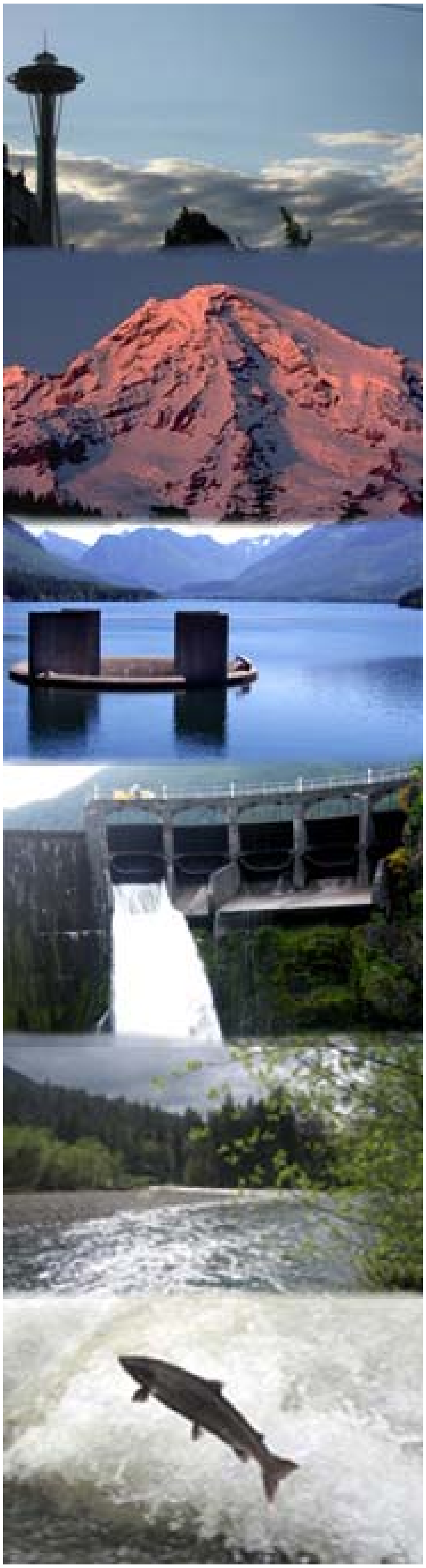

Technical Memorandum #4: Approach for Developing Climate Impacted Meteorological Data and its Quality Assurance/Quality Control

Prepared for:

Climate Change Technical Committee

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The report benefited from the committee members, including:

Member	**Affiliation**
Jane Lamensdorf-Bucher	King County Department of Natural Resources and Parks – Committee Chair
James Battin	NOAA
Geoff Clayton	Woodinville Water District Commissioner, Position 4
Holly Coccoli	Muckleshoot Tribe
Jefferson Davis	City of Kent
Paul Fleming	Seattle Public Utilities
Paul Hickey	Tacoma Water
Joan Kersnar	Seattle Public Utilities
Erin Leonhart	City of Kirkland
Maher Maher	Steward and Associates
Bruce Meaker	Snohomish PUD
Jim Miller	City of Everett
Phil Mote	University of Washington, Speaker
Steve Nelson	RH2 Engineering
Kelly Peterson	City of Kent
Jim Simmonds	King County Department of Natural Resources and Parks
Amy Snover	University of Washington, Principal, Climate Impacts Group
Chris Thorn	City of Auburn
Kurt Unger	Washington State Department of Ecology
Seshu Vaddey	US Army Corps of Engineers
Lara Whitely Binder	University of Washington, Climate Impacts Group
Facilitator and Technical Support Staff	
Tamie Kellogg	Committee Facilitator – Kellogg Consulting
Richard Palmer	Technical Lead, University of Washington, Principal Climate Impacts Group
Eset Alemu	Technical Support Staff, University of Washington
Donee Alexander	Technical Support Staff, University of Washington
Ben Enfield	Technical Support Staff, University of Washington
Kathleen King	Technical Support Staff, University of Washington
Courtney O'Neill	Technical Support Staff, University of Washington
Austin Polebitski	Technical Support Staff, University of Washington
Lee Traynham	Technical Support Staff, University of Washington
Matthew Wiley	Technical Support Staff, University of Washington

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Technical Memorandum #4
Approach for Developing Climate Impacted Meteorological Data and its Quality Assurance/Quality Control

Summary of Findings

This technical memo details the process of downscaling metrological data generated by General Circulation Models (GCMs) and evaluates the potential use of these data in evaluating the impacts of climate change in the Puget Sound. Comparison of the simulated Year 2000 period to the historic record reveals good overall agreement, though some minor challenges exist and are detailed. The downscaling method generates projections of base and future scenarios that are usable in detailed water resources studies. This study finds that global warming will have impacts on the Puget Sound region’s climate, and the nature of these impacts could present challenges to the region.

Introduction

This document describes the downscaling process used to generate the climate data that will be available in the online climate variable database, provides an overview of the characteristics of the data generated in the process, and discusses the projected spatial and temporal changes in the climate variables.

Brief Description of Downscaling and Products

“Downscaling” translates global climate signals produced by general circulation models (GCMs) into information that is useful in evaluating local hydrologic impacts. The information generated by GCMs is produced at a very coarse level. The metrological data produced by a GCM is representative of large areas (approximately 200 kilometers on a side), and this information must be translated to a much finer resolution within a watershed to be useful for regional studies.

The downscaling technique used in this work creates climate scenarios that reflect the regional scale climate statistics. To maintain the full range of natural variability that has been observed in the historic record, the downscaling method couples historic observed data with the statistical characteristics of the GCMs’ outputs. This method captures the regional signal described by the climate models, contains local scale phenomenon and patterns historically observed at a station, and maintains an appropriate range of variability.

The downscaled, climate-impacted scenarios are developed in three stages:

1. Downscale the climate variables from a GCM grid scale to a regional grid scale,
2. Bias-correct a single regional grid cell to an individual station location, and
3. Expand the station scale transient scenario into multiple, quasi-steady-state time series with full historic variability.

This process allows for a climate change signal to be captured from the GCM by incorporating the shifts in the climate variable's Cumulative Distribution Function (CDF – a CDF fully describes a probability function, it describes the probability that a variable takes on a value less than or equal to a specific number). This process creates a time series that represents a specific period in the future but also contains extreme events in the observed record. The magnitude of these events is shifted to correspond with the altered climate signal from the GCM.

The downscaling process uses data from four sources:

1. A GCM, which is in a gridded format at a resolution of approximately 2 degrees (approximately 200 kilometers on a side),
2. Historic meteorological data from specific weather stations, located throughout the region,
3. Historic meteorological data at a 1/8 degree, gridded resolution (12 kilometers on a side), and,
4. Historic sea level pressure data from the National Center for Environmental Prediction reanalysis runs.

This study briefly examines the characteristics of the input data, but focuses primarily on the products.

GCMs and Scenarios

GCMs use emissions scenarios that characterize atmospheric levels of greenhouse gasses that enhance global warming and sulfate aerosols that offset warming by promoting cloud formation as inputs. These scenarios assume that emissions levels are dependent on global social, economic, and technological developments. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to evaluate information related to anthropogenic climate change. As such, the IPCC has developed a suite of equally likely future emissions scenarios. Most of these scenarios are somewhat similar through 2050, at which point they begin to diverge and by 2100, in some cases, diverge dramatically.

Two scenarios, A2 and B1, were selected for use for this study. The A2 scenario describes a "heterogeneous world." In this case, economies develop regionally, and economic and technological growth is slow and fragmented. Fertility patterns will converge slowly and will eventually stabilize at a rate that exceeds replacement, resulting in a global population of 15 billion by 2100. In comparison to the other emission scenarios, A2 has a large increase in greenhouse gases. In contrast, the B1 scenario describes a converging world with rapid economic and technological development, improved equity, and a tendency toward service and information economies. In this case, the global population will peak at 8.7 billion in 2050, and will then decline, approaching 7 billion by 2100 (IPCC 2000). B1 has a smaller increase in greenhouse gases than other emission scenarios (Figure 1).

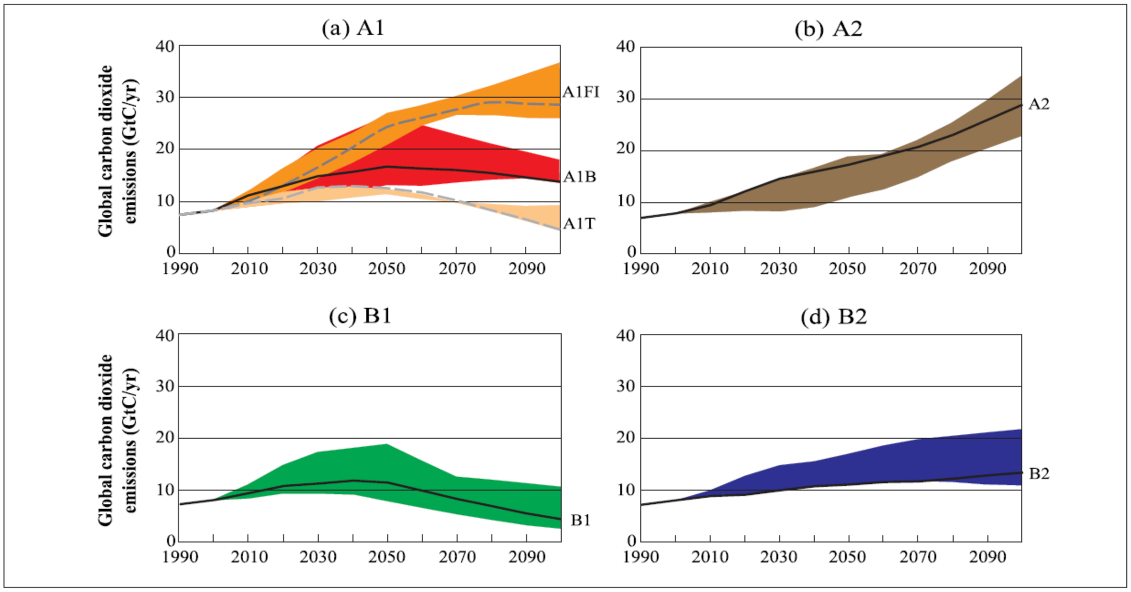

Figure 1: Total Global Annual CO2 Emissions from All Sources (Energy, industry, and land-use change) of the Four IPCC Scenario Families

The range of potential future emissions and climate scenarios generates the greatest source of uncertainty in the process of evaluating climate change. To deal with this uncertainty, an ensemble of GCM-scenario couples was selected to represent the range of possible future climate conditions, the average of which is considered to represent the most likely impact. The three GCM-scenario couples selected were GISS_B1, ECHAM5_A2, and IPSL_A2. The GISS model was developed by the National Aeronautics and Space Administration's (NASA) Goddard Institute for Space Studies in New York, New York. The ECHAM5 model was developed by the Max Planck Institute for Meteorology in Hamburg, Germany. The IPSL model was developed by the Institut Pierre Simon Laplace in Paris, France. These models are moderately sensitive, and have performed well in other studies when replicating the temperature and precipitation trends of the Northwest during the 20th century (Mote 2005).

