal to or below this value, according to the GCM projections used in this study. This analysis was conducted on the ensemble of GCMs therefore one model does not consistently produces the same percentile for each month.

For temperature (Table D-1):

- The 5th percentile of annual temperature change for the 2020s, 2050s, and 2080s on average is +0.8°C, +1.8°C and +2.4°C respectively.

- The 50th percentile of annual temperature change for the 2020s, 2050s and 2080s on average is +1.4°C, +2.8°C, and +3.9°C respectively.

- The 95th percentile of annual temperature change for the 2020s, 2050s and 2080s on average is +2.3°C, +4.1°C and +6.1°C respectively.

For precipitation (Table D-2):

- The 5th percentile of annual precipitation change for the 2020s, 2050s and 2080s on average is -1%, +3% and +5% respectively.
- The 50th percentile of annual precipitation change for the 2020s, 2050s and 2080s on average is +5%, +9% and +13% respectively.
- The 95th percentile of annual precipitation change for the 2020s, 2050s and 2080s on average is +11%, +18% and +24% respectively.

Figure E-1 shows the temperature climate scenarios summarized in line plots for the 2020s, 2050s and 2080s. Figure E-2 shows the precipitation climate scenarios for the 2020s, 2050s and 2080s. Statistics pertaining to the monthly minimum and maximum ensemble projections and historic normals in line plots are summarized in Table F-1 for temperature and in Table F-2 for precipitation.

7.5 EVAPOTRANSPIRATION

Projected changes to evapotranspiration rates are presented in Appendix H for the three future horizons. Results include an average of CRCM4.3.2 simulations and an ensemble range for each month and on an annual basis. The ensemble averages project increasing evapotranspiration for most months, however, some individual models indicate a decrease for certain months in certain future horizons. May is projected to experience the greatest increase in evapotranspiration while winter months are projected to have minimal change. The ensemble average projects annual evapotranspiration to increase with time into the 2020s, 2050s and 2080s

8 CONCLUSIONS

This study aimed at determining projections for future climate with respect to temperature and precipitation within the immediate Keeyask Generating Station study area.

An ensemble of 139 future climate scenarios were developed for three emission scenarios (A1B, A2, B1) for three future time periods 2020s, 2050s, and 2080s.

Annual climate change scenarios showed that temperature and precipitation is projected to increase with time. Results show mean temperature change of +1.5°C for the 2020s, +2.8°C for the 2050s, and +4.1°C for the 2080s. Change in annual precipitation is also likely to occur with projected mean values of 5% for the 2020s, 10% for the 2050s and 14% for the 2080s. Seasonal climate observations showed that both temperature and precipitation will generally increase with time for all seasons. Furthermore, of the four seasons, winter is likely to experience the greatest range of mean temperature change. Generally, the CRCM temperature and precipitation projections fall within the same range of the ensemble of global climate models. In addition, the CRCM simulations have projected an increase in the rates of evapotranspiration.

Acknowledgements:

We acknowledge the international modeling groups for providing their data for analysis, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modeling (WGCM) and their Coupled Model Intercomparison Project (CMIP) and Climate Simulation Panel for organizing the model data analysis activity, and the IPCC WG1 TSU for technical support and Ouranos for providing the CRCM data, technical support and document review.

9 GLOSSARY

GLOSSARY

anthropogenic	Resulting from or produced by human beings.
baseline	Reference for measurable quantities from which an alternative outcome can be measured, e.g. a non-intervention scenario used as a reference in the analysis of intervention scenarios.
climate change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.
correlation	A statistical relation between two or more variables such that systematic changes in the value of one variable are accompanied by systematic changes in the other.
covariance	A measure of the strength of the correlation between two or more sets of random variates.
dematerialization	The progression of becoming markedly less concerned with material things than with spiritual, intellectual, or cultural values.
greenhouse effect	Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the greenhouse effect.
greenhouse gas	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur

	hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).
negative covariance	Indicates that *higher* than average values of one variable tend to be paired with *lower* than average values of the other variable.
normal	The average or mean over a specific time period.
positive covariance	Indicates that *higher* than average values of one variable tend to be paired with *higher* than average values of the other variable.
projection	A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasise that projections involve assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised, and are therefore subject to substantial uncertainty.
scenario	A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline.

10 REFERENCES

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11 APPENDIX A - ABBREVIATIONS

ABBREVIATIONS

CRCM	Canadian Regional Climate Model
EIA	environmental impact assessment
GCM	Global Climate Model
GS	generating station
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
km	kilometers
RCM	Regional Climate Model
SRES	Special Report on Emissions Scenarios
WMO	World Meteorological Organization