Previous studies by the Climate Impacts Group (for instance, Mote et al., 2000) has suggested that, in general, the ECHAM5_A2 model represents a "middle-of-the-road" scenario in which the climate undergoes moderate warming and precipitation increase by mid-21st century. Alternatively, IPSL_A2 is significantly wetter and warmer, while GISS_B1 is slightly drier and warmer (Figure 2). The GCM data used for this study support this conclusion; however, these generalized descriptions of the climate depicted by each GCM do not apply over all four time periods in all seasons.

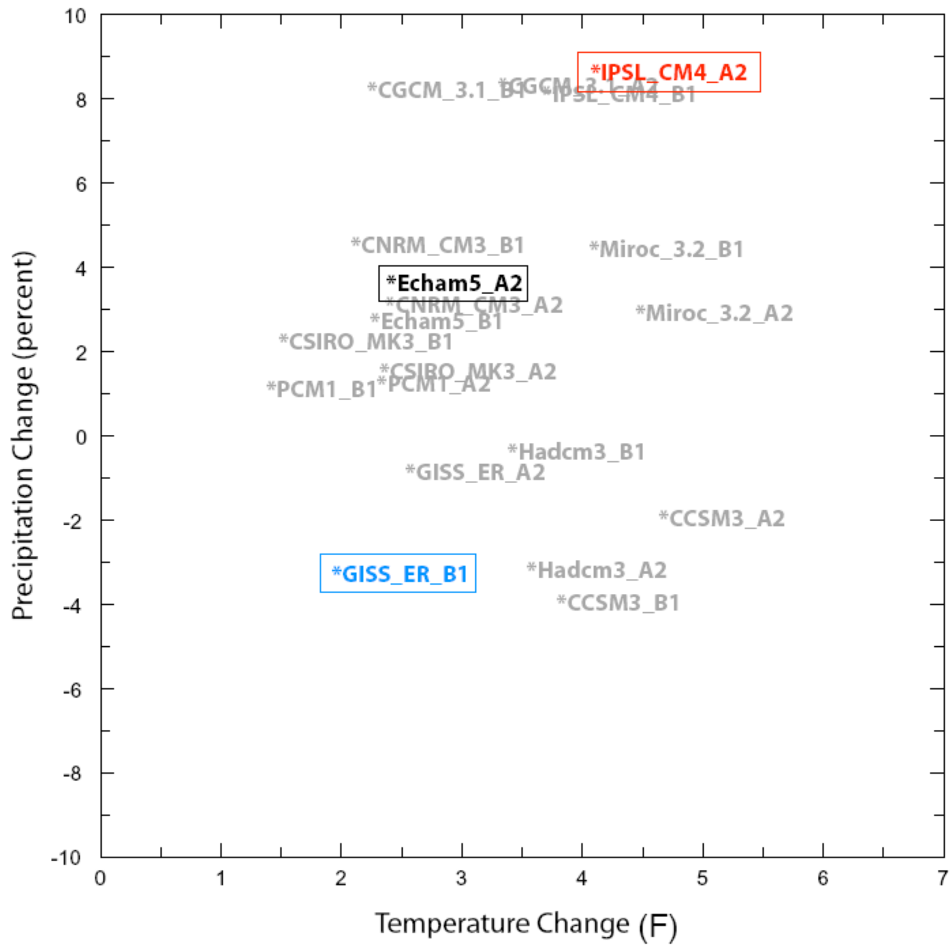

Figure 2: Scatterplot of Change in Annually Averaged Temperature and Precipitation for Various GCM-scenario Combinations as of 2040's (2030 - 2059 minus 1970 - 1999) *(Source: Mote, P. W., E. Salathe, and C. Peacock. 2005. Scenarios of Future Climate for the Pacific Northwest. University of Washington: Climate Impacts Group.)*

An in-depth discussion of the selection of these three GCMs can be found in Mote, Salathe, and Peacock 2005.

QA/QC Methods for Climate Data and Computer Code

The generation of climate impacted data uses several different models and numerous calculations, as such it is important to eliminate the possibility of computation errors. The elimination of introduced errors during data processing is necessary from a data assurance/quality control standpoint (QA/AC).

Two sources of uncertainty are addressed in this technical memo. The first is associated with the GCM-scenario couples, and the second is associated with the downscaling process. One way to address uncertainty associated with the GCMs is to bracket or capture it through selection of multiple GCM-scenario couples as discussed above. A summary of the range is provided in the climate change results section. A second source of uncertainty occurs in the downscaling process, where climate variables are translated from a coarse resolution to a fine one. It is necessary to eliminate introduced errors during this data processing to minimize uncertainty to the extent possible.

The primary objectives of this section are to highlight the methods in which the downscaling process was evaluated. This section:

1. Briefly describes inputs used and the location of documentation associated with these inputs,
2. Provides a description of the computer code used in the downscaling process and assess to the documented computer code, and
3. Compares the historic data to the simulated 2000 period.

Description of Inputs Used in Downscaling Process

The input sources used in this study originate from many different data sources and in some cases, data warehouses, each with various methods for quality control. This section highlights the source of input data and documentation.

Historic Meteorological Station Data

These data come from the National Climatic Data Center (NCDC), whose parent organization is NOAA. These data consist of stations that are part of the NOAA's monitoring programs and stations within the COOP program. Documentation of database management and descriptions of specific stations can be found at: http://www.ncdc.noaa.gov/oa/ncdc.html. A map of meteorological station locations is found in Appendix B.

Uncertainty Associated with Historic Data

Historic observed datasets have inherent uncertainties due to measurement error. This measurement error is introduced by a human observer or by the meteorological equipment. The errors typically consist of missing the extremes, such as days with trace or very small amounts of precipitation or days with very large amounts. In days with small amounts of precipitation, the majority or error stems from observer subjectivity. In any day with a precipitation event, measurement error due to equipment can occur from wind effects. Although it is important to understand these uncertainties and quantify them, that is outside the scope of this paper. Much work is performed at the centers that collect and compile the data used in this study to minimize these errors.

VIC Grid Dataset

The VIC meteorological grid dataset was created by researchers at the University of Washington for use in hydrologic models. This dataset can be downloaded from: http://www.hydro.washington.edu/SurfaceWaterGroup/DataInfo.html. This website also contains documentation of the process used to create the gridded dataset from station data at the NCDC. That data set creation has been previously documented (Hamlet, and Lettenmaier, 2005).

GCM Data

GCM data used in the downscaling process can be obtained at:

1. GISS – Goddard Space Science Institute: http://aom.giss.nasa.gov/
2. IPSL – Institut Pierre Simon Laplace: http://www.ipsl.jussieu.fr/
3. ECHAM – Max Planck Institute for Meteorology: http://www.mpimet.mpg.de/

Each institute has code and data quality documentation that can be downloaded as well as online resources to answer general questions about the models and their output.

NCEP SLP Data

The National Center for Environmental Prediction (NCEP), whose parent organization is NOAA, produces "reanalysis" output for climate variables for many regions. The reanalysis runs provide sea level pressure over a gridded surface that is used to scale precipitation values to the regional cell level. Information can be found at:
http://www.cdc.noaa.gov/cdc/reanalysis/reanalysis.shtml.

Description of Computer Code Used for Downscaling

A list of the programs and subprograms used in the downscaling process and description of their purpose is provided in Appendix A.

QA/QC of Data: Methods and Results

In addition to careful review of the code used in downscaling and testing of the individual programs and subprograms, the second method of QA/QC is a comparison of the simulated 2000 period with an observed historic period (i.e. 1927-2000 and 1950-2000). It is anticipated that these two data set should be similar. For this analysis, twelve stations are compared, with at least one station in each WRIA for spatial consistency. Figure 3 contains boxplots of monthly temperatures at three locations. (Box plot presents a summary of data, typically showing the median, the 25th and 75th quartiles, and approximately the 5 and 95th percentiles.) Figure 4 presents histograms of average temperature for three stations: Cedar, Everett, and Seatac. The observed historic data are presented at the upper portion of the figure in light blue, with the output for each GCM in a different color, i.e. blue for ECHAM5, red for GISS and green for the IPSL GCM's. It is important to note that for some more limited records, i.e. Seatac's, an effort was made to extend the record's history through use of statistical relationships. These extended records are used in this study.

The relative frequencies and distributions match well for the three stations (Figures 3 and 4). Because the simulated time is a thirty-one year period centered on the year 2000, we do not expect the distributions to match exactly. Rather, we would expect them to be similar as demonstrated, and perhaps slightly warmer as our regional climate has warmed more rapidly over the 20th century. For the Cedar Lake station, the IPSL GCM has a slight cold bias toward the extremes, but is within a reasonable range for the seventy-fifth percentile range. Figure 4 depicts a similar situation, but with histograms which depict the distribution of average monthly temperature over the period 1950-2000.