12 APPENDIX B - GCM SCATTER PLOTS

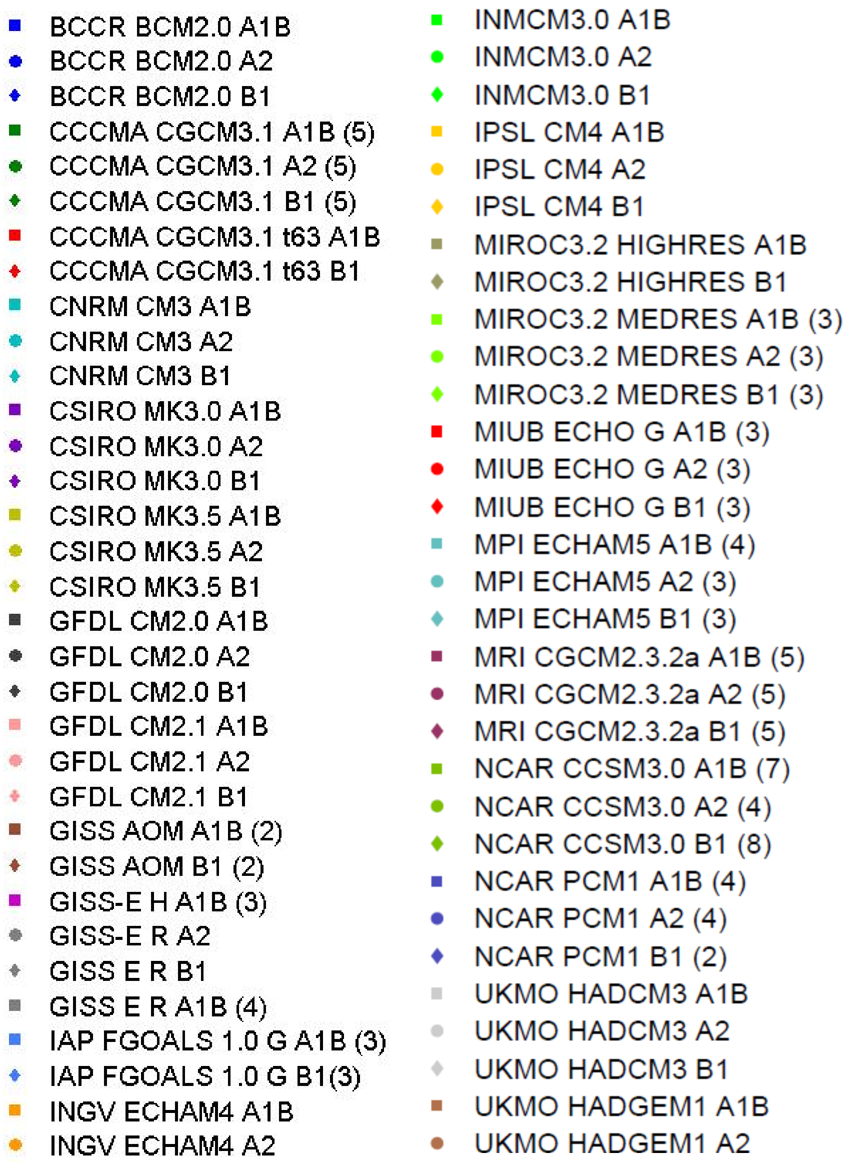

Figure B- 1: Climate Change Scenarios Legend- ( ) represent # of runs

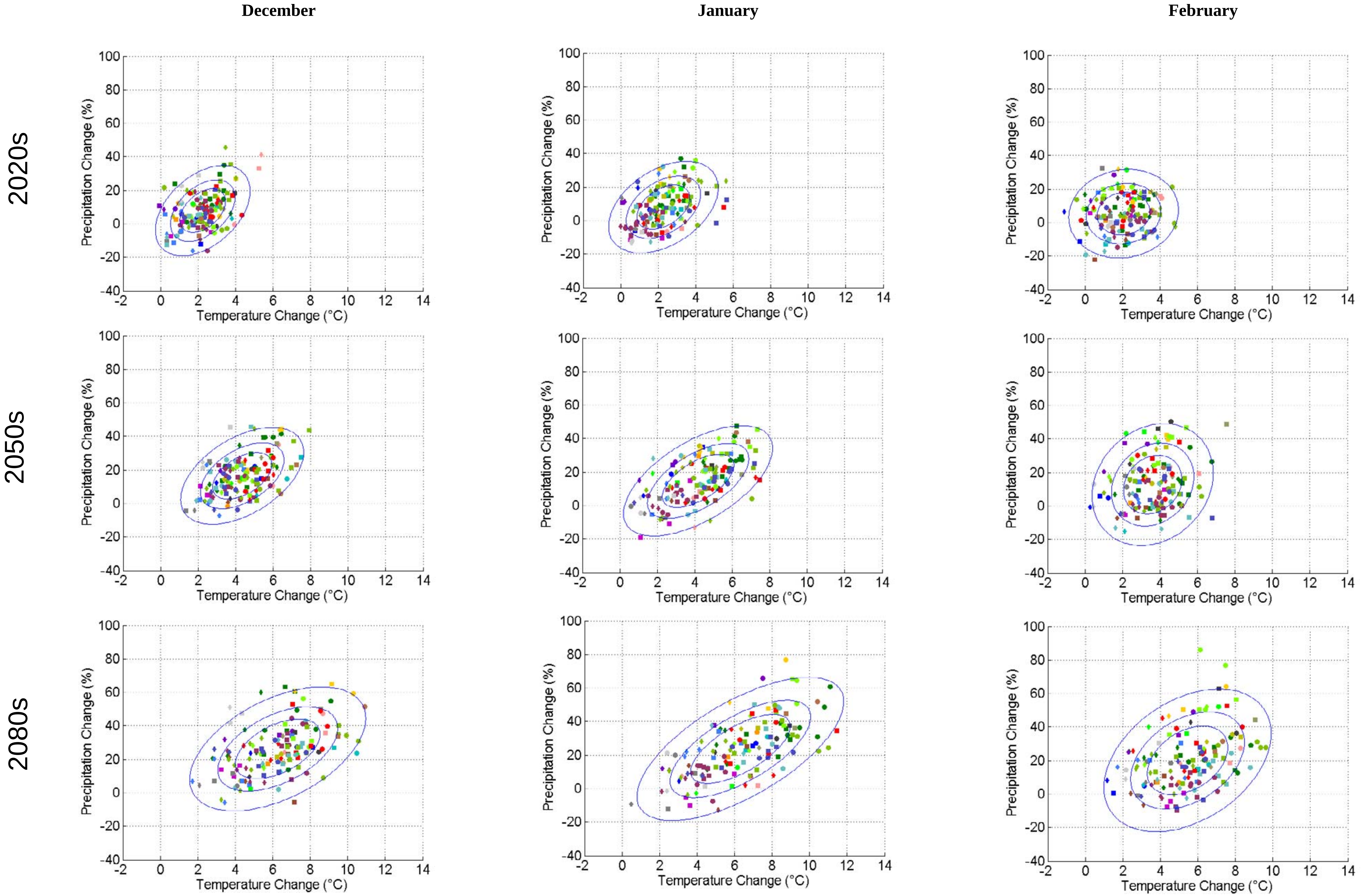

Figure B- 2: Winter Climate Change Scenarios for Keeyask

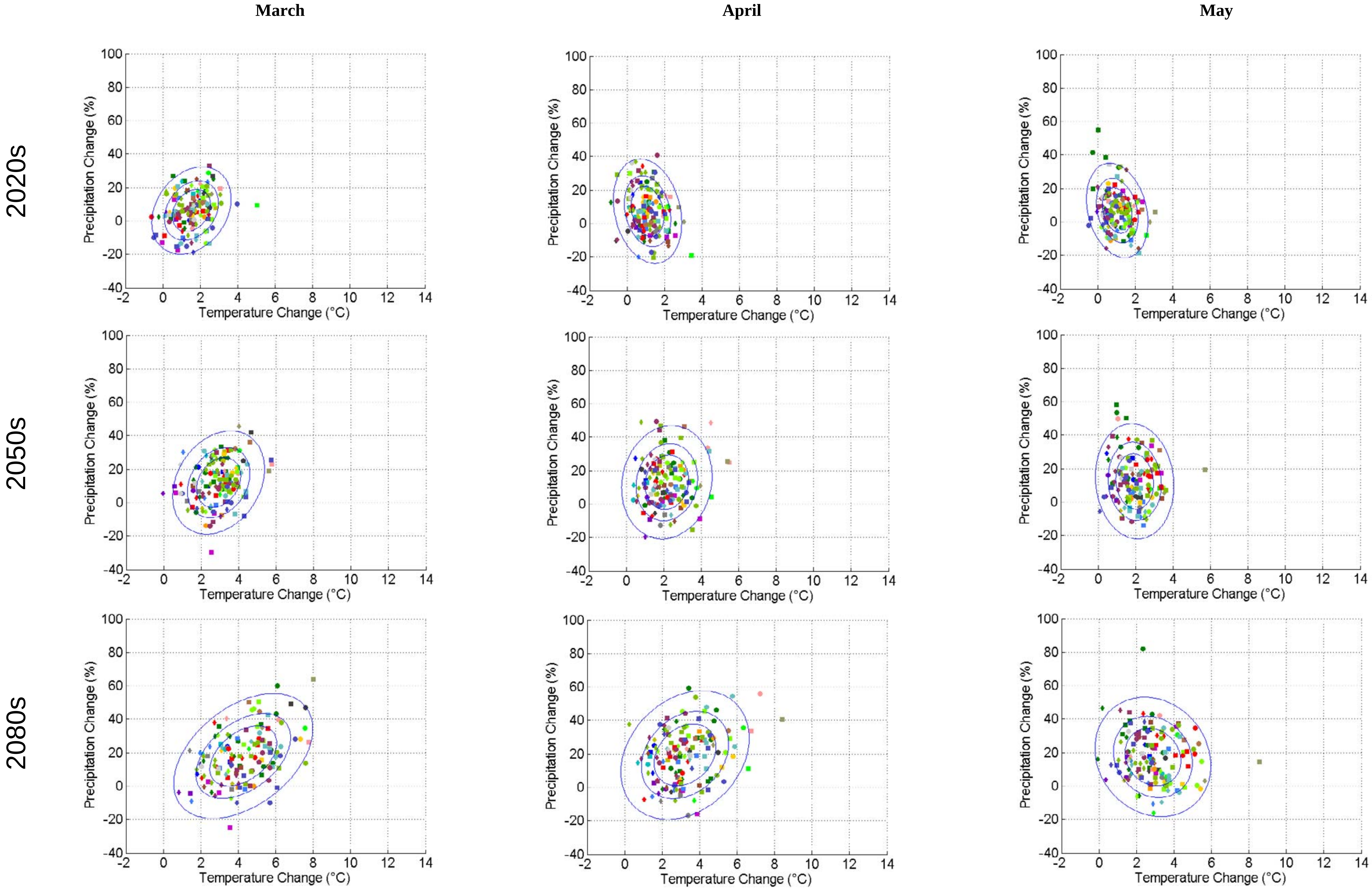

Figure B- 3: Spring Monthly Climate Change Scenarios for Keeyask

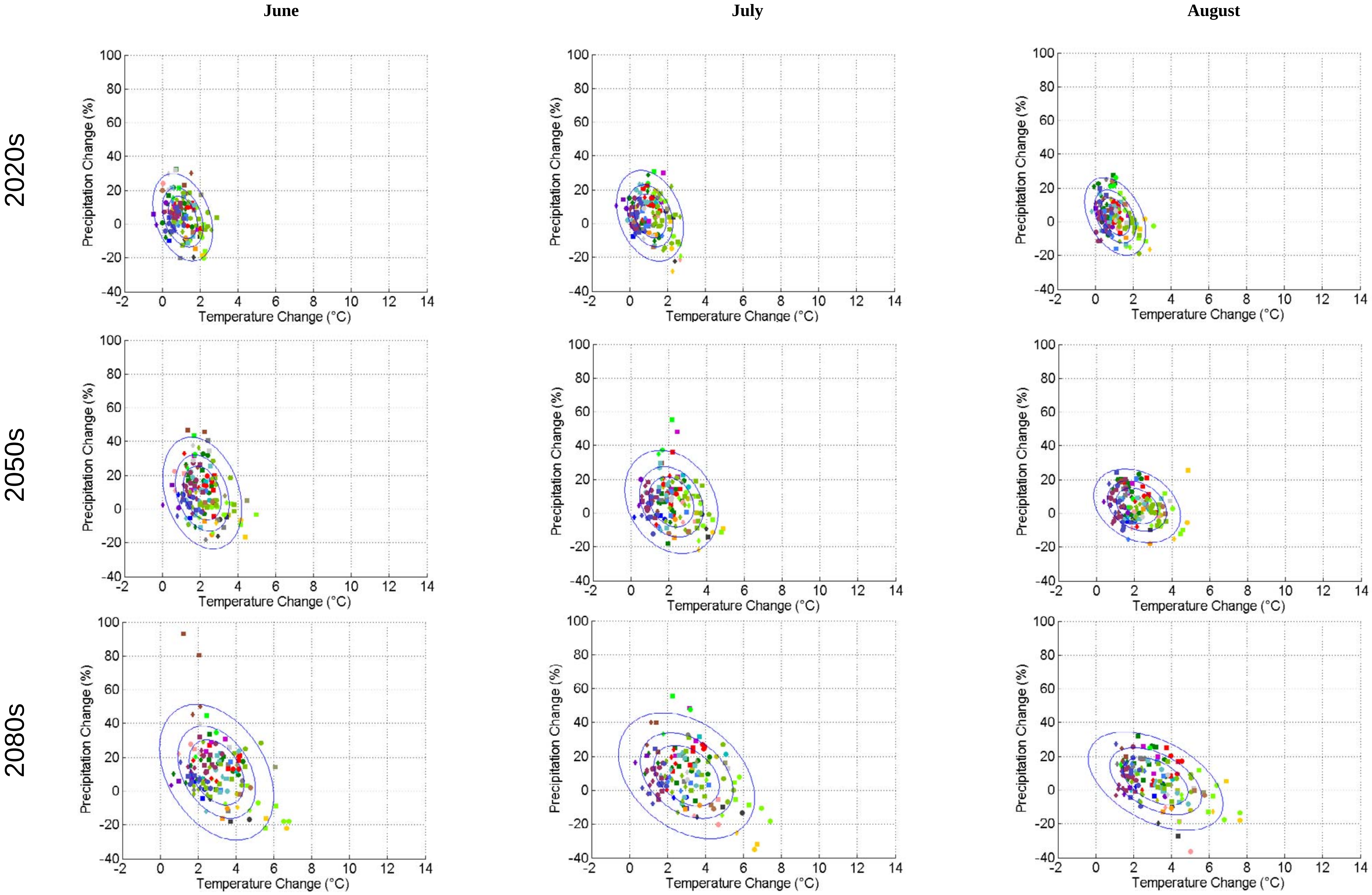

Figure B- 4: Summer Monthly Climate Change Scenarios for Keeyask

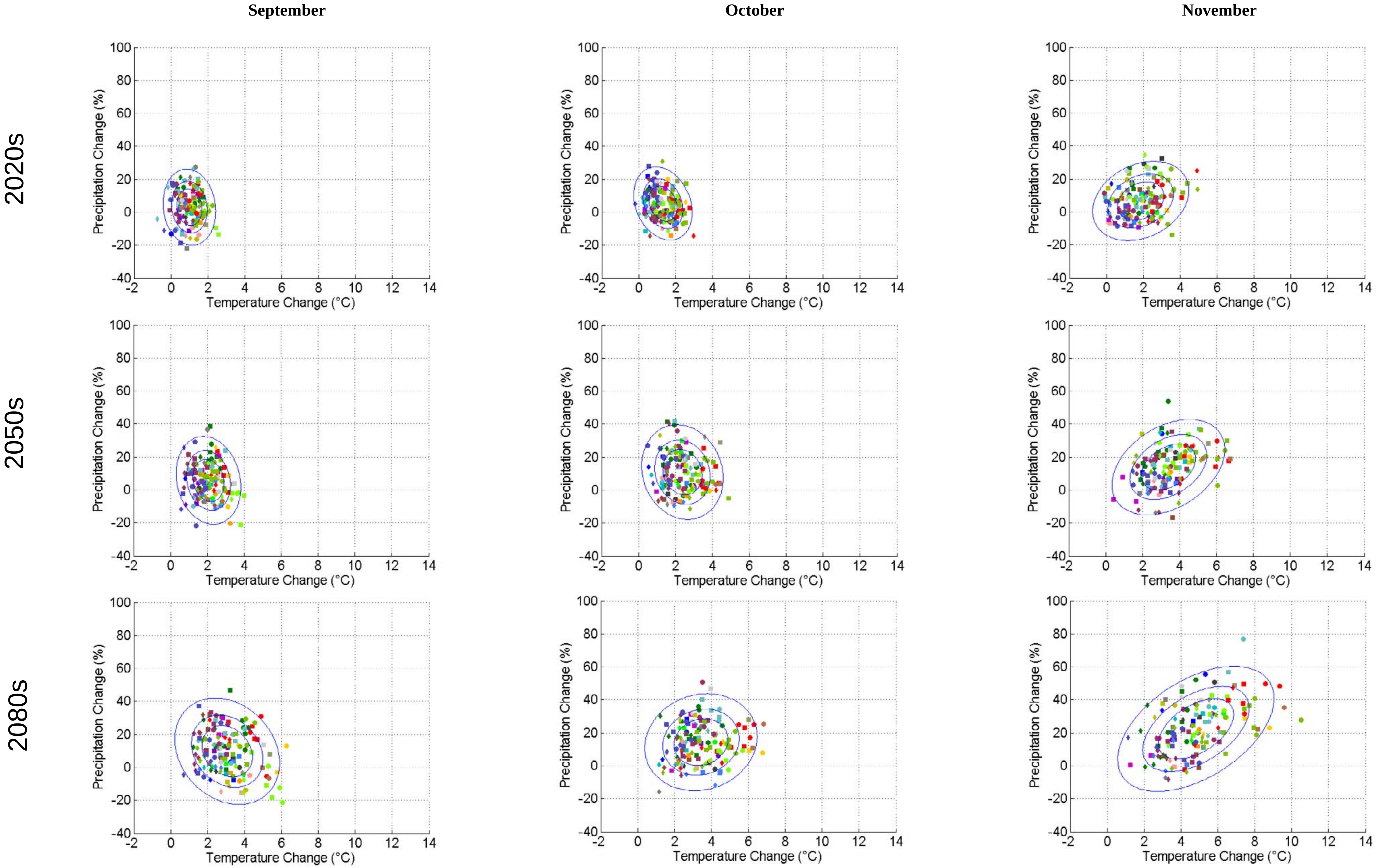

Figure B- 5: Autumn Climate Change Scenarios for Keeyask

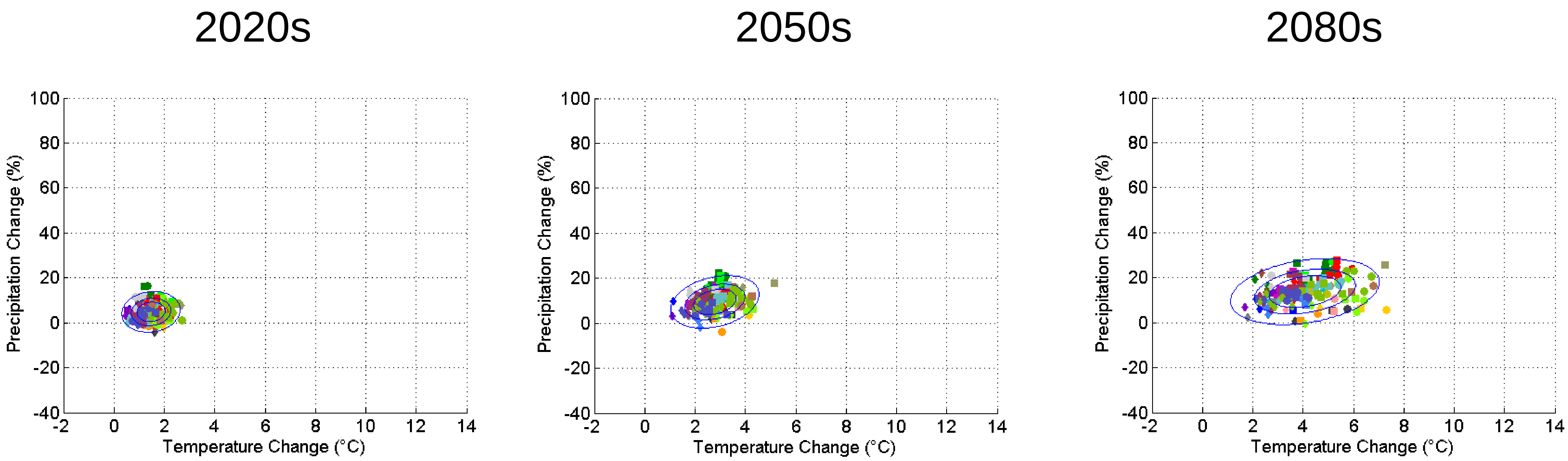

Figure B- 6: Annual Climate Change Scenarios for Keeyask

13 APPENDIX C - GCM: TEMPERATURE AND PRECIPITATION CONFIDENCE LEVEL INFORMATION

Table C- 1: Monthly GCM Temperature Adjustment Factors Distribution Level Information (ºC) for winter

Future Time Period	Confidence Level (%)	Dec				Jan		Feb		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	1.0	2.2	3.5	0.9	2.3	3.7	0.7	2.0	3.5
	75	0.5		4.0	0.3		4.3	0.1		4.0
	95	-0.3		4.8	-0.6		5.2	-0.9		5.0
2050s	50	2.8	4.3	5.9	2.3	4.2	6.1	2.1	3.6	5.2
	75	2.1		6.6	1.5		6.9	1.4		5.8
	95	1.1		7.6	0.2		8.1	0.4		6.8
2080s	50	4.0	6.3	8.5	3.7	6.3	9.0	3.3	5.4	7.6
	75	3.1		9.5	2.6		10.1	2.4		8.5
	95	1.6		11.0	0.8		11.8	1.0		9.9

Table C- 2: Monthly GCM Temperature Adjustment Factors Distribution Level Information (ºC) for spring

Future Time Period	Confidence Level (%)	Mar			Apr			May		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	0.5	1.5	2.5	0.2	1.1	2.0	0.3	1.0	1.8
	75	0.1		3.0	-0.1		2.3	-0.1		2.2
	95	-0.6		3.6	-0.7		2.9	-0.6		2.7
2050s	50	1.8	2.9	4.1	1.0	2.2	3.3	0.9	1.9	3.0
	75	1.3		4.6	0.5		3.8	0.5		3.4
	95	0.5		5.4	-0.2		4.6	-0.1		4.0
2080s	50	2.5	4.3	6.1	1.6	3.2	4.9	1.4	2.9	4.4
	75	1.7		6.8	0.9		5.6	0.8		5.0
	95	0.6		8.0	-0.2		6.6	-0.2		6.0

Table C- 3: Monthly GCM Temperature Adjustment Factors Distribution Level Information (ºC) for summer

Future Time Period	Confidence Level (%)	Jun				Jul		Aug		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	0.3	1.1	1.8	0.2	1.1	1.9	0.3	1.0	1.8
	75	0.0		2.2	-0.1		2.3	0.0		2.2
	95	-0.5		2.7	-0.7		2.8	-0.6		2.7
2050s	50	1.1	2.1	3.1	1.0	2.1	3.3	1.0	2.1	3.3
	75	0.7		3.5	0.5		3.8	0.6		3.7
	95	0.0		4.2	-0.3		4.6	-0.1		4.4
2080s	50	1.5	3.0	4.4	1.3	3.0	4.7	1.5	3.2	4.9
	75	0.9		5.0	0.6		5.5	0.7		5.6
	95	0.0		6.0	-0.6		6.6	-0.4		6.7

Table C- 4: Monthly GCM Temperature Adjustment Factors (ºC) Distribution Level Information for autumn

Future Time Period	Confidence Level (%)	Sep				Oct		Nov		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	0.3	1.0	1.7	0.6	1.3	2.1	0.6	1.9	3.1
	75	0.0		2.0	0.2		2.4	0.1		3.6
	95	-0.4		2.4	-0.3		2.9	-0.7		4.5
2050s	50	1.2	2.1	2.9	1.3	2.4	3.4	1.9	3.4	4.9
	75	0.9		3.3	0.9		3.9	1.3		5.5
	95	0.3		3.8	0.2		4.6	0.3		6.5
2080s	50	1.7	3.0	4.4	2.0	3.4	4.9	2.8	4.8	6.8
	75	1.1		5.0	1.4		5.5	1.9		7.7
	95	0.2		5.9	0.4		6.5	0.6		9.0

Table C- 5: Monthly GCM Precipitation Adjustment Factors Distribution Level Information (%) for winter

Future Time Period	Confidence Level (%)	Dec				Jan		Feb		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	-5	8	21	-5	8	21	-7	5	18
	75	-10		26	-11		27	-13		23
	95	-19		35	-19		35	-21		32
2050s	50	3	17	30	-1	15	31	-5	13	30
	75	-3		36	-8		37	-12		38
	95	-12		45	-18		48	-24		49
2080s	50	8	26	44	3	24	44	0	20	41
	75	1		51	-5		53	-9		49
	95	-11		63	-19		66	-22		63

Table C- 6: Monthly GCM Precipitation Adjustment Factors Distribution Level Information (%) for spring

Future Time Period	Confidence Level (%)	Mar				Apr		May		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	-6	6	19	-8	7	22	-7	7	20
	75	-12		24	-14		29	-12		26
	95	-20		32	-24		39	-21		35
2050s	50	-3	12	27	-3	13	29	-4	12	29
	75	-9		33	-10		36	-11		36
	95	-19		43	-21		47	-22		47
2080s	50	0	18	36	1	19	38	0	17	35
	75	-7		43	-7		45	-7		42
	95	-19		55	-19		58	-18		53

Table C- 7: Monthly GCM Precipitation Adjustment Factors Distribution Level Information (%) for summer

Future Time Period	Confidence Level (%)	Jun				Jul		Aug		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	-8	4	16	-8	5	18	-8	3	14
	75	-14		22	-14		23	-13		19
	95	-22		30	-22		31	-20		26
2050s	50	-7	9	25	-8	7	21	-6	4	15
	75	-13		32	-14		27	-10		19
	95	-24		43	-24		37	-17		26
2080s	50	-8	11	30	-9	9	26	-9	5	19
	75	-16		38	-17		34	-15		25
	95	-29		51	-29		46	-24		34

Table C- 8: Monthly GCM Precipitation Adjustment Factors Distribution Level Information (%) for autumn

Future Time Period	Confidence Level (%)	Sep				Oct		Nov		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2020s	50	-8	3	14	-5	5	16	-5	7	18
	75	-13		19	-10		20	-10		23
	95	-20		26	-17		27	-17		31
2050s	50	-7	6	19	-3	11	25	0	14	28
	75	-12		24	-9		30	-6		34
	95	-21		32	-18		40	-15		43
2080s	50	-6	10	25	0	14	28	4	22	41
	75	-12		32	-6		34	-3		48
	95	-22		42	-15		44	-16		60

Table C- 9: Annual GCM Precipitation and Temperature Adjustment Factors Distribution Level Information (%)

Future Time Period	Confidence Level (%)	Temperature Change (ºC)			Precipitation Change (%)		
		Min	Mean	Max	Min	Mean	Max
2020s	50	0.9	1.5	2.0	0	5	9
	75	0.7		2.3	-1		11
	95	0.3		2.6	-4		14
2050s	50	1.9	2.8	3.6	4	10	15
	75	1.6		4.0	2		17
	95	1.0		4.5	-2		21
2080s	50	2.6	4.1	5.5	7	14	21
	75	2.1		6.1	4		24
	95	1.1		7.0	-1		28

14 APPENDIX D - GCM FREQUENCY ANALYSIS ON ADJUSTMENT FACTORS

Table D- 1: Monthly GCM Temperature Frequency Analysis on Adjustment Factors (°C)

Month	**5th Percentile**			**50th Percentile**			**95th Percentile**		
	2020s	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
January	0.5	1.3	2.5	2.1	4.4	6.4	4.2	7.0	9.6
February	0.0	1.3	2.4	2.1	3.8	5.5	3.9	5.6	8.3
March	0.2	1.0	2.0	1.6	3.0	4.1	2.7	4.4	6.8
April	0.0	0.8	1.3	1.0	2.0	3.0	2.2	4.0	5.7
May	0.0	0.7	1.1	1.0	1.8	2.8	2.2	3.4	5.1
June	0.2	1.0	1.5	1.0	2.0	2.7	2.2	3.7	5.3
July	0.1	0.8	1.0	1.0	2.0	2.9	2.4	3.8	5.7
August	0.2	0.8	1.4	1.0	2.0	3.1	2.3	3.7	6.0
September	0.1	0.9	1.5	1.0	2.0	3.0	1.9	3.3	5.3
October	0.4	1.2	1.6	1.2	2.3	3.3	2.4	4.1	5.8
November	0.2	1.7	2.5	1.8	3.2	4.7	3.6	6.0	8.0
December	0.4	2.4	3.3	2.3	4.3	6.5	3.9	6.4	9.5
Annual	0.8	1.8	2.4	1.4	2.8	3.9	2.3	4.1	6.1

Table D- 2: Monthly GCM Precipitation Frequency Analysis on Adjustment Factors (%)

Month	**5th Percentile**			**50th Percentile**			**95th Percentile**		
	2020s	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**	**2020s**	**2050s**	**2080s**
January	-9	-7	-3	8	15	22	28	36	51
February	-12	-7	-3	5	11	18	21	42	52
March	-13	-8	-4	6	11	18	24	31	46
April	-11	-8	-5	7	11	21	31	38	45
May	-10	-9	-3	6	11	16	27	38	39
June	-13	-11	-16	4	9	9	21	33	34
July	-14	-11	-15	4	7	9	22	27	32
August	-12	-9	-14	2	4	6	21	20	25
September	-13	-10	-12	3	5	10	18	23	30
October	-8	-6	-4	5	9	13	20	31	33
November	-7	-3	-1	6	14	20	26	34	49
December	-8	1	4	7	15	24	27	40	55
Annual	-1	3	5	5	9	13	11	18	24