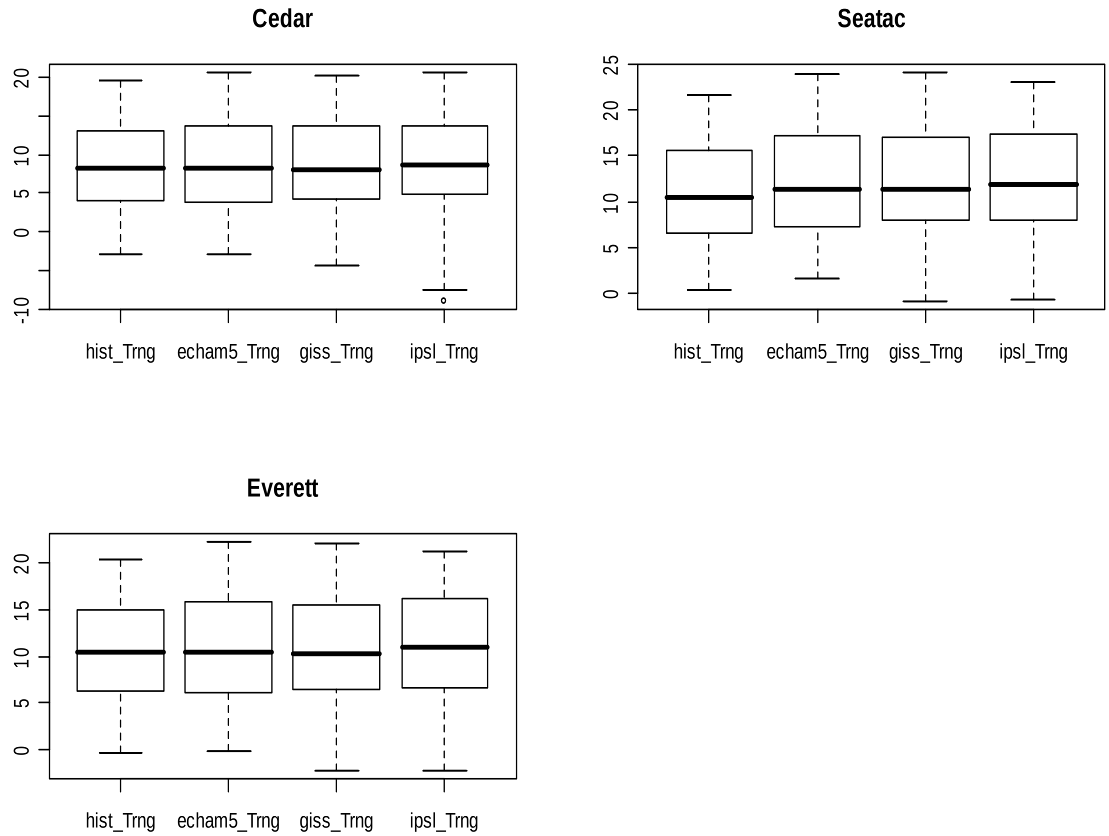

Figure 3: Box plots of Average Monthly Temperature for the Historic Record and the 2000 Simulated Period for each GCM

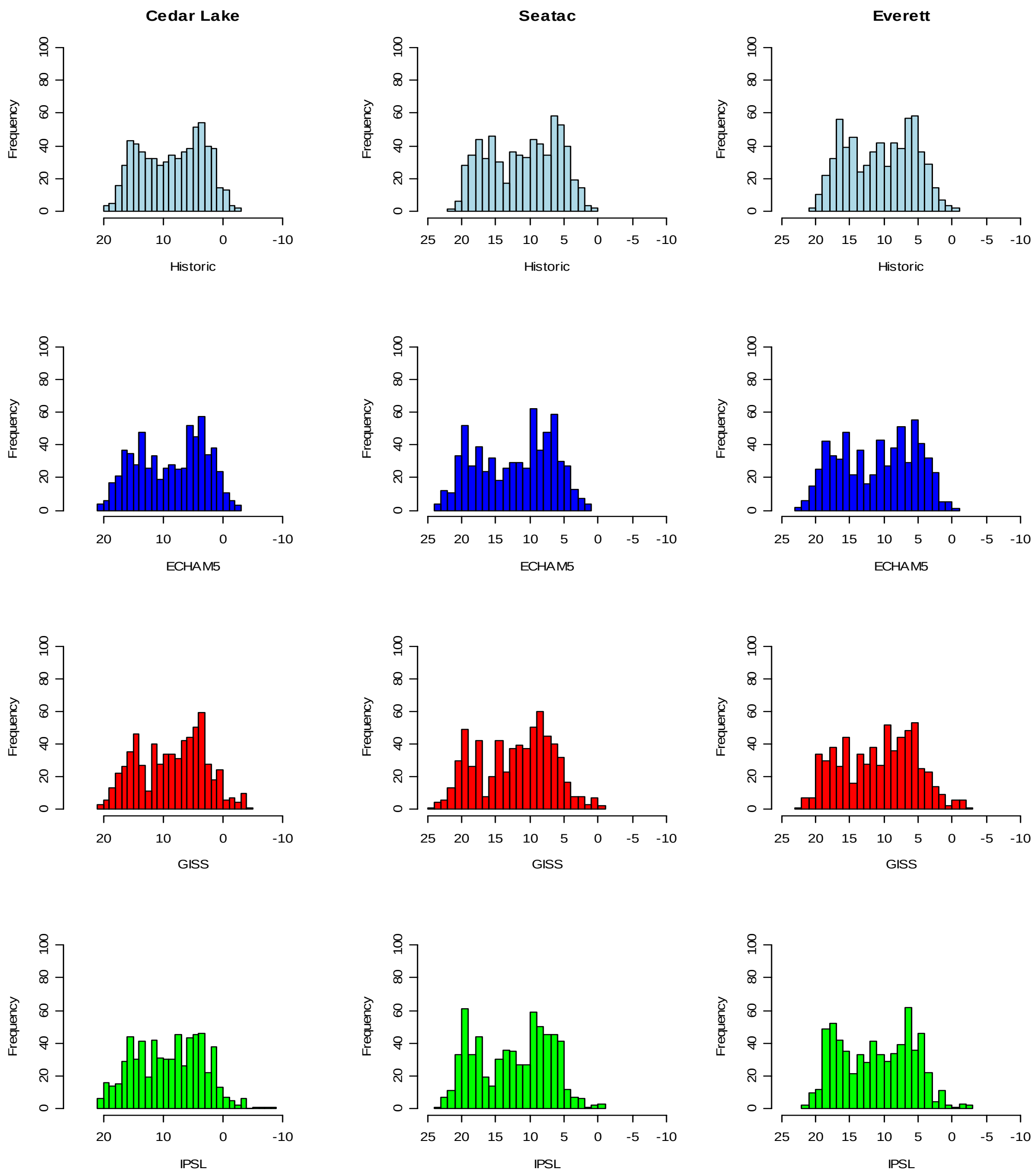

Figure 4: Histograms of Average Monthly Temperature for the Historic Record and the 2000 Simulated Period for each GCM

Similar graphs are constructed for precipitation. Figures 5 and 6 show good agreement between cumulative monthly precipitation at the three stations. The GCMs, particularly the GISS and IPSL models, tend to slightly over-predict months that have substantial rainfall. Figure 6, which plots frequency of cumulative precipitation in meters, depicts an over prediction of months without rain.

The frequency axis on the histogram can be interpreted as the number of months from the entire historic record that fall in a category, such as degrees C or cumulative precipitation in meters. If all the values of frequency are summed in the histogram, one arrives at the total number of data points in the dataset. The histogram is a convenient way to display the frequency of an event or range of events relative to the frequency of all other events.

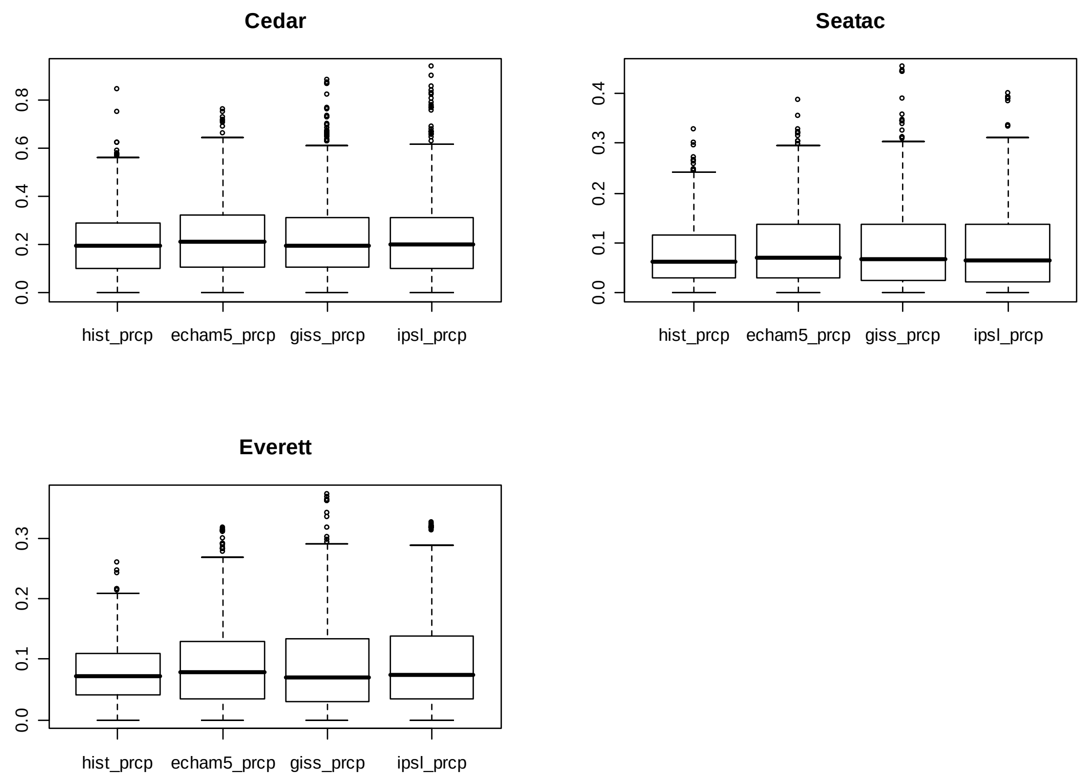

Figure 5: Box plots of Cumulative Monthly Precipitation for the Historic Record and the 2000 Simulated Period for each GCM

The over predication of dry days is apparent at stations that have a higher percentage of months with cumulative precipitation close to zero, such as Cedar Lake.