15 APPENDIX E - GCM CLIMATE SCENARIOS LINE PLOTS

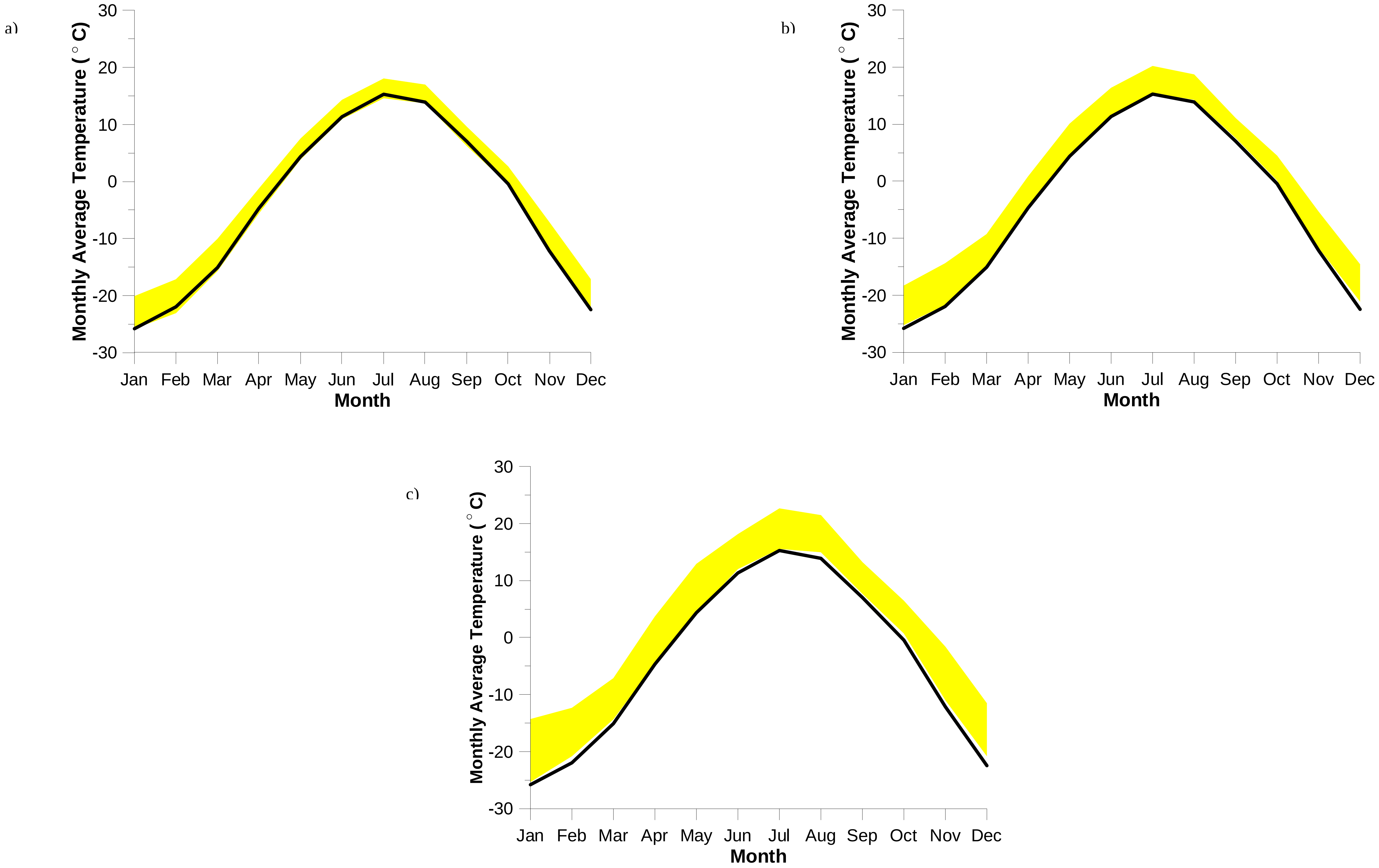

Figure E- 1: Monthly Average Keeyask Temperature from GCM Climate Scenarios Ensemble for (a) 2020s (b) 2050s (c) 2080s

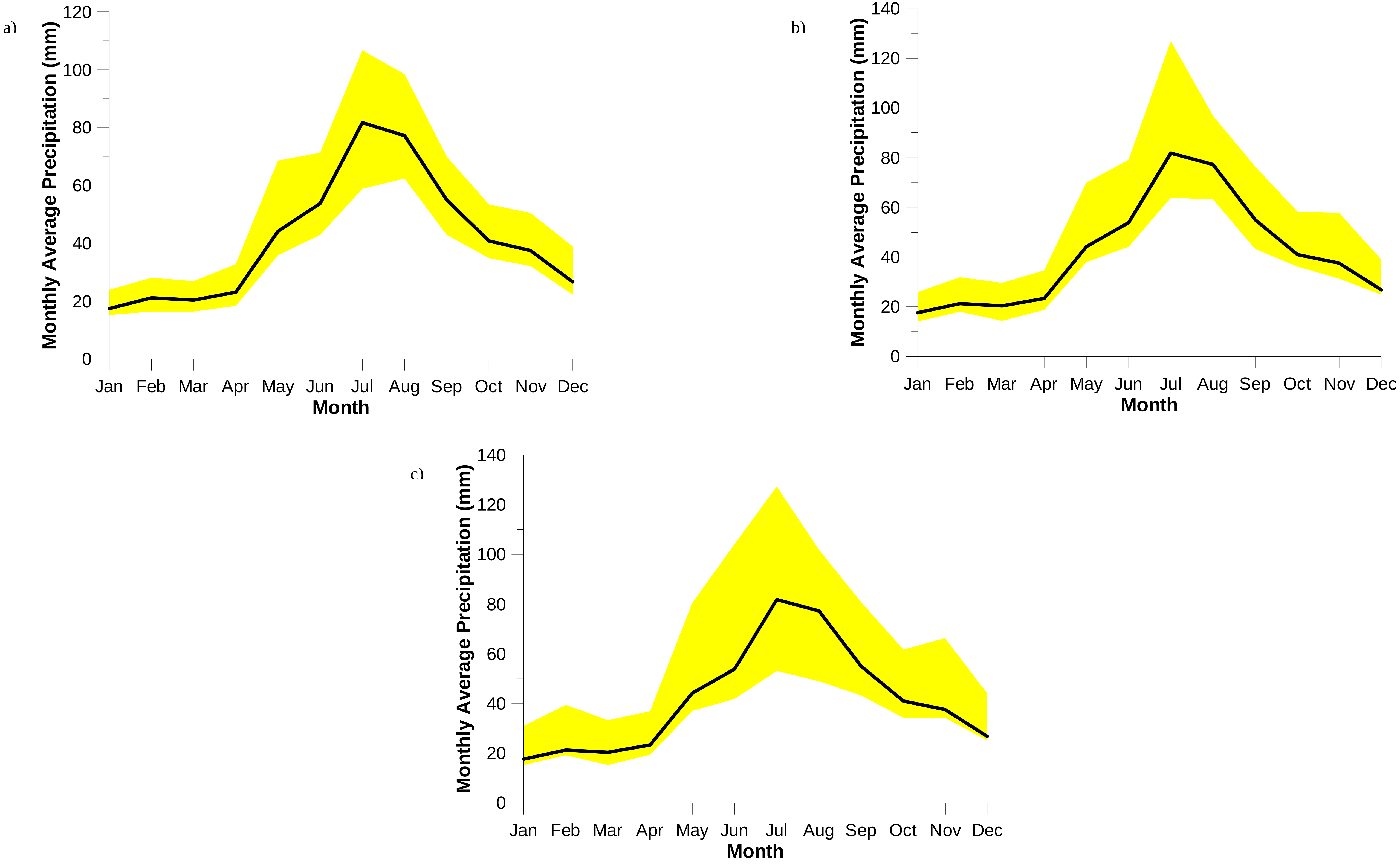

Figure E- 2: Monthly Average Keeyask Precipitation from GCM Climate Scenarios Ensemble for (a) 2020s (b) 2050s (c) 2080s

16 APPENDIX F - DIFFERENCES BETWEEN CURRENT CLIMATE AT GILLAM A. AND FUTURE GCM CLIMATE SCENARIOS

Table F- 1: Minimum and Maximum Ensemble GCM Temperature Projections Compared to Historic Normals (°C)

	2020 GCM Ensemble Minimum	*Historic Normals*	2020 GCM Ensemble Maximum	2050 GCM Ensemble Minimum	*Historic Normals*	2050 GCM Ensemble Maximum	2080 GCM Ensemble Minimum	*Historic Normals*	2080 GCM Ensemble Maximum
January	-25.8	*-25.8*	-20.1	-25.2	*-25.8*	-18.3	-25.3	*-25.8*	-14.3
February	-23.1	*-22.0*	-17.2	-21.7	*-22.0*	-14.4	-20.8	*-22.0*	-12.4
March	-15.7	*-15.1*	-10.0	-15.1	*-15.1*	-9.3	-14.3	*-15.1*	-7.1
April	-5.5	*-4.7*	-1.3	-4.3	*-4.7*	0.8	-4.4	*-4.7*	3.7
May	3.9	*4.4*	7.5	4.5	*4.4*	10.1	4.4	*4.4*	13.0
June	11.0	*11.4*	14.3	11.5	*11.4*	16.4	12.0	*11.4*	18.2
July	14.6	*15.3*	18.0	15.5	*15.3*	20.2	15.6	*15.3*	22.7
August	13.7	*13.9*	17.0	14.3	*13.9*	18.8	15.0	*13.9*	21.5
September	6.3	*7.0*	9.6	7.6	*7.0*	11.0	7.7	*7.0*	13.3
October	-0.6	*-0.4*	2.6	0.1	*-0.4*	4.5	0.8	*-0.4*	6.4
November	-12.2	*-12.1*	-7.1	-11.7	*-12.1*	-5.3	-11.0	*-12.1*	-1.6
December	-22.6	*-22.5*	-17.1	-21.1	*-22.5*	-14.6	-20.8	*-22.5*	-11.6