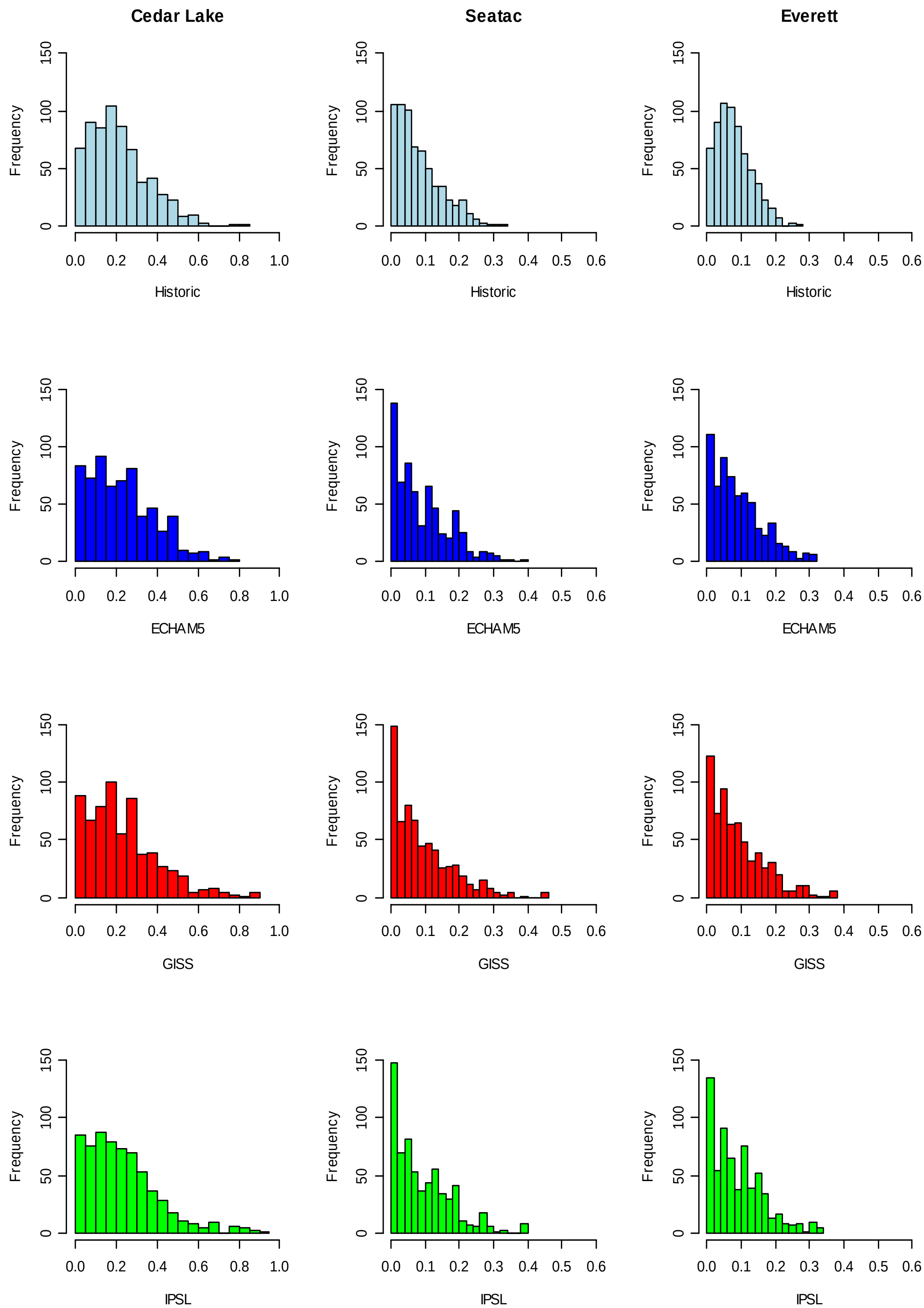

Figure 6: Histograms of Cumulative Monthly Precipitation for the Historic Record and the Simulated 2000 period for Each GCM

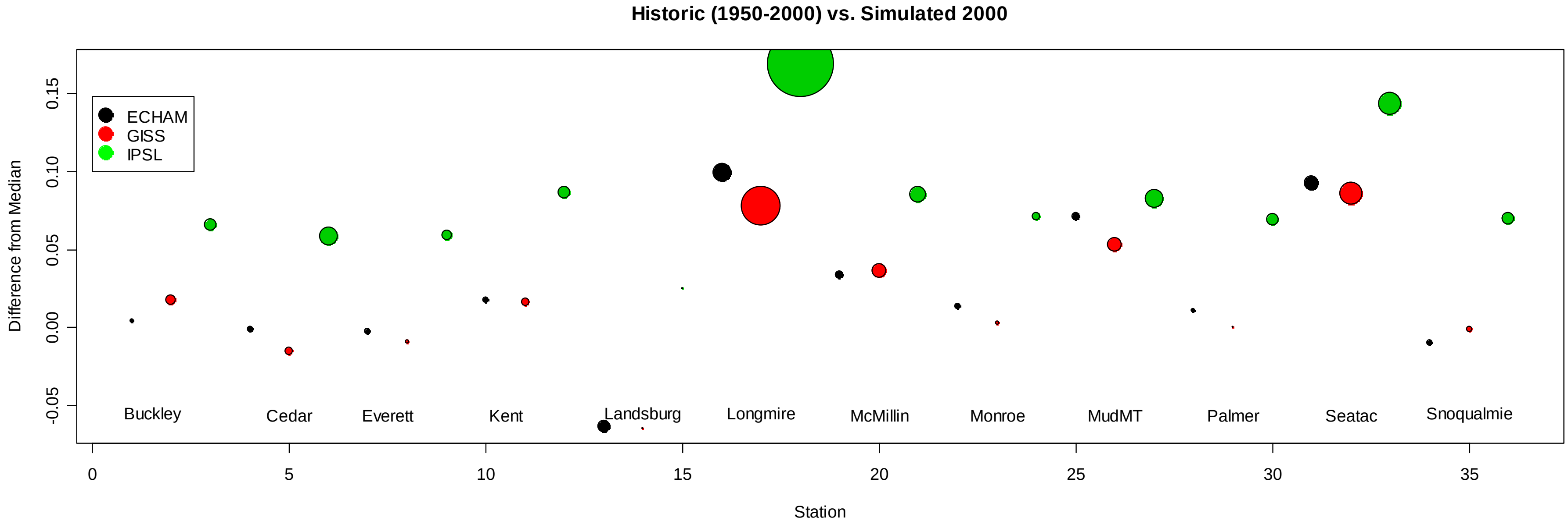

Figure 7: Percent Difference from Historic - Average Monthly Temperature

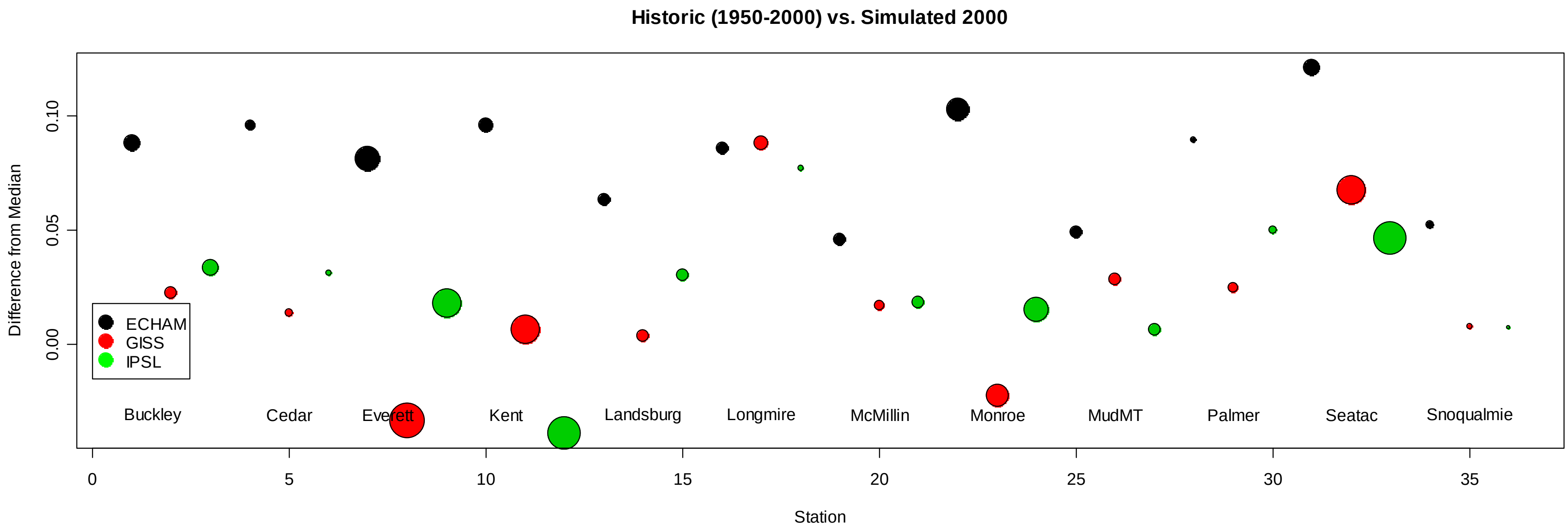

Figure 8: Percent Difference from Historic - Cumulative Monthly Precipitation

Figures 7 and 8 compare the simulated 2000 period to the historic data. These plots show the percent change in median value between the simulated 2000 and historic periods on the y-axis for the twelve stations for each of the three GCMs. The size of the points for each station-GCM combination is the percent of absolute difference of the 75th and 25th percentiles from the historic. This statistic indicates how well the distribution is being replicated. For temperature, the largest departure is with the Longmire station. At Longmire, the IPSL GCM (the green dot on Figure 7), has a positive bias of 15% for the median temperature and a seemingly large bias for the combined 75th and 25th percentile differences. To further examine this, a plot of CDFs for average monthly temperature at Longmire is depicted below in Figure 9.

In Figure 9, the IPSL GCM has a slight extreme cold bias that reduces the 25th percentile (Figure 7). The median trends toward a warm bias, which is visible from the orange line (IPSL) always being about 0.8 degrees C warmer than the historic record. The deviation from the median could be acceptable due to the average difference in temperature between the historic record and the simulated 2000 period. As seen in the Figure 7, most GCMs are slightly warmer (~5%) in the simulated 2000 period when compared to the historic period.

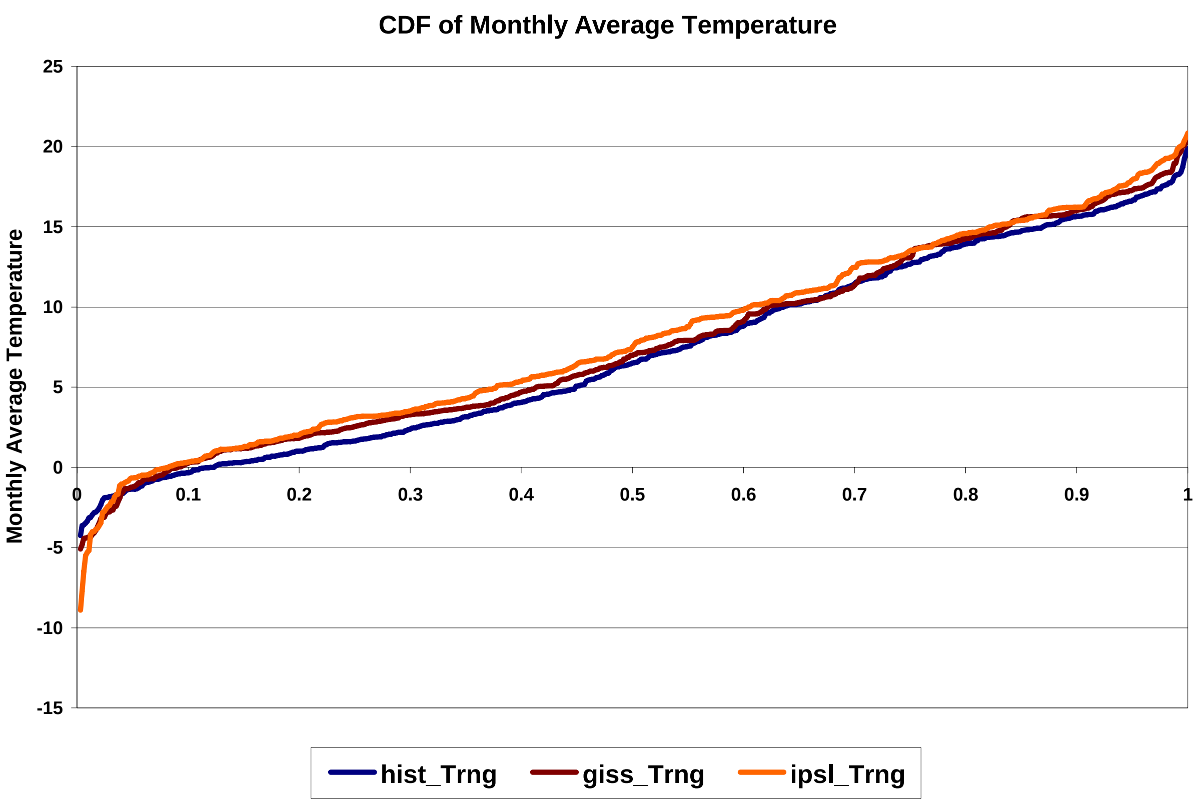

Figure 9: Average Monthly Temperature for Longmire

For precipitation, ECHAM5 has a slight positive bias in precipitation compared to the historic record, but the shape of the CDF is good. The GISS and IPSL GCMs appear less biased, but do not reproduce the distributions of precipitation as well as the ECHAM5. It is important to note that precipitation data is highly variable, making it difficult to reproduce. Figure 10 depicts this for Longmire, where very low precipitation amounts in the GCMs and months without precipitation cause the disagreement with the historic record. For months with less than one centimeter of rain per month (about 0.2 inches), the GCMs deviate from the historic record. This is partly due to the deviation caused from many zero precipitation months in the simulated climate (~8 months) in comparison to the historic record which only has one month of no precipitation. These additional months of zero precipitation can probably be attributed to the downscaling process, in which the CDF of the 31-year record is truncating some of the lower historic values to zero. It is important to note that the volume of water is small for these months.

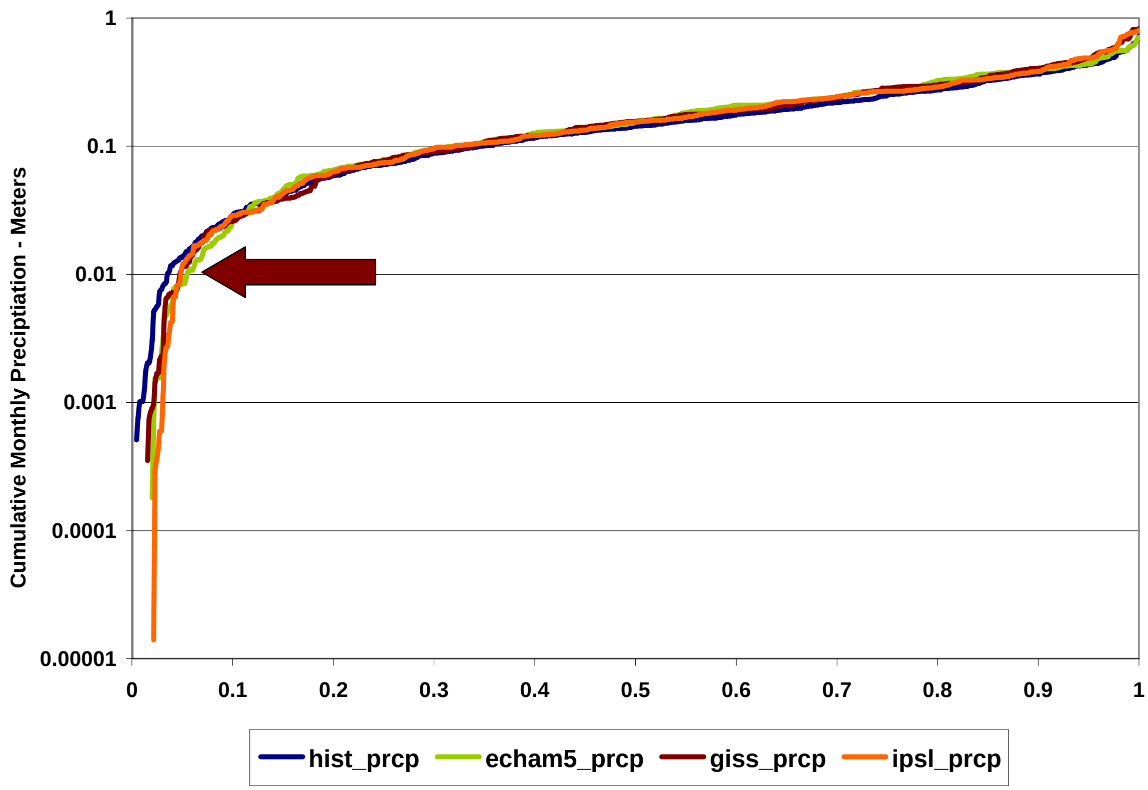

Figure 10: Cumulative Monthly Precipitation for Longmire

Lastly, it is important to identify the seasons in which these deviations occur and their relative values. Figure 11 compares the full historic period of record (WY 1928-2004) to both the most recent 20-year historic period (WY 1984 – 2004) and the 2000 simulated period for the Cedar Lake, Seatac, Everett, and Mud Mountain meteorological stations. At all stations, the summers tend to be warmer than the historic period, typically by one degree Celsius. The winter periods are slightly warmer at Seatac and Mud Mountain, with no distinct pattern at Cedar Lake or Everett. Overall, the warm bias in the summer is expected and can be contributed to the warming that has occurred during the 20th century.