Table F- 2: Minimum and Maximum Ensemble GCM Precipitation Projections Compared to Historic Normals (mm)

	2020 GCM Ensemble Minimum	*Historic Normals*	2020 GCM Ensemble Maximum	2050 GCM Ensemble Minimum	*Historic Normals*	2050 GCM Ensemble Maximum	2080 GCM Ensemble Minimum	*Historic Normals*	2080 GCM Ensemble Maximum
January	15	*18*	24	14	*18*	26	15	*18*	31
February	16	*21*	28	18	*21*	32	19	*21*	39
March	16	*20*	27	14	*20*	30	15	*20*	33
April	18	*23*	33	19	*23*	35	19	*23*	37
May	36	*44*	68	38	*44*	70	37	*44*	80
June	43	*54*	71	44	*54*	79	42	*54*	104
July	59	*82*	107	64	*82*	127	53	*82*	127
August	62	*77*	98	63	*77*	97	49	*77*	102
September	43	*55*	70	43	*55*	76	43	*55*	81
October	35	*41*	53	36	*41*	58	34	*41*	62
November	32	*38*	50	31	*38*	58	34	*38*	66
December	22	*27*	39	25	*27*	39	25	*27*	44

17 APPENDIX G - CRCM SCATTER PLOTS

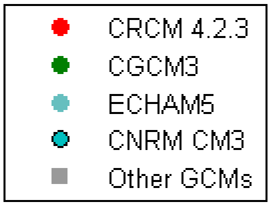

Figure G- 1: Canadian Regional Climate Model Scatter Plot Legend

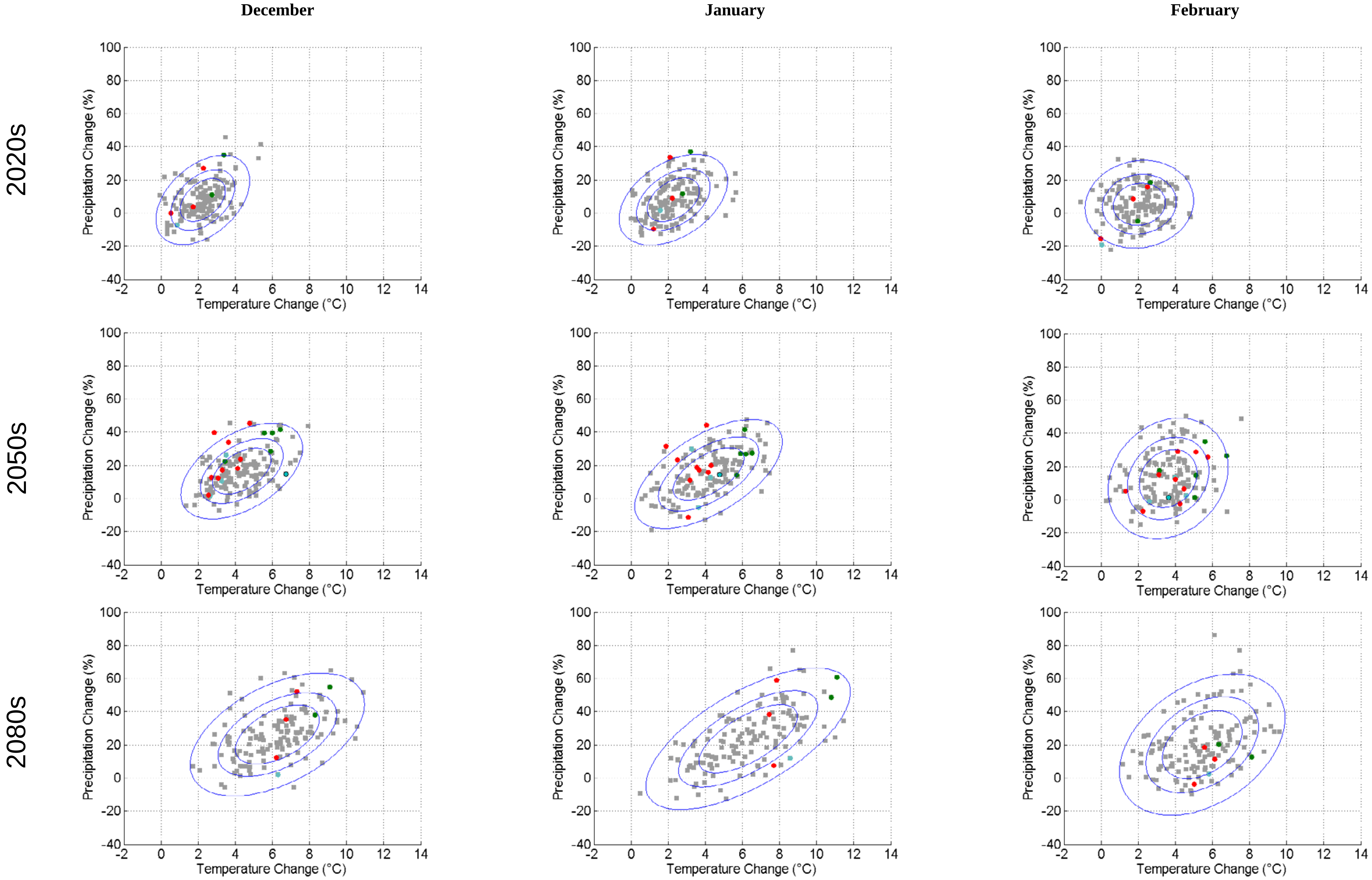

Figure G- 2: Winter CRCM Climate Change Scenarios for Keeyask

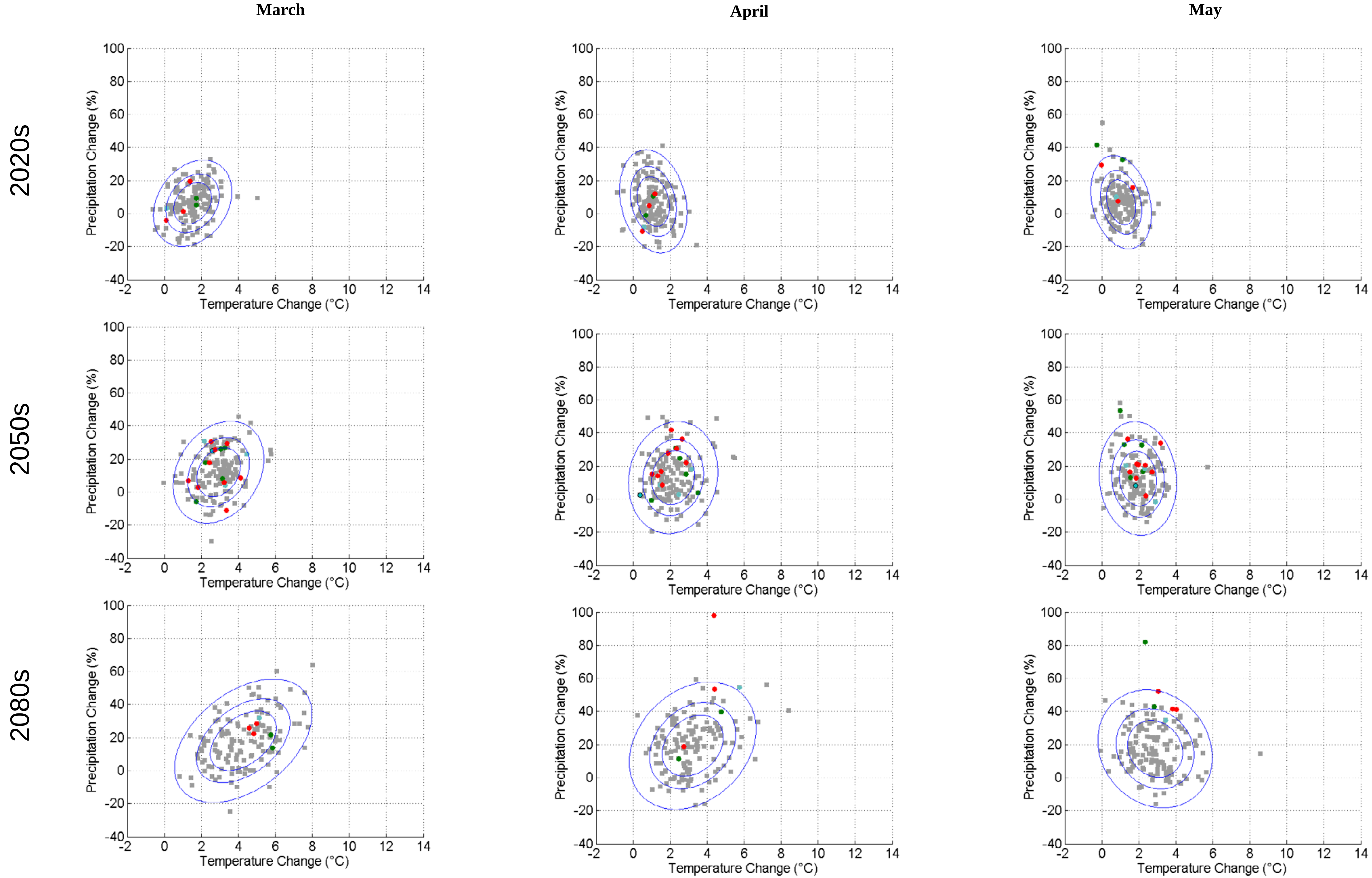

Figure G- 3: Spring CRCM Climate Change Scenarios for Keeyask

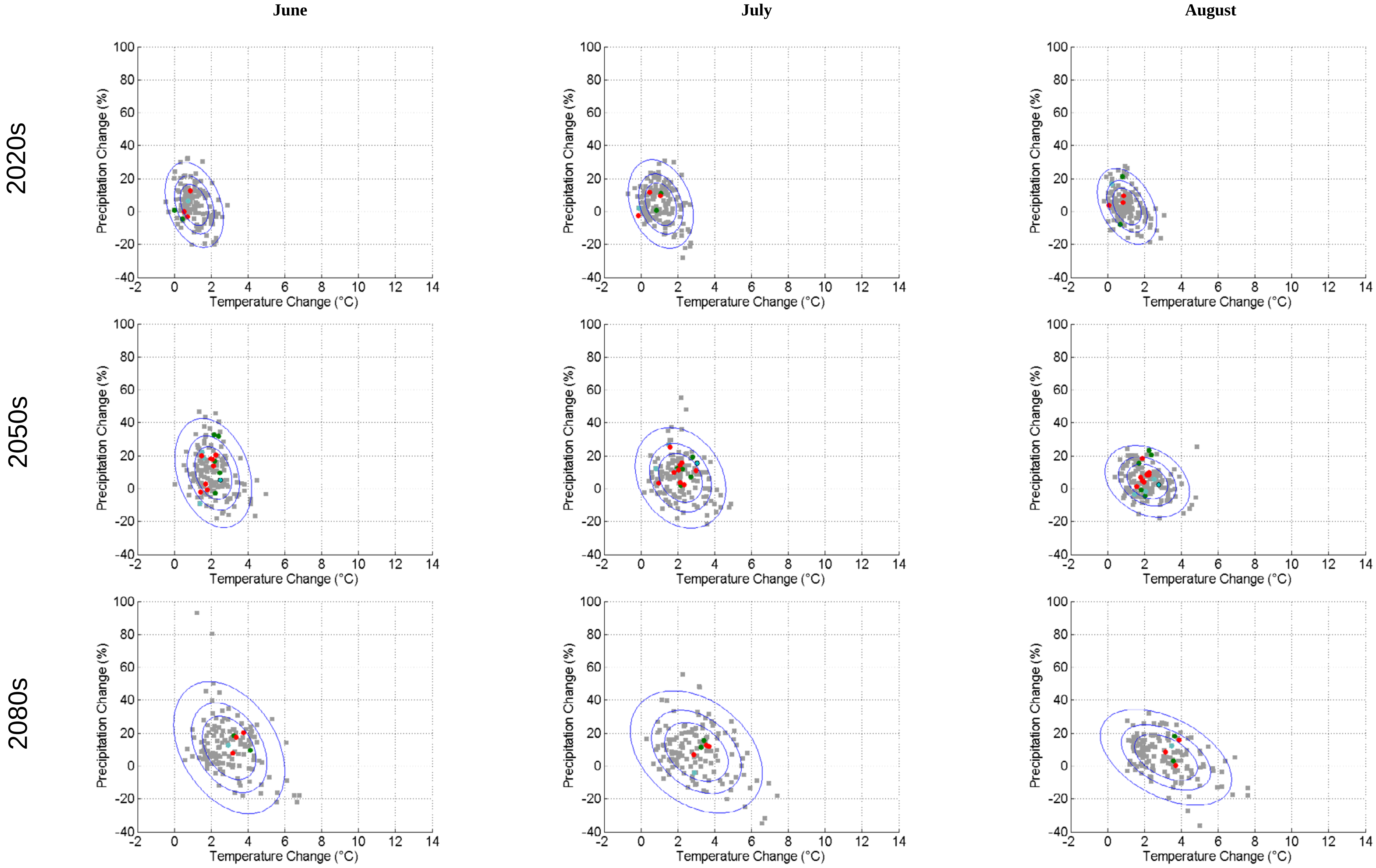

Figure G- 4: Summer CRCM Climate Change Scenarios for Keeyask

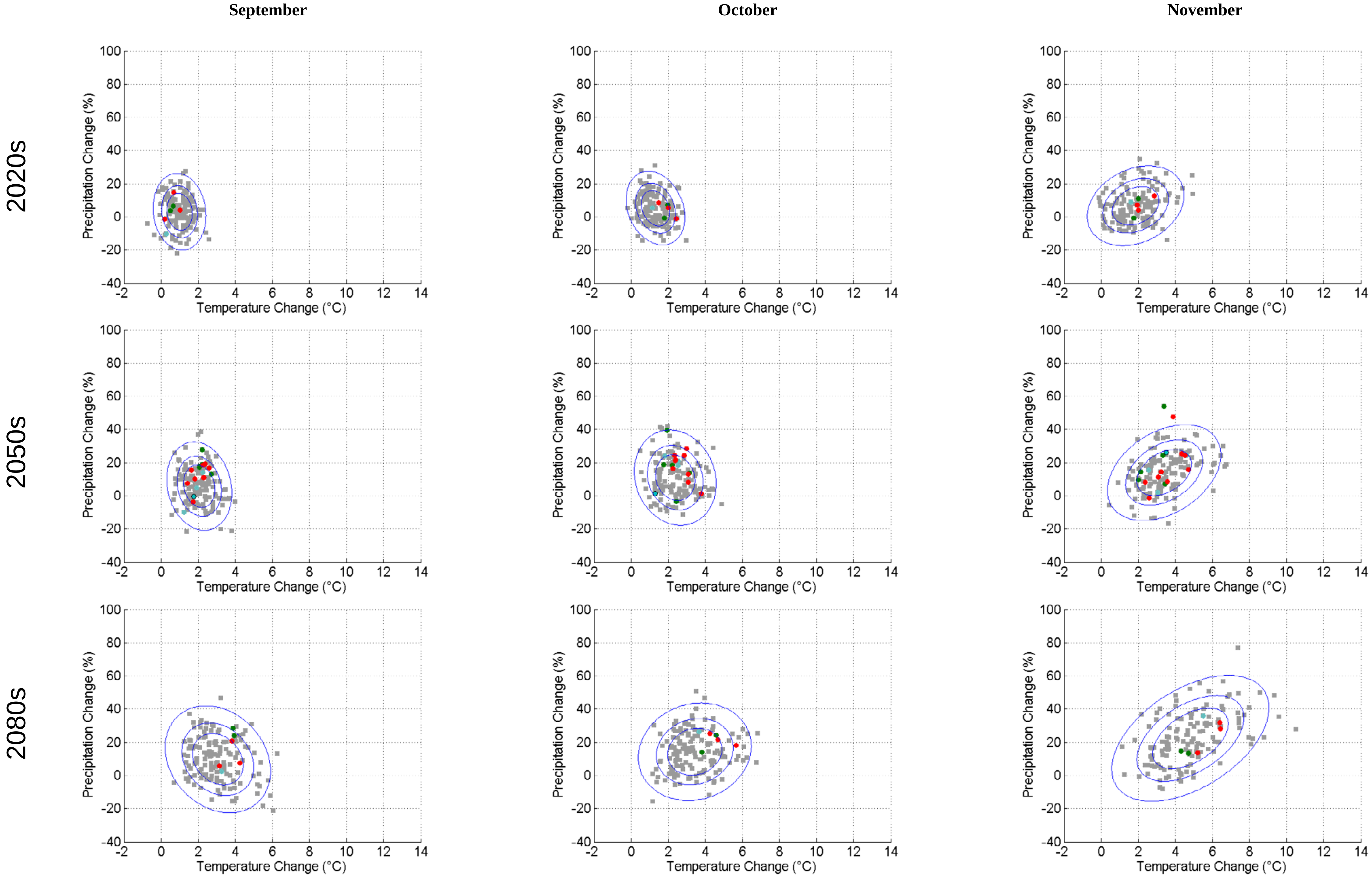

Figure G- 5: Autumn CRCM Climate Change Scenarios for Keeyask

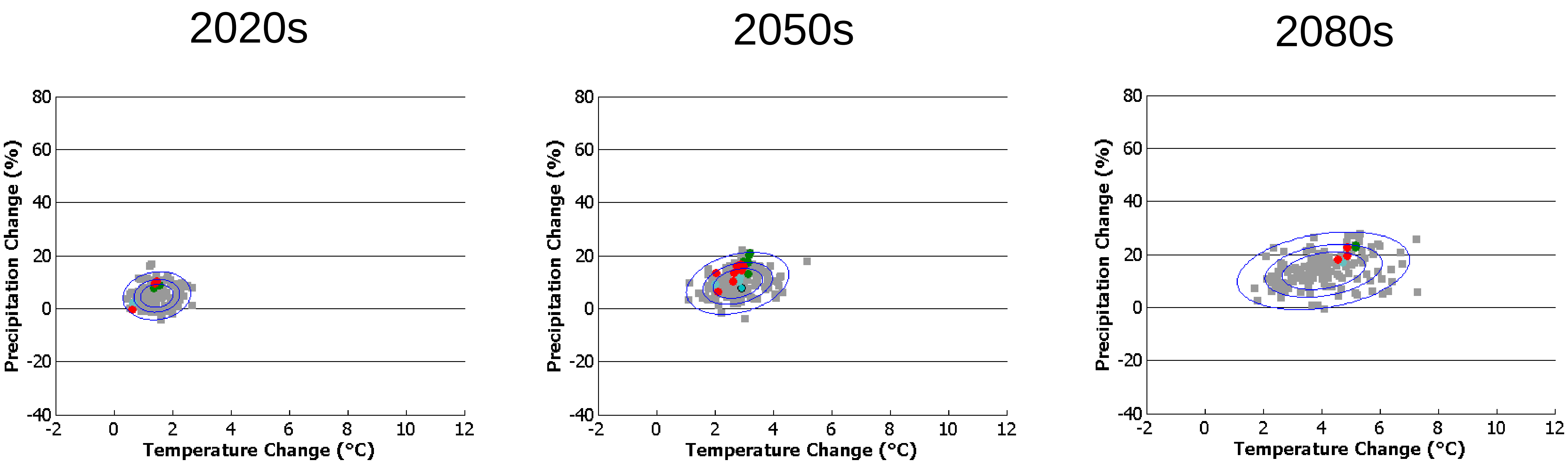

Figure G- 6: Annual CRCM Climate Change Scenarios for Keeyask

18 APPENDIX H:CRCM EVAPOTRANSPIRATION RESULTS

The evapotranspiration data presented in this appendix are calculated from CRCM4.2.3 runs. Values are presented as changes in mm/month and mm/year, rounded to one decimal point. Supporting information on CRCM4.2.3 evapotranspiration data is provided below:

CRCM4.2.3 computes evapotranspiration in units of $kg/m^2{\cdot}s$ as an upward moisture flux from the surface into the atmosphere. While the CRCM4.2.3 utilizes a separate calculation for evaporation over oceans and lakes, the only inland lakes considered in the model is the Great Lakes system. Other grid points that fall over inland lakes are artificially assigned a "land" classification. The grid points in the Keeyask study area are classified as land and a lumped evapotranspiration term is calculated. The lumped term includes;

- evaporation over bare ground,
- water extraction from the surface layer due to transpiration,
- sublimation rate from snow cover,
- sublimation rate of frozen water from vegetation,
- evaporation rate of liquid water from vegetation.

Complex parameterizations are used to describe the above terms, such as soil, aerodynamic and bulk stomatal resistances. The evapotranspiration rate is calculated simultaneously with the evolution of all other surface energy fluxes. The surface energy budget equation is resolved iteratively to derive the surface temperature, which is then used to calculate evapotranspiration. This method limits the surface evapotranspiration by the energy immediately available at the surface.