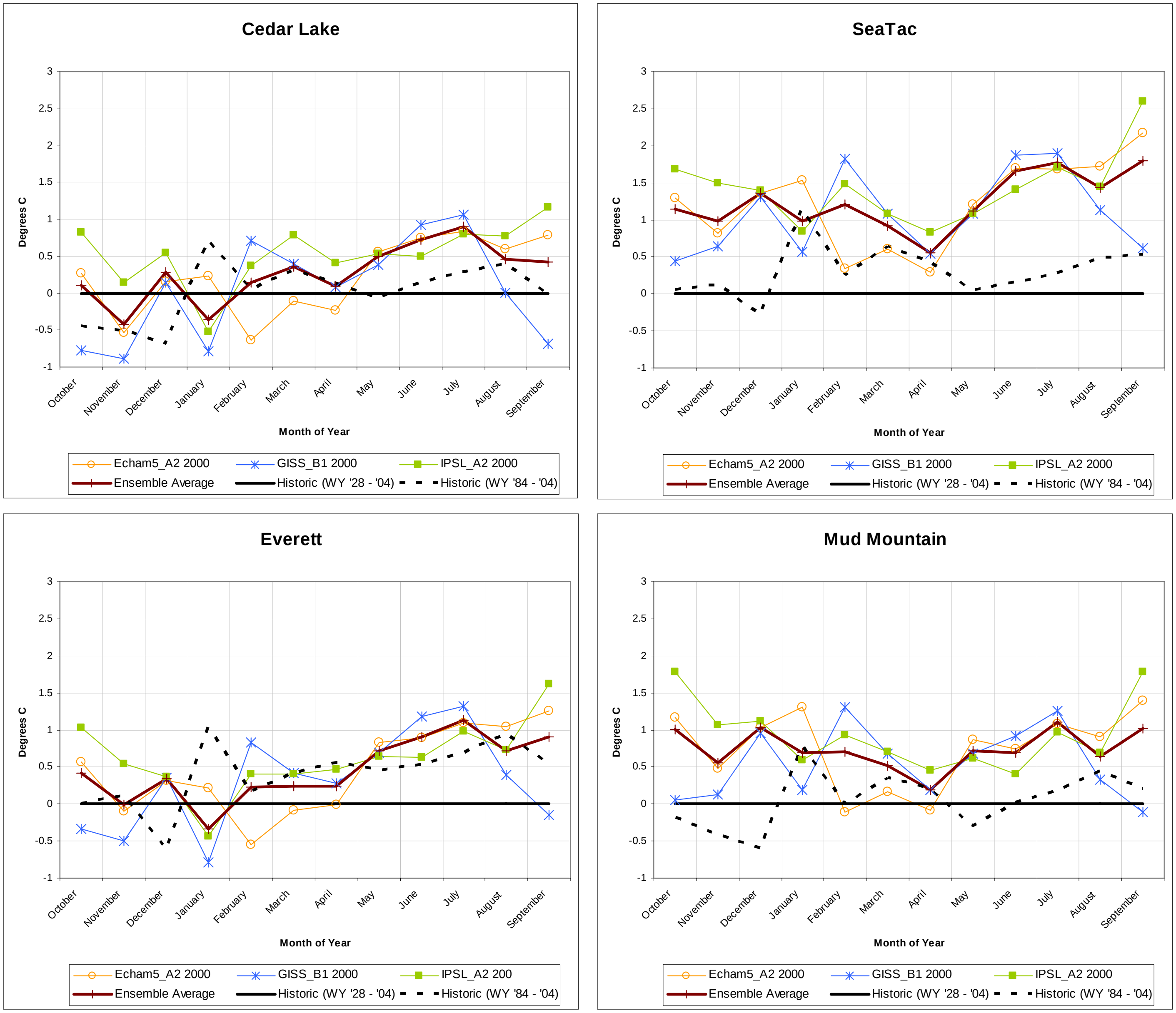

Figure 11: Simulated 2000 vs. Historic Average Monthly Temperature at Four Stations

Climate Change Results

Temperature

Figure 12 displays the change in average monthly temperatures produced by each model in the four time periods relative to the full historic record (WY 1928 – 2004) (14 station average). For the 2000 time series, monthly average temperature outputs from all three GCMs are similar and values are typically within 1°C of the historic values year-round at all stations. Seasonally, the three models are similar in that they show comparable warming during summer months (May – July). The models diverge slightly during spring (February – April) when both GISS_B1 and IPSL_A2 are warm while ECHAM5_A2 is cool, and also in the fall (August – October) when IPSL_A2 and ECHAM5_A2 are warm and GISS_B1 is cool. The GCM ensemble average difference in 2000 vs. historic average annual temperatures for the region is 0.46°C.

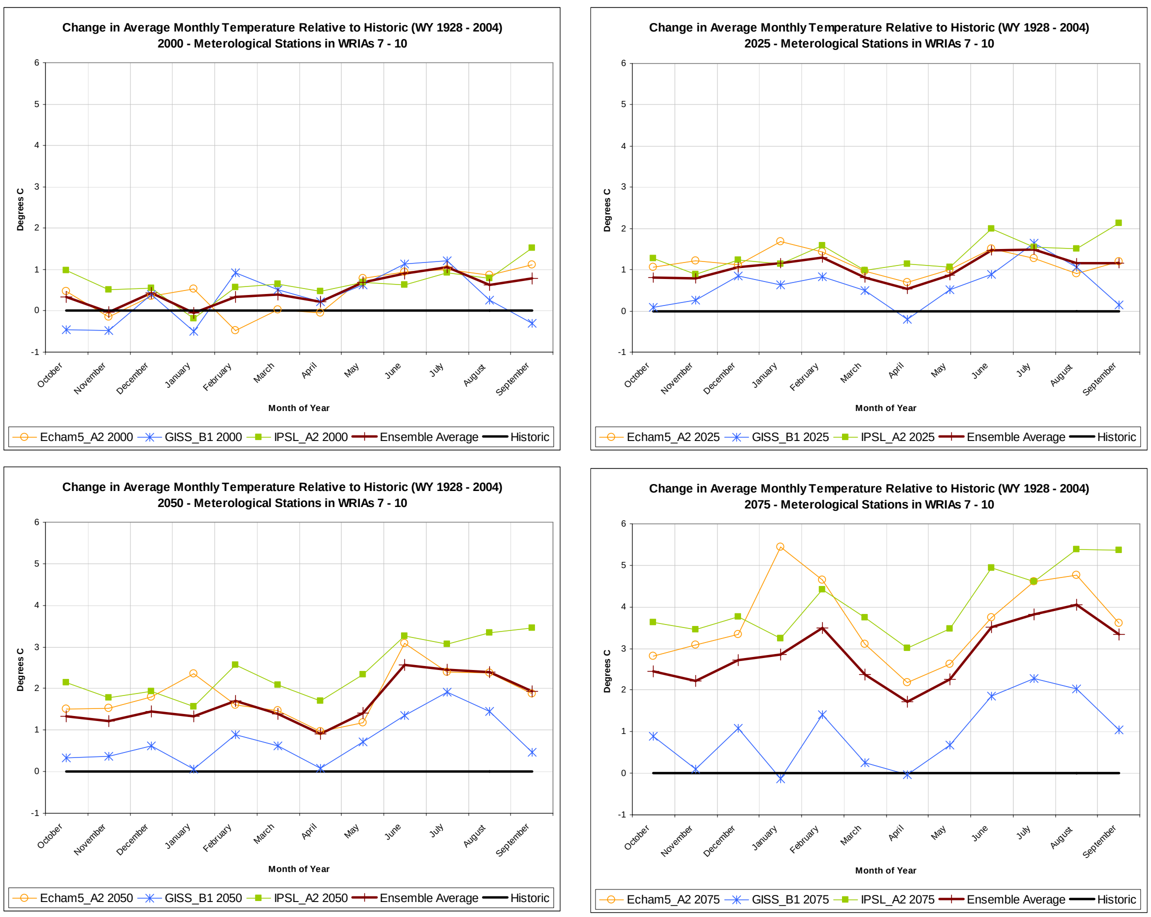

Figure 12: Change in Average Monthly Temperature, Averaged Over 14 Meteorological Stations: ECHAM5_A2, GISS_B1, & IPSL_A2 for 2000, 2025, 2050 & 2075

In the 2025 period, both ECHAM5_A2 and IPSL_A2 have a greater warming trend (~0.5°C – 1.0°C) than that described by GISS_B1, except during late summer (July – August), when GISS_B1 suggests comparable warming. All three models indicate that slightly more warming will occur during later winter, early spring, and summer months than at other times of year. The 2025 GCM ensemble average annual temperature increase relative to the historic record is 1.05°C.

By 2050, IPSL_A2 and GISS_B1 appear to depict very similar trends, however, monthly average temperatures projected by IPSL_A2 are consistently ~1-2°C higher than those forecast by GISS_B1. ECHAM5_A2 values typically fall between the values of the other two models which serve as high and low bounds, though ECHAM5_A2 tends to favor the high temperatures comparable to those forecast by IPSL_A2 during winter. Again, all three models indicate that more warming will occur during later winter, early spring, and summer months than at other times of year; however, both IPSL_A2 and GISS_B1 show less change in the month of January than in surrounding months. The 2050 ensemble average temperature increase relative to the historic record is 1.46°C for the region.

Table 1: Change in Average Monthly Temperature (C) 2050 vs. Historic

	ECHAM5_A2	GISS_B1	IPSL_A2	GCM Average
Average Winter (DJFM) Temperature	1.81	0.54	2.04	1.46
Average Summer (MJJA) Temperature	2.26	1.35	3.01	2.21

Table 1 highlights the seasonal changes in average temperatures between 2050 and the historic period. During the summer months (May, June, July, and August), ECHAM5_A2 adequately represents the ensemble average with a value of 2.26°C, while GISS_B1 and IPSL_A2 establish low and high predictions at ~0.8°C below and above the average, respectively. This is illustrated in Figure 13, which is a geospatial representation of average summer temperatures in 2050 relative to simulated 2000 temperatures as suggested by each GCM. The input data for these plots comes from the regional grid used in the downscaling process. Each pixel in the region is assigned a value based on its distance from the nearest grid node and the temperature change values at those stations.

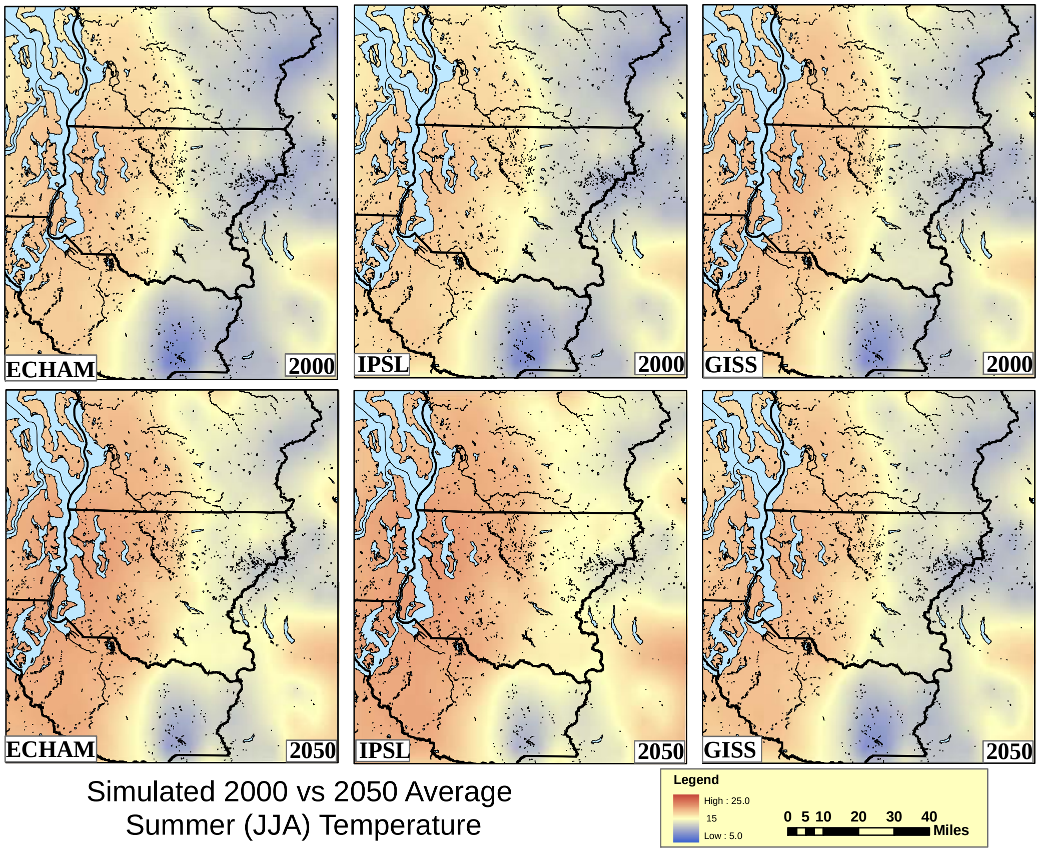

Figure 13: Change in Average Monthly Temperatures in Summer (JJA): 2050 vs. 2000

However, in winter, temperatures predicted by the ECHAM5_A2 model resemble the high values of IPSL_A2 such that the ensemble average for the winter period is significantly higher than the GISS_B1 value and lower than both the ECHAM5_A2 and IPSL_A2 values. Figure 14, a geospatial representation of the 2050 warming trends during winter, suggests that the majority of winter warming will occur east of the Puget Sound, in an area including the region's water supply basins.

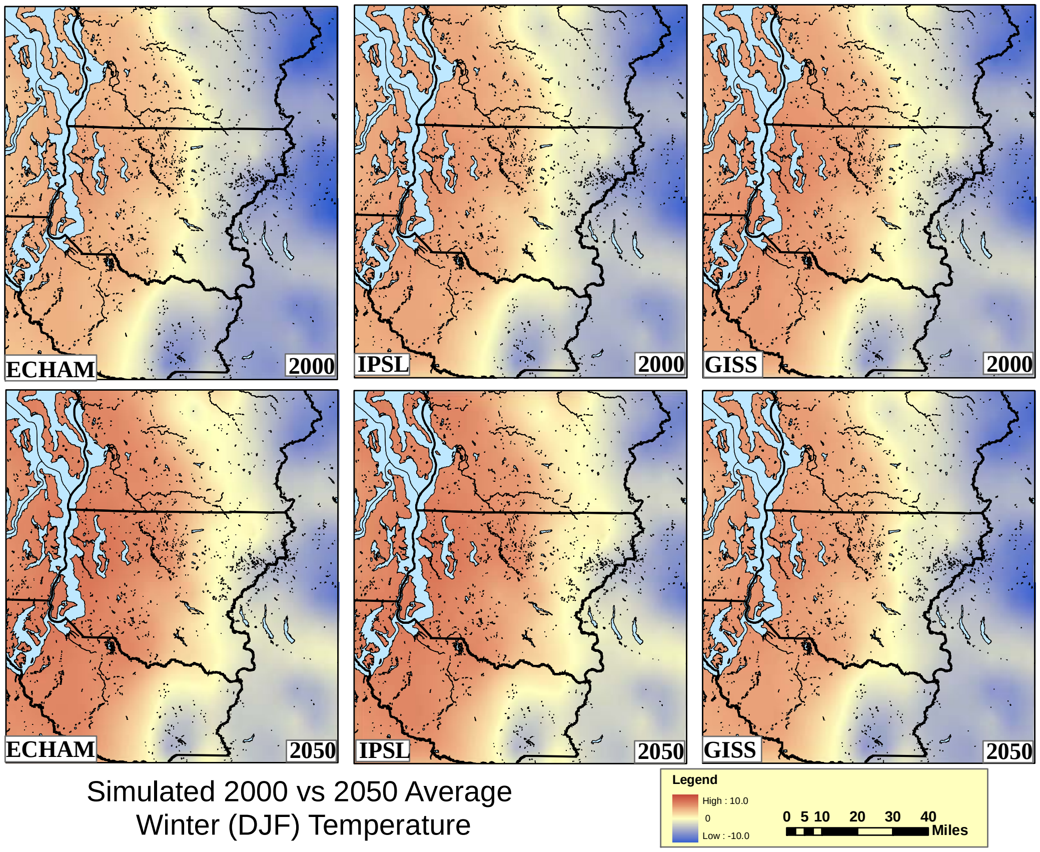

Figure 14: Change in Average Monthly Temperatures in Winter (DJF): 2050 vs. 2000

Even during the 2075 period, GISS_B2 forecasts little warming relative to historic temperatures except in the summer months. Towards the end of the century, both ECHAM5_A2 and IPSL_A2 indicate a significant amount of warming throughout the year, with increased temperatures being most prominent in late winter, early spring, and late summer.

Precipitation

Trends in precipitation output, both over time and between GCM's, are less apparent than those present in temperature values. Figure 15 shows the change (mm) in total monthly precipitation relative to the full historic record (WY 1928 – 2004) for all models and all time periods averaged over all stations (14 station average).

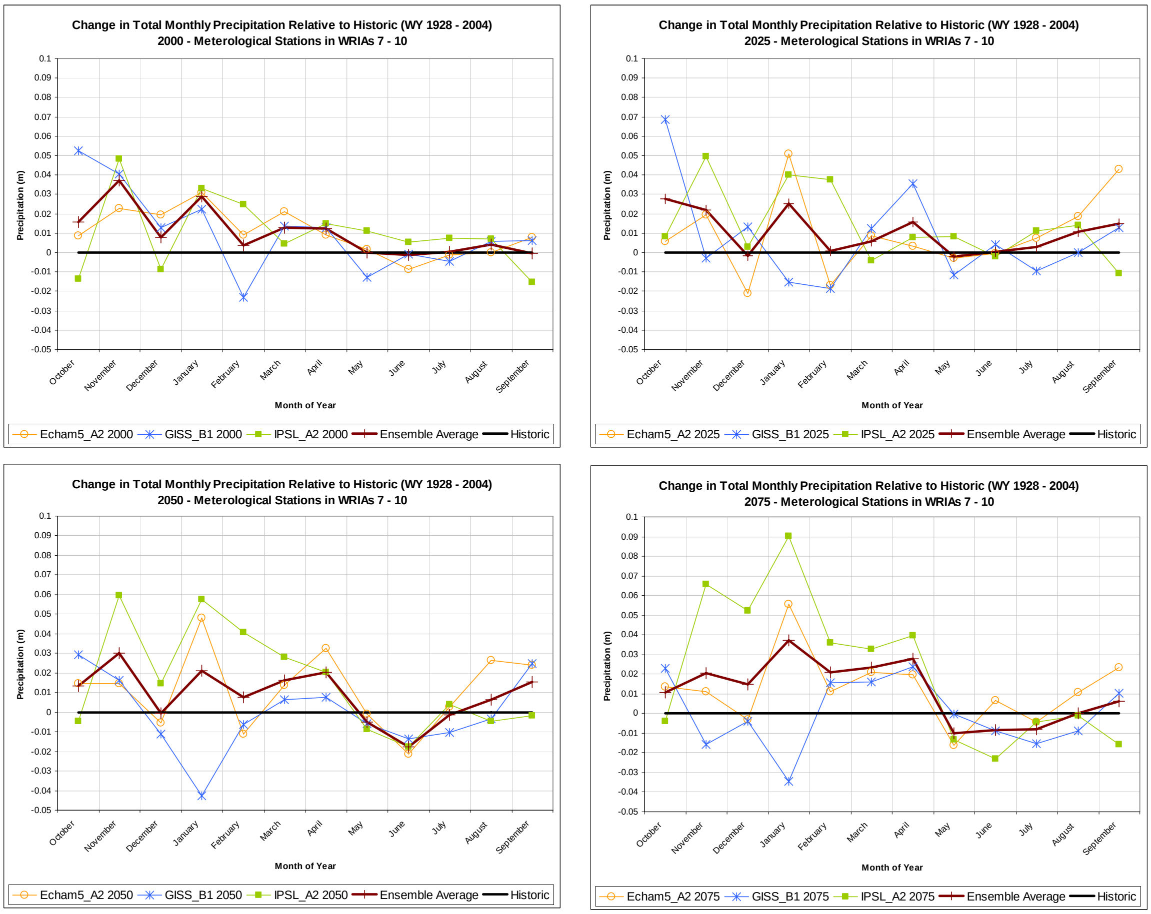

Figure 15: Change in Total Monthly Precipitation Relative to Historic Period (14 Station Average)

For the 2000 time series, monthly precipitation outputs from all three GCMs are fairly dissimilar, though most values fall within 20% of the historic record. Throughout all time periods, GISS_B1 is characterized by a decline in summer precipitation followed by increased precipitation during fall months. Also, in contrast to the other two models, GISS_B1 shows little to no increase in precipitation during the later winter and early spring periods, and consistently indicates a decline in January precipitation.

In contrast, IPSL_A2 output for the 2000 period is more than 10% wetter than the historic record in 7 months of the year. This trend is consistent through the later time periods, as the IPSL_A2 model describes progressively wetter winter and spring periods, with most values exceeding a 20% increase by 2075. However, IPSL_A2 is not consistent in its predictions for summer months, suggesting increased precipitation in the 2000 and 2025 periods, but decreases in the

2050 and 2075 periods. Echam_A2 provides the most annually consistent 2000 scenario as it is ~5% - 15% wetter in nine months of the year, and is dry in only one month. In later time periods it predicts significantly increased precipitation in fall months, as well as in January.