Since baseline measurements are not available, it is difficult to determine the model's accuracy in predicting evapotranspiration. Using the Hydrological Atlas of Canada - Water Balance Map as a reference (G. den Hartog, 1975), CRCM4.2.3 appears to slightly over predict annual evapotranspiration rates. The over prediction is perhaps an indication of bias in the model which should be considered when interpreting and using the data.

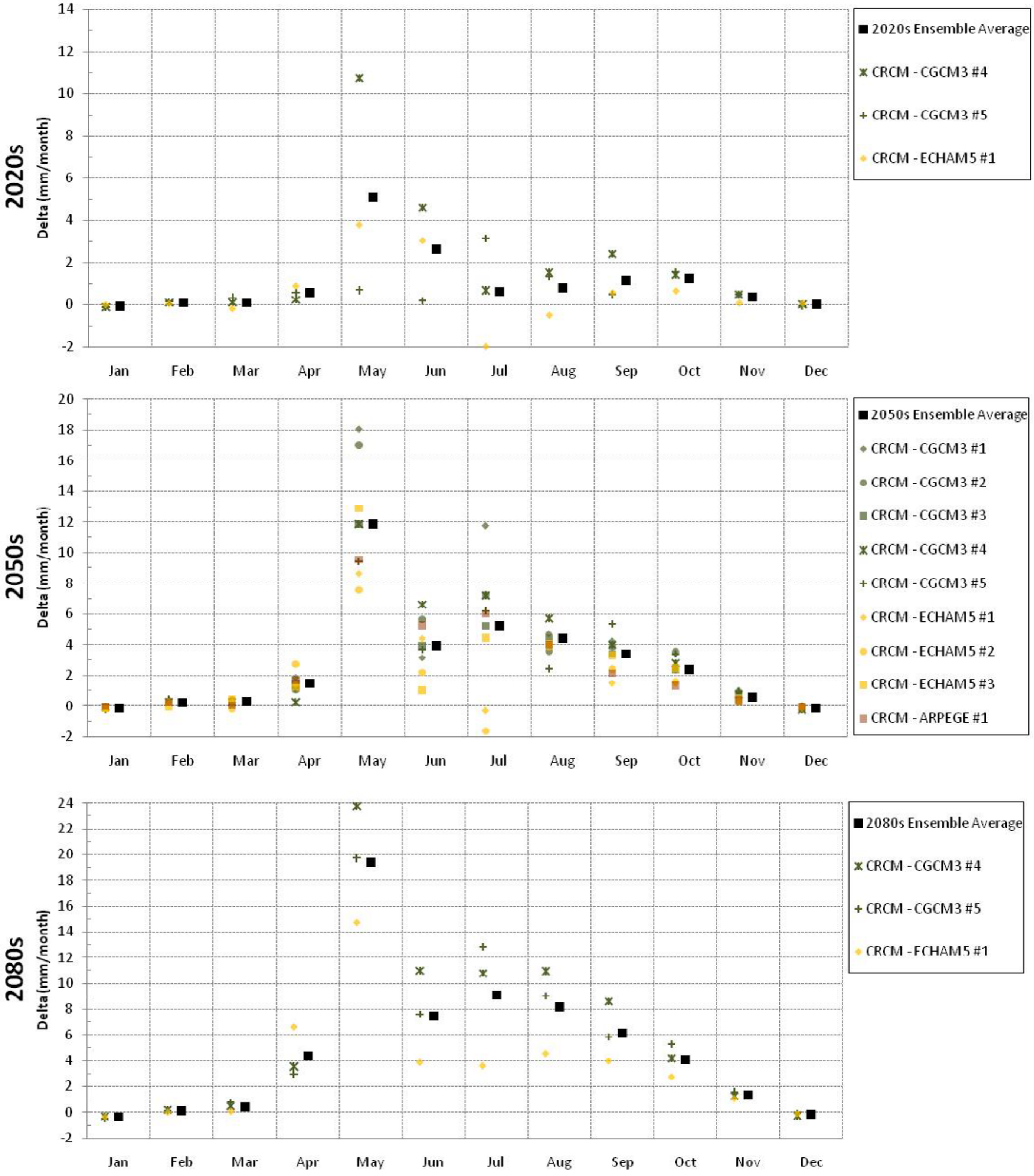

Figure H- 1: Evapotranspiration Deltas 2020s (top) 2050s (middle) 2080s (bottom)

Table H- 1: Monthly Changes to Evapotranspiration

	Ensemble Evapotranspiration Changes (mm/month)								
	2020s			2050s			2080s		
Month	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
January	-0.1	-0.1	0.0	-0.3	-0.2	0.0	-0.5	-0.4	-0.3
February	0.0	0.1	0.2	-0.1	0.2	0.5	0.0	0.1	0.2
March	-0.2	0.1	0.3	-0.2	0.3	0.7	0.1	0.4	0.7
April	0.2	0.6	0.9	0.3	1.5	2.7	3.0	4.4	6.6
May	0.7	5.1	10.7	7.6	11.9	18.1	14.7	19.4	23.8
June	0.2	2.6	4.6	1.0	3.9	6.6	3.9	7.5	11.0
July	-2.0	0.6	3.1	-1.6	5.2	11.8	3.6	9.1	12.8
August	-0.5	0.8	1.5	2.4	4.4	7.1	4.6	8.2	11.0
September	0.5	1.2	2.4	1.5	3.4	5.3	4.0	6.1	8.6
October	0.7	1.2	1.6	1.3	2.4	3.5	2.8	4.1	5.3
November	0.1	0.4	0.5	0.3	0.6	1.0	1.1	1.3	1.6
December	-0.1	0.0	0.1	-0.3	-0.1	0.0	-0.2	-0.1	-0.1

Table H- 2: Ensemble Average: Annual Changes to Evapotranspiration

	2020s	**2050s**	**2080s**
Annual Average (mm/month)	1.0	2.8	5.0
Annual (mm/year)	12.5	33.3	60.1