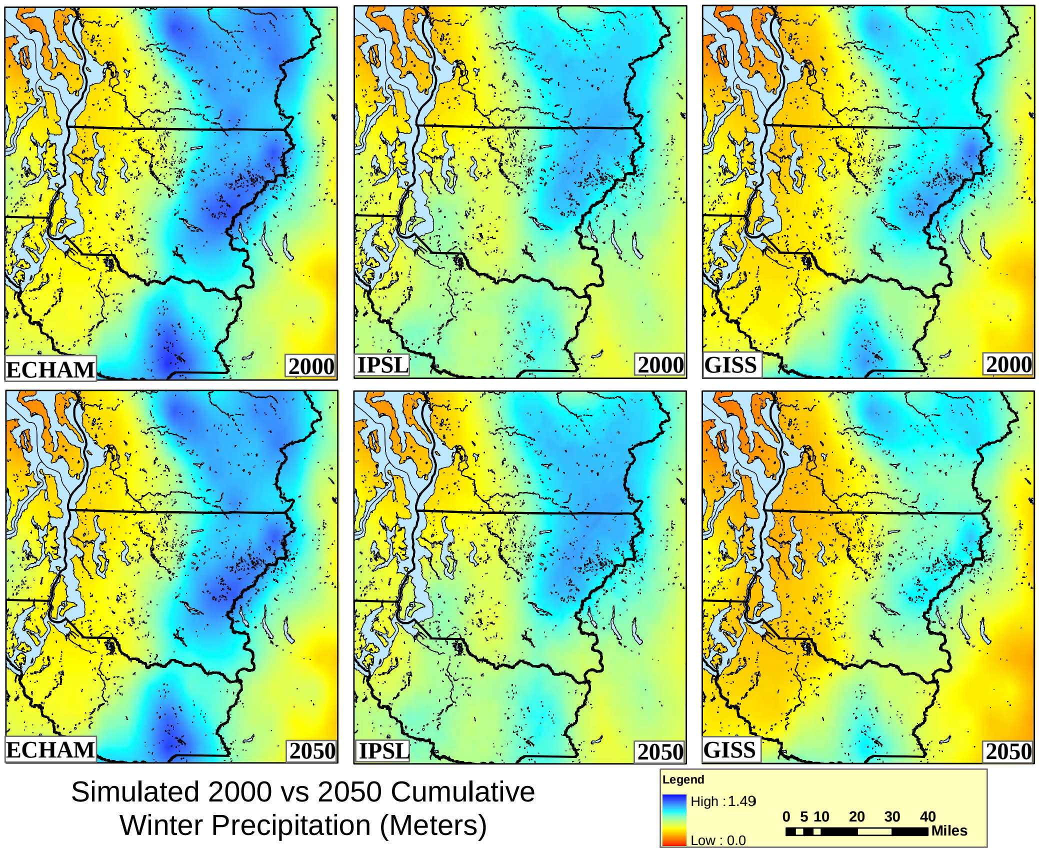

Figure 16: Absolute Change in Monthly Winter (DJF) Precipitation: 2000 vs. 2050

Figure 16 displays the difference between the year 2000 simulated precipitation and the 2050 simulated precipitation. For the most part, the changes are slight, with GISS showing a decrease between 2000 and 2050, and the other two GCMs projecting slight increases in precipitation. On an annual basis, the changes seen in annual precipitation are slightly more pronounced, as seen in Figure 17, though the overall trends in precipitation are harder to define than the temperature trends.

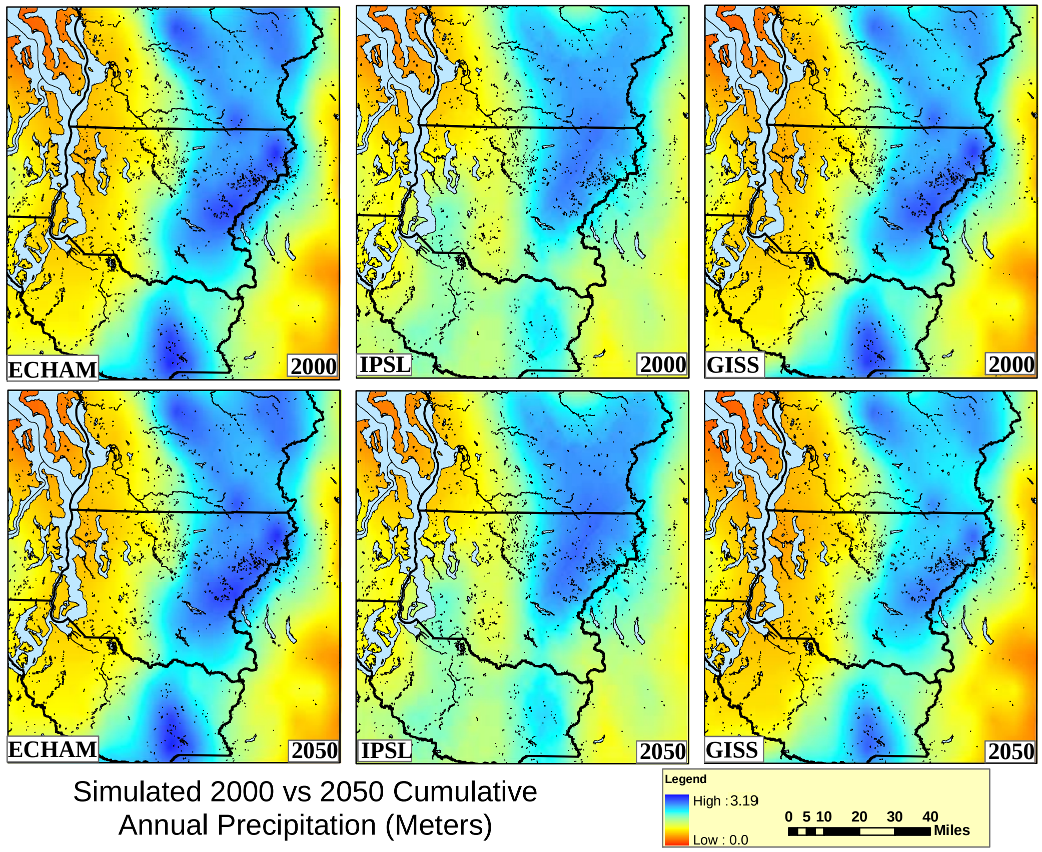

Figure 17: GCM Ensemble Change in Total Annual Precipitation

Summary and Conclusions

The three GCM model/scenario couples (ECHAM5_A2, GISS_B1, and IPSL_A2) selected for this study provide a broad range of future scenarios for investigation. In general, the GCM ensemble suggests that regional annual temperatures can be expected to increase 0.5°C every 25 years through 2050. The model output also suggests further increased rates of warming at the end of the century, such that the change in annual temperatures between 2050 and 2075 may exceed 1°C. The most significant warming is most likely to occur during summer months, with a forecasted relative range increase of 1.35 to 3.01°C by 2050. However, winter temperatures are likely to increase notably as well, by as much as 0.54 to 2.04°C by 2050.

In contrast, few trends can be discerned from the GCM precipitation output. In general, the ensemble suggests little change in annual total precipitation over time relative to the 2000 base period. Seasonally, a slight decline in monthly average precipitation is expected during the summer, while a moderate increase in winter precipitation is likely. However, it should be noted that the three GCMs express a wide range of precipitation values for each month and period. The final product from the downscaling process is a reasonable representation of our current climate, though some minor imperfections exist. As with all data, it is cautioned that these minor imperfections, mostly relating to differences from the historic record, be detailed in any study performed using this dataset. That being noted, the downscaling process has generated data which, overall, has good quality and representativeness of what has been observed historically. The good measure to which the simulated 2000 period mimics the historic record gives reason to find the downscaling technique a viable method in which to scale future projections of climate to our region.

References

Hamlet A.F.,Lettenmaier D.P., 2005: Production of temporally consistent gridded precipitation and temperature fields for the continental U.S., *J. of Hydrometeorology*, 6 (3): 330-336

Mote, P. W., E. Salathé, and C. Peacock, 2005: Scenarios of Future Climate for the Pacific Northwest. Climate Impacts Group, University of Washington.

IPCC (Intergovernmental Panel on climate Change), 2000: *Special Report on Emission Scenarios, A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, Nakicenovic, Nebojsa and Swart, Rob, Editors. Cambridge University Press, Cambridge, United Kingdom.

Appendix A: List of Programs and Subprograms used in the Downscaling Process

Regional Gridcell to Station Location Process
In this process, monthly data at the regional gridcell level is bias corrected and downscaled to a station level. This process uses two scripts to bias correct the data, **extract_stations.scr** and **bias_correct_gcm_monthlies.scr**.

Extract_station.scr
The **extract_station.scr** extracts climate data from gridcells in which the station of interest resides. It operates on .netcdf files generated from the GCM to regional grid process. This extraction process creates a file of data for the single gridcell, with the associated station name, climate variable name, and scenario and gcm as the filename. The **bia_correct_gcm_monthlies.scr** next processes the extracted gridcell data to produce a bias corrected, monthly time-step, station file.

Bias_Correct_GCM_Monthlies.scr
This script takes in the extracted gridcell information and bias-corrects the data based on generated quantile maps. These quantile maps are generated prior to this process through use of the **make_quantiles** script in which historic VIC data and historic station data are transformed into CDFs for the time period of 1950-2000. This data is stored as a .cdf file, these are files are referred to as quantile maps. The next step in processing the data involves calling **interpolate.c** program. **The interpolate.c** program uses the quantile map files for a specific station and variable and interpolates between the historic station and historic VIC gridcell to obtain the value in which to adjust the data from the extracted gridcell step.

The output from this process is a bias-corrected, station level, monthly dataset for each station and each climate variable. These files use the name from the input file but a .bcd extension is attached to designate that the data has been bias-corrected. This file is processed by the **build_expanded_bcd_slice script**, which is the final step in creating a quasi-steady-state climate impacted time-series at the station level.

Build_Expanded_BCD_Slice.scr
This script selects the period of interest for use in the steady-state climate analysis, removes trends in this slice of transient monthly data, and applies the "detrended" monthly time-series to the historic station data by perturbing each month by the appropriate factor that represents the projected climate.

The script first reads in the monthly bias-corrected climate impacted time-series for the climate variable of interest, the corresponding historic station data, and a user input for the Year of Interest (YOI). The YOI is the point in which to center the slice of data.
The daily historic data for each station are aggregated to monthly values using the **daily_to_monthly_mets.scr.** The script next creates CDFs of the monthly values for the historic data and for the sliced data. Monthly DT and DP values are calculated from a mapping between the two. Applying these DT and DP values by month to the daily historic time series generates a quasi-steady-state daily time series centered on the YOI.

Appendix B: Regional Map of Meteorological Stations